Design of the Compton polarimeter for the FCC-ee

Jasper Burvill, Robert Kieffer, Stewart Boogert, Robert Appleby,
on behalf of the FCC EPOL working group

Overview

The Future Circular Collider

- The **Future Circular Collider** (FCC) is a proposed 91km accelerator ring to push the boundaries of the next century of particle physics research.
- Would follow the same programme as LEP/LHC, starting as an electron-positron collider (FCC-ee) then being replaced by a hadron collider (FCC-hh) in the same tunnel.
- The FCC-ee will be a **precision machine**, probing the standard model as broadly and deeply as possible.
- Will run at 4 modes based on particle resonances: Z, W, ZH, and $t\bar{t}$.

The Future Circular Collider

- The FCC feasibility study concluded in 2025, and consolidated the following parameters for the four modes of operation:

Parameter	**Z**	**W**	**ZH**	$\mathbf{t\bar{t}}$
Beam Energy [GeV]	45.6	80	120	182.5
Synchrotron radiation/beam [MW]	50	50	50	50
Beam current [mA]	1270	137	26.7	4.9
Luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	145	20	7.5	1.4
Total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.9	0.17
Electrical power operation [MW]	250	275	297	381
Electrical energy per year [TWh]	1.17	1.32	1.41	1.85

The Future Circular Collider

- The FCC feasibility study concluded in 2025, and consolidated the following parameters for the four modes of operation:

Parameter	**Z**	**W**	**ZH**	$\mathbf{t\bar{t}}$
Beam Energy [GeV]	45.6	80	120	182.5
Synchrotron radiation/beam [MW]	50	50	50	50
Beam current [mA]	1270	137	26.7	4.9
Luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	145	20	7.5	1.4
Total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.9	0.17
Electrical power operation [MW]	250	275	297	381
Electrical energy per year [TWh]	1.17	1.32	1.41	1.85

- 1.45×10^{36} $cm^{-2}s^{-1}$ instantaneous luminosity at Z mode.

The Future Circular Collider

- The FCC feasibility study concluded in 2025, and consolidated the following parameters for the four modes of operation:

Parameter	Z	W	ZH	$t\bar{t}$
Beam Energy [GeV]	45.6	80	120	182.5
Synchrotron radiation/beam [MW]	50	50	50	50
Beam current [mA]	1270	137	26.7	4.9
Luminosity / IP [10^{34} cm^{-2}s^{-1}]	145	20	7.5	1.4
Total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.9	0.17
Electrical power operation [MW]	250	275	297	381
Electrical energy per year [TWh]	1.17	1.32	1.41	1.85

- 1.45×10^{36} cm^{-2}s^{-1} instantaneous luminosity at Z mode.
- Maximum Z mode luminosity at LEP was ~3×10^{31} cm^{-2}s^{-1}.
  - ⇒ ~10^5 increase in luminosity for FCC-ee
  - ⇒ FCC-ee will exceed the total number of Z mode collisions in the 6-year run at LEP in **~2 minutes.**

The Future Circular Collider

- The FCC feasibility study concluded in 2025, and consolidated the following parameters for the four modes of operation:

Parameter	Z	W	ZH	$t\bar{t}$
Beam Energy [GeV]	45.6	80	120	182.5
Synchrotron radiation/beam [MW]	50	50	50	50
Beam current [mA]	1270	137	26.7	4.9
Luminosity / IP [10^{34} cm^{-2}s^{-1}]	145	20	7.5	1.4
Total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.9	0.17
Electrical power operation [MW]	250	275	297	381
Electrical energy per year [TWh]	1.17	1.32	1.41	1.85

- 1.45×10^{36} cm^{-2}s^{-1} instantaneous luminosity at Z mode.
- Maximum Z mode luminosity at LEP was ~3×10^{31} cm^{-2}s^{-1}.
  - $\Rightarrow$ ~10^5 increase in luminosity for FCC-ee
  - $\Rightarrow$ FCC-ee will exceed the total number of Z mode collisions in the 6-year run at LEP in **~2 minutes.**
- Pressure on detectors and instrumentation to make the most of this!

The Future Circular Collider

- FCC-ee as a high-precision machine includes a very precise **energy calibration**.

The Future Circular Collider

- FCC-ee as a high-precision machine includes a very precise **energy calibration**.
- Table from the Feasibility Study Report giving estimates on E_{CM}-related uncertainties for FCC-ee at Z and W modes:

Table 24: Current projected $\sqrt{s}$-related uncertainties on selected electroweak observables.

	Observable				
Uncertainty	m_Z (keV)	Γ_Z (keV)	$\sin^2\theta_W^{\mathrm{eff}}$ ($\times 10^{-6}$)	$\frac{\Delta\alpha_{QED}(m_Z^2)}{\alpha_{QED}(m_Z^2)}$ ($\times 10^{-5}$)	m_W (keV)
Absolute	100	2.5	–	0.1	150
Point-to-point	14	11	1.2	0.5	50
Sample size	1	1	0.1	–	3
Energy spread	–	5	–	0.1	–
Total $\sqrt{s}$-related	101	12	1.2	0.5	158
FCC-ee statistical	4	4	1.2	3.9	180

The Future Circular Collider

- FCC-ee as a high-precision machine includes a very precise **energy calibration**.
- Table from the Feasibility Study Report giving estimates on E_{CM}-related uncertainties for FCC-ee at Z and W modes:

Table 24: Current projected $\sqrt{s}$-related uncertainties on selected electroweak observables.

Uncertainty	Observable				
	m_Z (keV)	Γ_Z (keV)	$\sin^2\theta_W^{\text{eff}}$ ($\times 10^{-6}$)	$\frac{\Delta\alpha_{\text{QED}}(m_Z^2)}{\alpha_{\text{QED}}(m_Z^2)}$ ($\times 10^{-5}$)	m_W (keV)
Absolute	100	2.5	–	0.1	150
Point-to-point	14	11	1.2	0.5	50
Sample size	1	1	0.1	–	3
Energy spread	–	5	–	0.1	–
Total $\sqrt{s}$-related	101	12	1.2	0.5	158
FCC-ee statistical	4	4	1.2	3.9	180

$m_z = 91.2$ GeV => Precision of $\sim 10^{-7}$ required to reach statistical uncertainty

=> Compare to $\sim 10^{-4}$ at LEP

Resonant Depolarisation

- The precise energy calibration required by FCCee can be achieved via **resonant depolarisation (RDP).**

Resonant Depolarisation

- The precise energy calibration required by FCCee can be achieved via **resonant depolarisation (RDP).**
- A beam is polarised if there is an average alignment in the spins of the individual particles in a given direction.

Resonant Depolarisation

- The precise energy calibration required by FCCee can be achieved via **resonant depolarisation (RDP).**
- A beam is polarised if there is an average alignment in the spins of the individual particles in a given direction.
- As a polarised beam circles the collider, its spins will **precess** due to the bending magnetic field.
- It can be shown that the spin tune of this precession v_0 is related to the average relativistic factor $\langle \gamma \rangle$ as:

$$v_0 \approx a\langle \gamma \rangle = a\frac{\langle E \rangle}{mc^2}$$

  where a is a constant related to the gyromagnetic ratio of the particle.
- If we can measure the spin tune we can deduce the **average beam energy.** But how do we measure the spin tune?

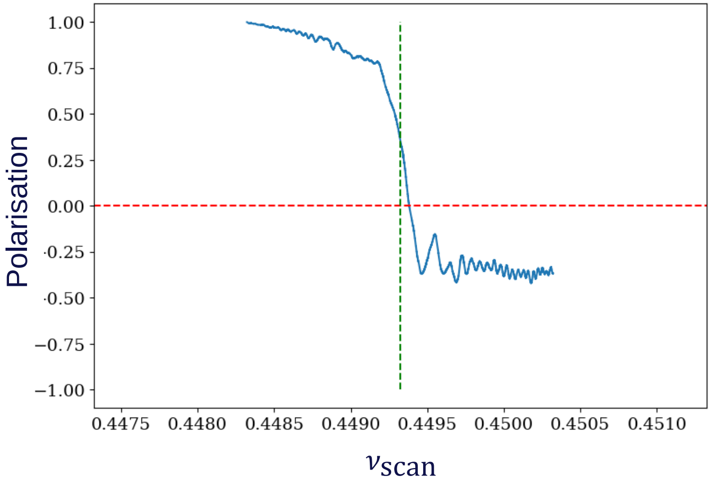
Resonant Depolarisation

- If a horizontal dipole ‘kick’ is applied at a frequency in **resonance** with the spin tune, the beam will rapidly **depolarise.**

Resonant Depolarisation

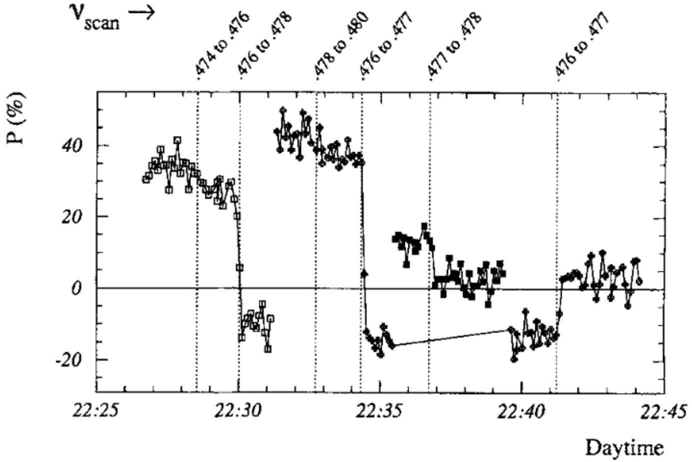
- If a horizontal dipole ‘kick’ is applied at a frequency in **resonance** with the spin tune, the beam will rapidly **depolarise.**
- By scanning across kicker frequencies and measuring the point of depolarisation, we can measure the spin tune and thus the average energy.

RDP scan simulated in XSuite



G. Iadarola, et al, “Spin tracking and equilibrium polarization computation in Xsuite: implementation and benchmarks”, presented at the IPAC’26, Deauville, France, May 2026, paper

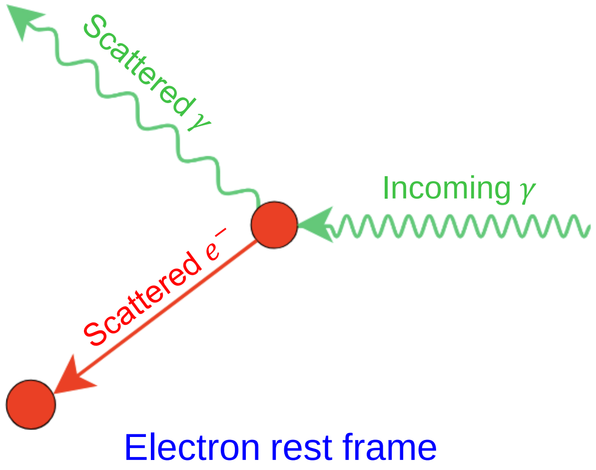
RDP scan data from LEP

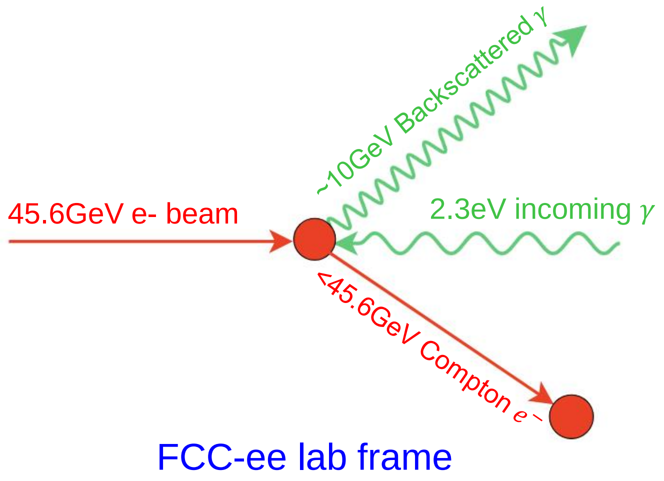


Arnaudon, L., et al. "Accurate determination of the LEP beam energy by resonant depolarization." *Zeitschrift für Physik C Particles and Fields* 66.1 (1995): 45-62.

How to measure polarisation?

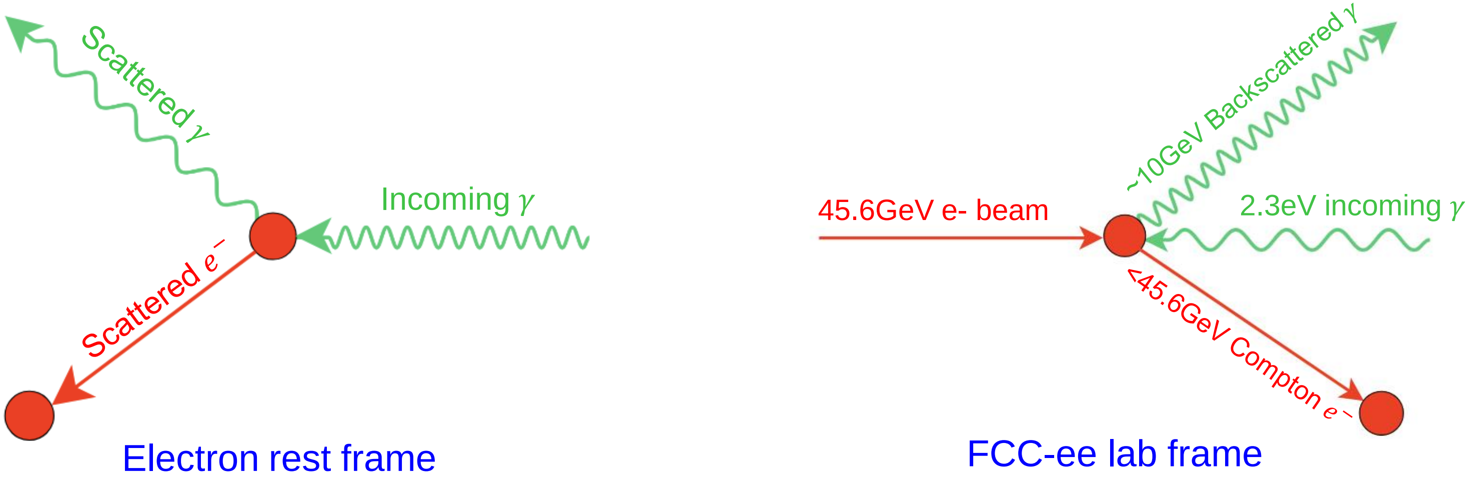
- The key process behind the polarimeter is **Compton scattering** between electrons and photons.
- The direction of the scattered particles depends on the polarisation of the electrons and the helicity (circular polarisation) of the photons.





How to measure polarisation?

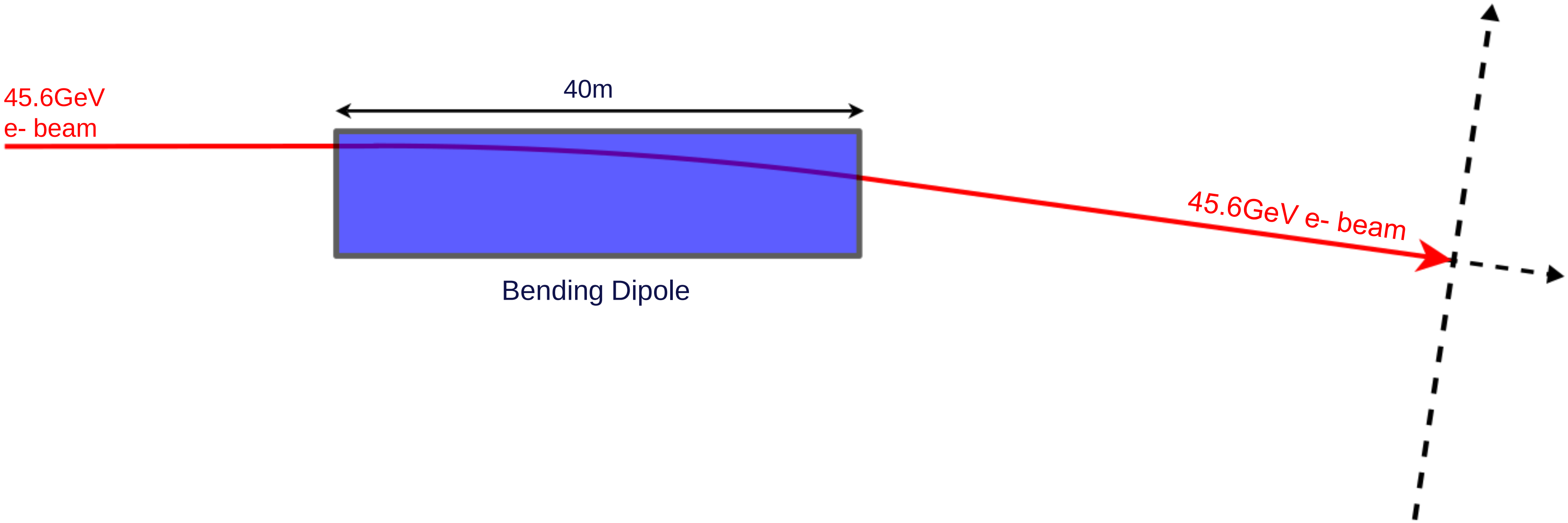
- The key process behind the polarimeter is **Compton scattering** between electrons and photons.
- The direction of the scattered particles depends on the polarisation of the electrons and the helicity (circular polarisation) of the photons.



- Can measure polarisation from the distributions of Compton products by colliding a laser with the beam.
- Colliding bunches should not be polarised => run RDP scan on **polarised pilot bunches.**

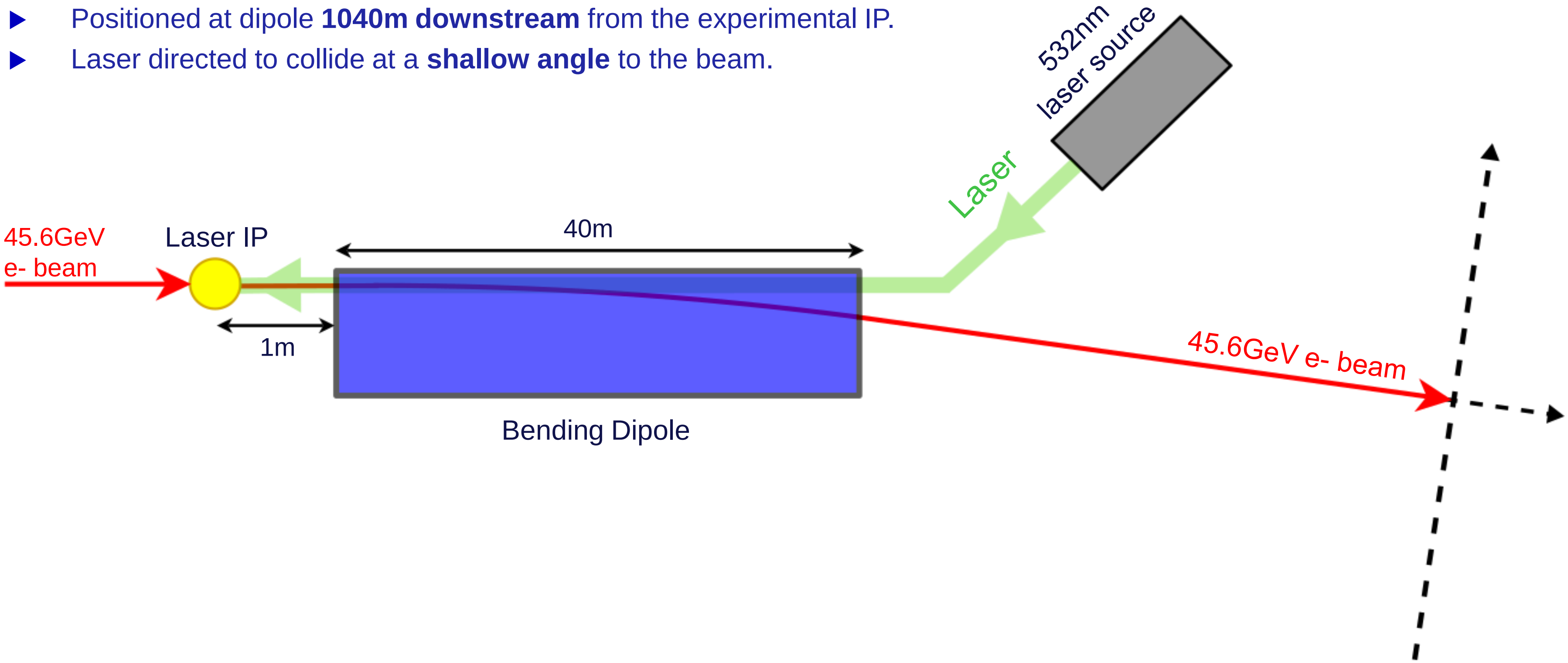
Polarimeter layout

- Positioned at dipole **1040m downstream** from the experimental IP.



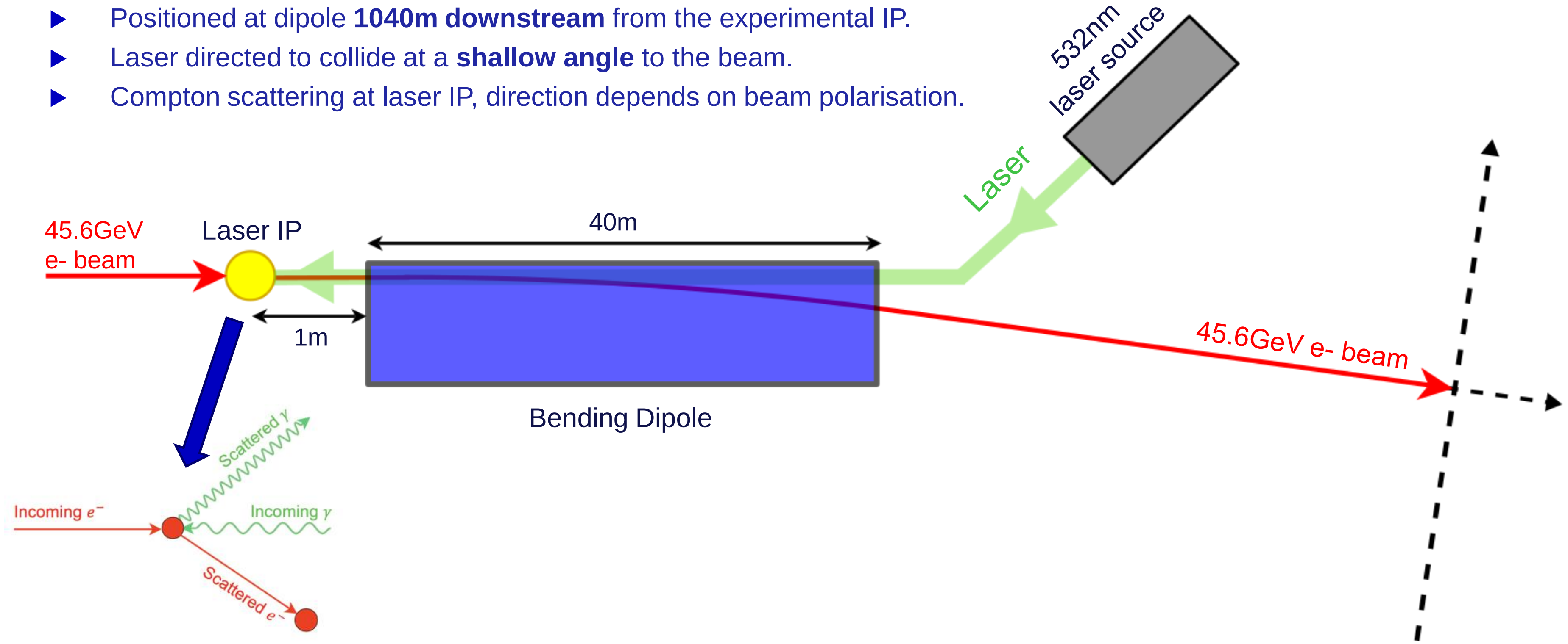
Polarimeter layout

- Positioned at dipole **1040m downstream** from the experimental IP.
- Laser directed to collide at a **shallow angle** to the beam.



Polarimeter layout

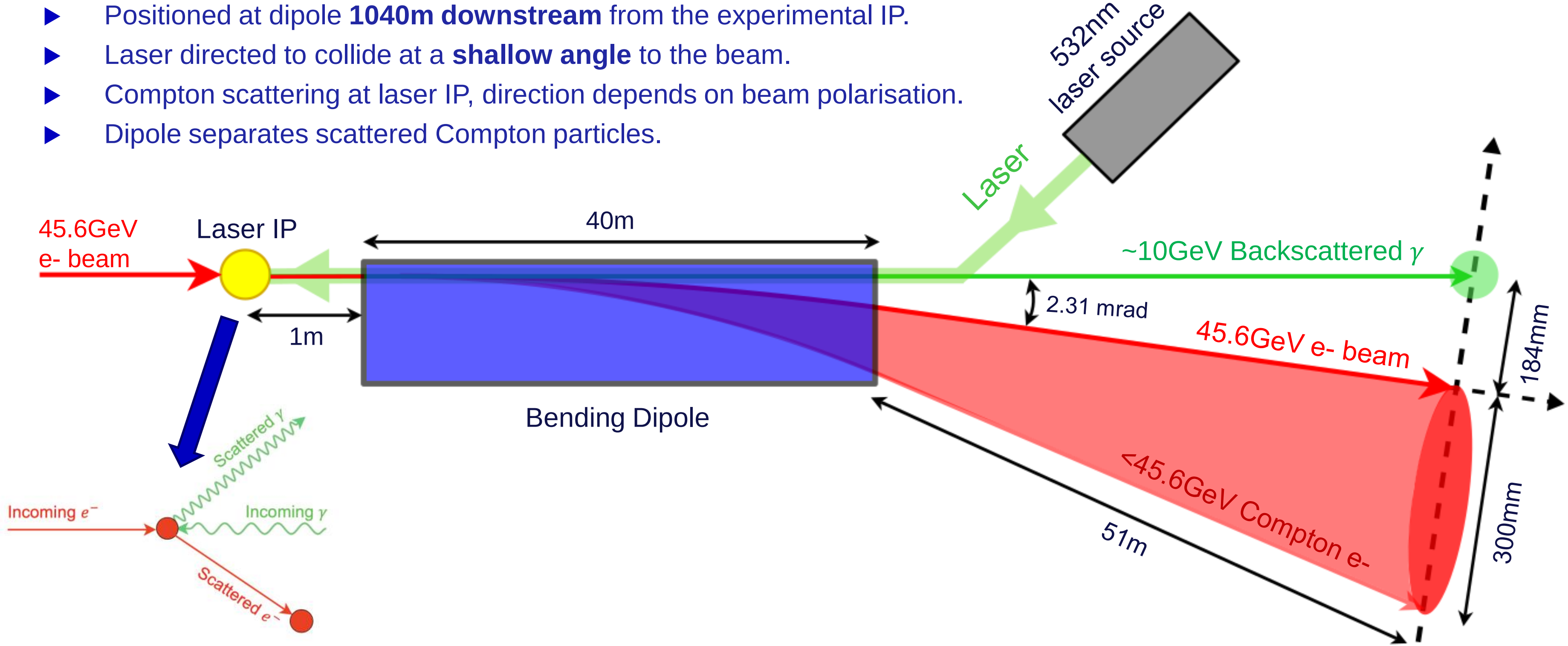
- Positioned at dipole **1040m downstream** from the experimental IP.
- Laser directed to collide at a **shallow angle** to the beam.
- Compton scattering at laser IP, direction depends on beam polarisation.



Compton Scattering

Polarimeter layout

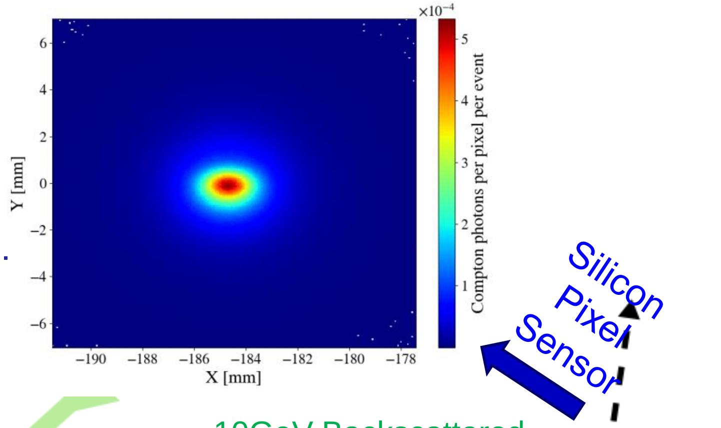
- Positioned at dipole **1040m downstream** from the experimental IP.
- Laser directed to collide at a **shallow angle** to the beam.
- Compton scattering at laser IP, direction depends on beam polarisation.
- Dipole separates scattered Compton particles.

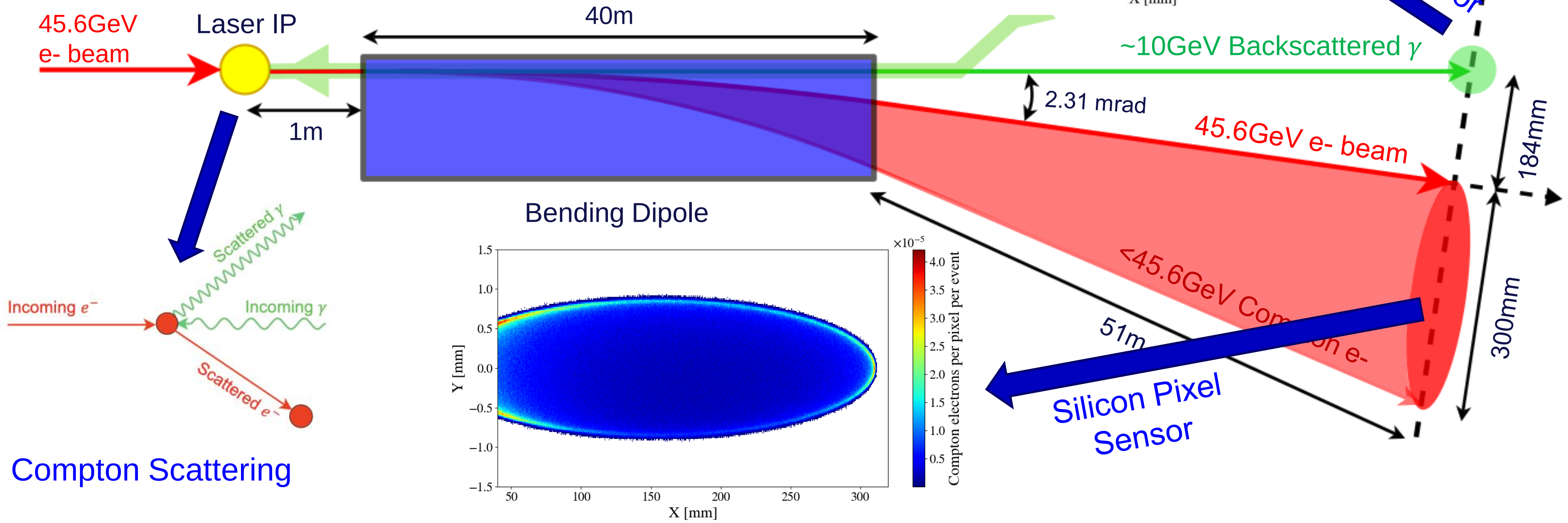


Compton Scattering

Polarimeter layout

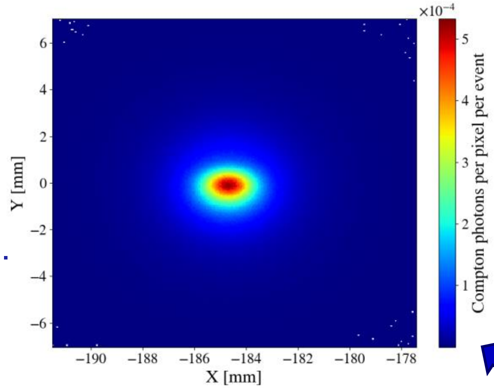
- Positioned at dipole **1040m downstream** from the experimental IP.
- Laser directed to collide at a **shallow angle** to the beam.
- Compton scattering at laser IP, direction depends on beam polarisation.
- Dipole separates scattered Compton particles.
- Silicon pixel sensors measure Compton distributions.

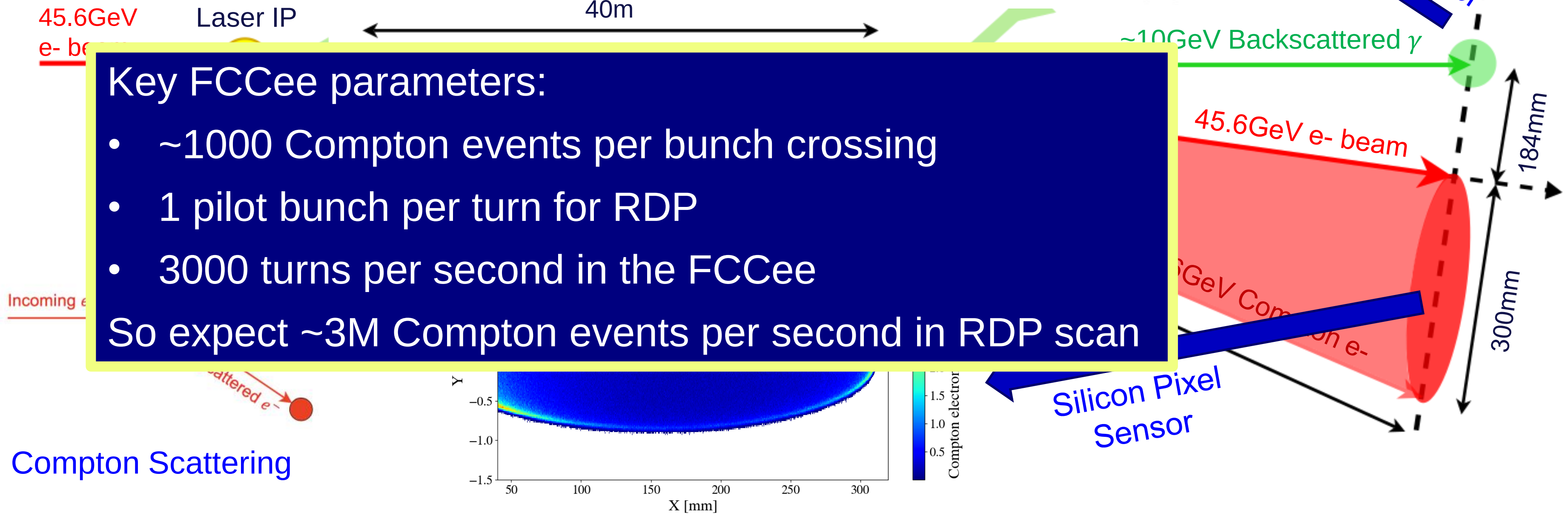




Polarimeter layout

- Positioned at dipole **1040m downstream** from the experimental IP.
- Laser directed to collide at a **shallow angle** to the beam.
- Compton scattering at laser IP, direction depends on beam polarisation.
- Dipole separates scattered Compton particles.
- Silicon pixel sensors measure Compton distributions.





Key FCCee parameters:

- ~1000 Compton events per bunch crossing
- 1 pilot bunch per turn for RDP
- 3000 turns per second in the FCCee

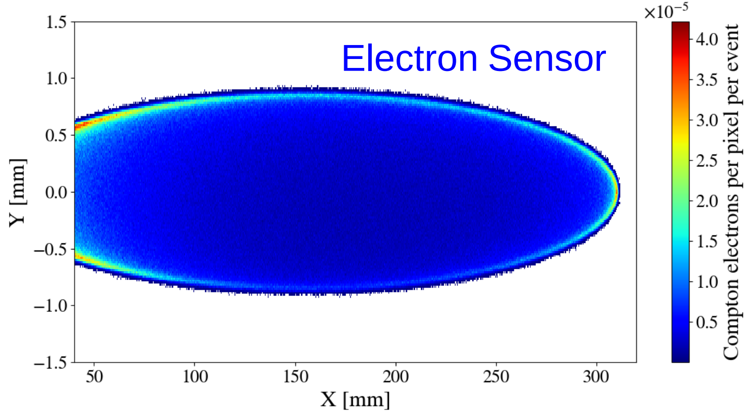
So expect ~3M Compton events per second in RDP scan

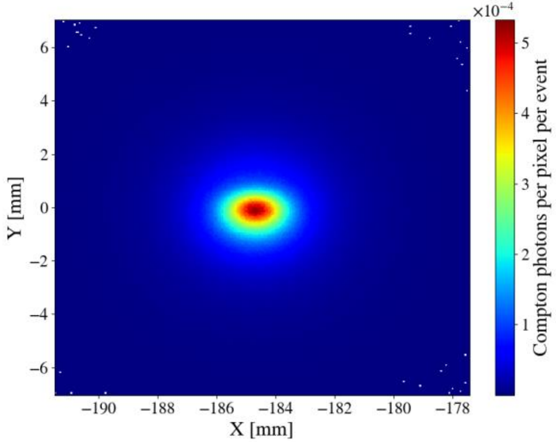
Simulating the polarimeter

- Simulations were performed using **BDSIM (B**eam **D**elivery **Sim**ulation), a Geant4-based 3D radiation transport model designed for simulating accelerators and beamlines.

- BDSIM is capable of simulating the Compton scattering process, the interaction of the scattered particles with matter, and the energy deposition in the silicon sensors.

100% Vertically Polarised Beam





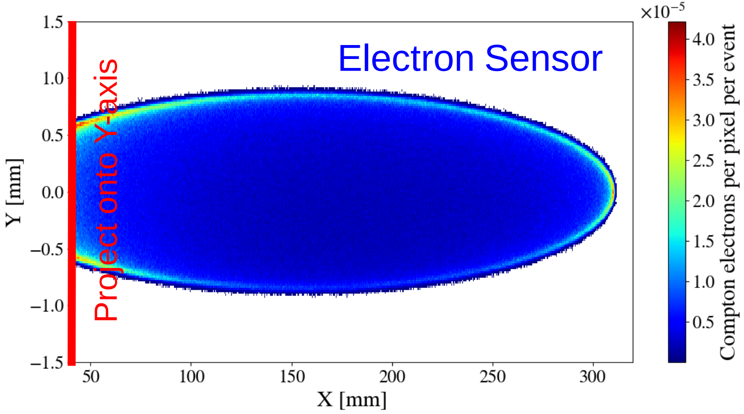
Photon Sensor

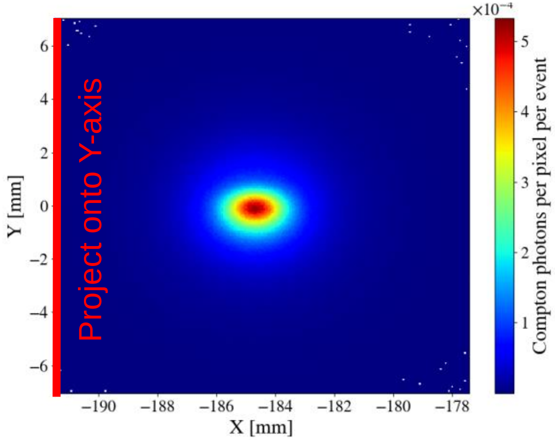
Simulating the polarimeter

- Simulations were performed using **BDSIM (B**eam **D**elivery **Sim**ulation), a Geant4-based 3D radiation transport model designed for simulating accelerators and beamlines.

- BDSIM is capable of simulating the Compton scattering process, the interaction of the scattered particles with matter, and the energy deposition in the silicon sensors.

100% Vertically Polarised Beam



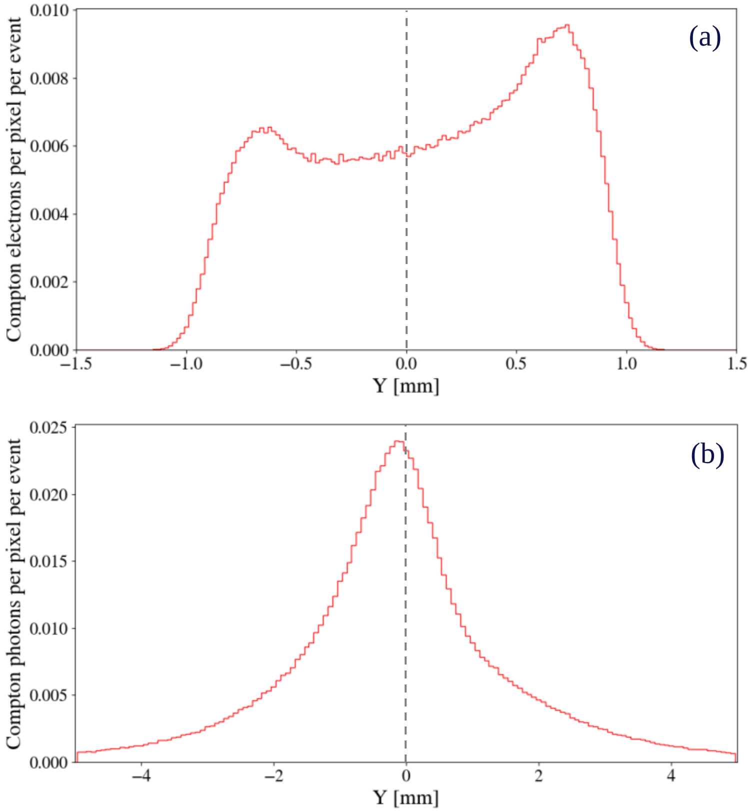


Photon Sensor

Simulating the polarimeter

- Simulations were performed using **BDSIM** (**B**eam **D**elivery **Sim**ulation), a Geant4-based 3D radiation transport model designed for simulating accelerators and beamlines.
- BDSIM is capable of simulating the Compton scattering process, the interaction of the scattered particles with matter, and the energy deposition in the silicon sensors.

100% Vertically Polarised Beam

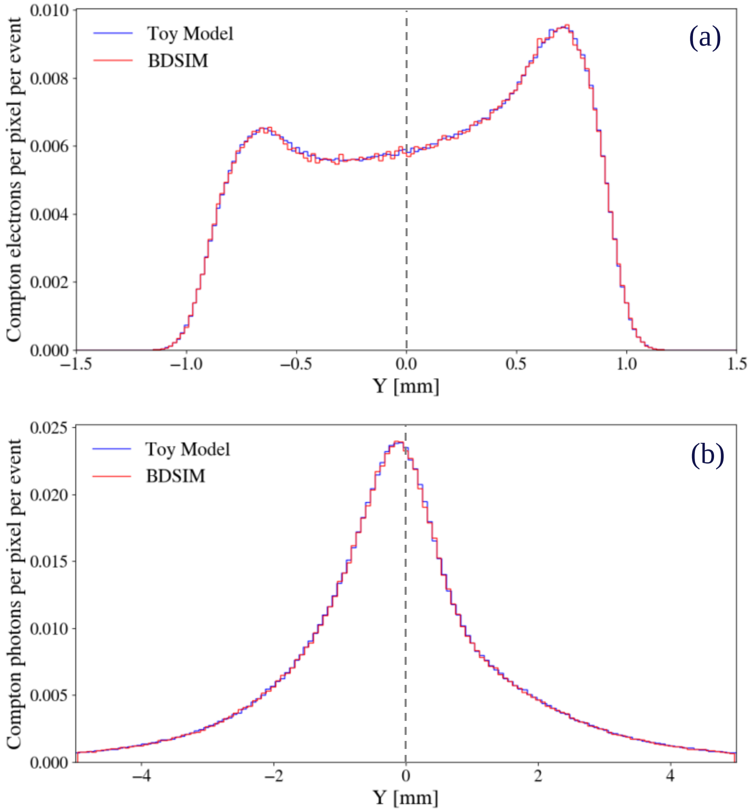


Simulated prediction of polarimeter (a) electron and (b) photon profile

Simulating the polarimeter

- Simulations were performed using **BDSIM (B**eam **D**elivery **Sim**ulation), a Geant4-based 3D radiation transport model designed for simulating accelerators and beamlines.
- BDSIM is capable of simulating the Compton scattering process, the interaction of the scattered particles with matter, and the energy deposition in the silicon sensors.
- The BDSIM model has been benchmarked against a Toy Monte Carlo (ToyMC) model built specifically to model the polarimeter.
- Can use these simulation results to estimate the performance of the polarimeter.

100% Vertically Polarised Beam



Simulated prediction of polarimeter (a) electron and (b) photon profile

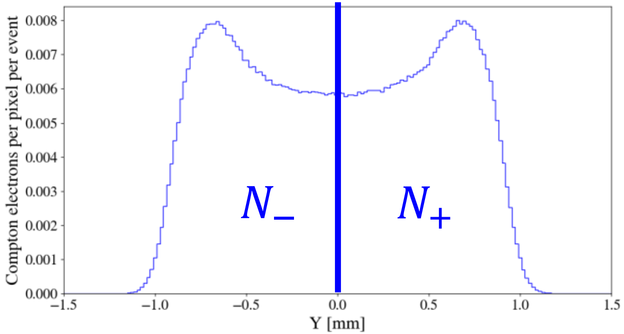
Polarimeter performance

- With the model constructed, we can make estimates of the precision of the polarimeter.

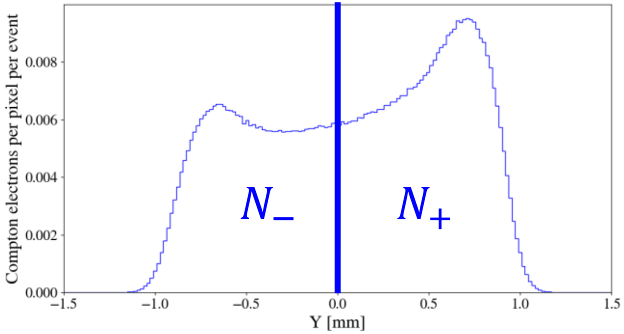
Polarimeter performance

- With the model constructed, we can make estimates of the precision of the polarimeter.
- In the case of the electron sensor, we can quantify the effect of polarisation on the distribution with the **asymmetry:**

$$\text{Asymmetry} = \frac{N_+ - N_-}{N_+ + N_-} \qquad \text{where } N_{+/-} \text{ is the number of electrons above/below } y = 0$$



Unpolarised



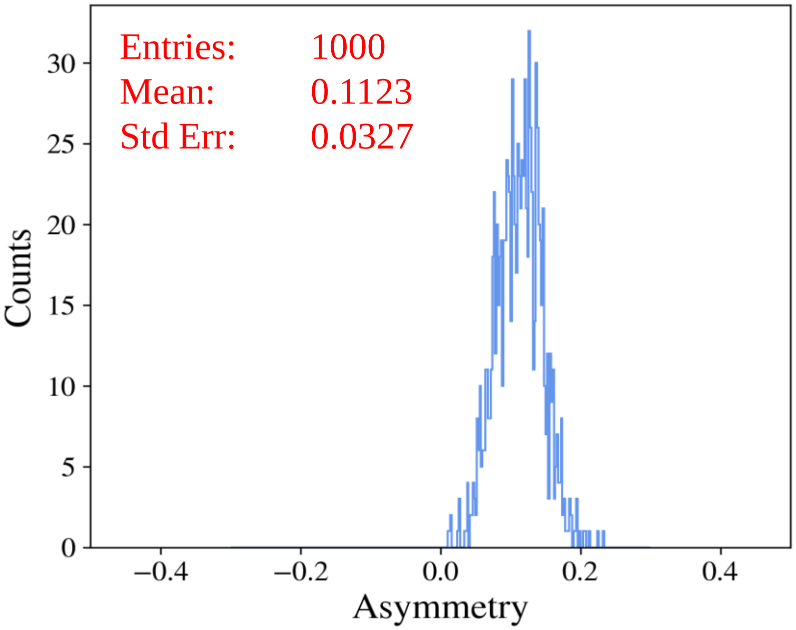
100% Vertically Polarised

- This is a useful measure as it is **directly proportional** to the polarisation of the beam.

Polarimeter performance

- Performed analysis of the **electron sensor** at a bunch-by-bunch (1000 Compton events) measurement, found relative error on the polarisation of **~29%.**
- Far too high to be useful for RDP, however we can predict that to reach a 1% error would take **~0.28s**, which is well within our requirements.

100% Polarised Beam

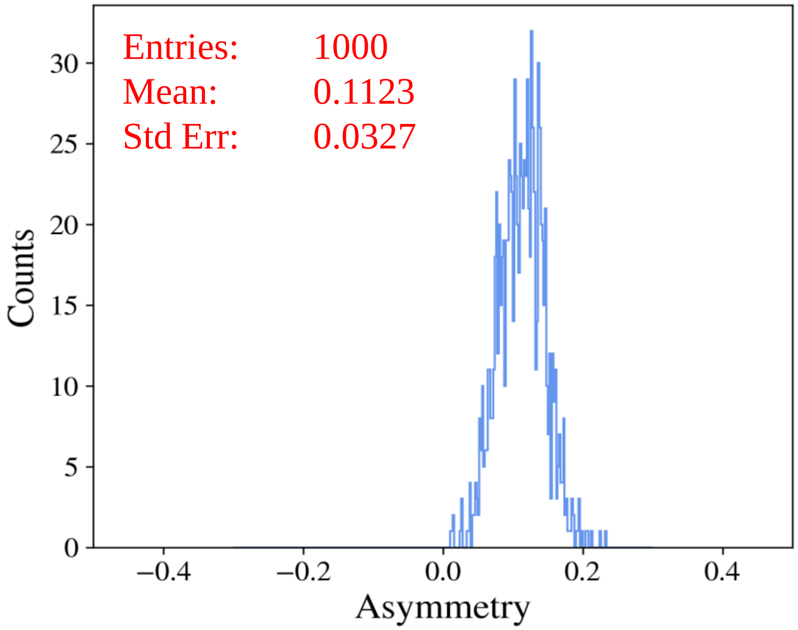


Histogram displaying the asymmetry in the Compton electron distribution for a single bunch crossing i.e. 1000 events

Polarimeter performance

- Performed analysis of the **electron sensor** at a bunch-by-bunch (1000 Compton events) measurement, found relative error on the polarisation of **~29%.**
- Far too high to be useful for RDP, however we can predict that to reach a 1% error would take **~0.28s**, which is well within our requirements.
- A similar analysis for the **photon sensor** yielded a **~23%** relative error on a bunch-by-bunch measurement, and **~0.17s** data taking time to reach a 1% error.

100% Polarised Beam

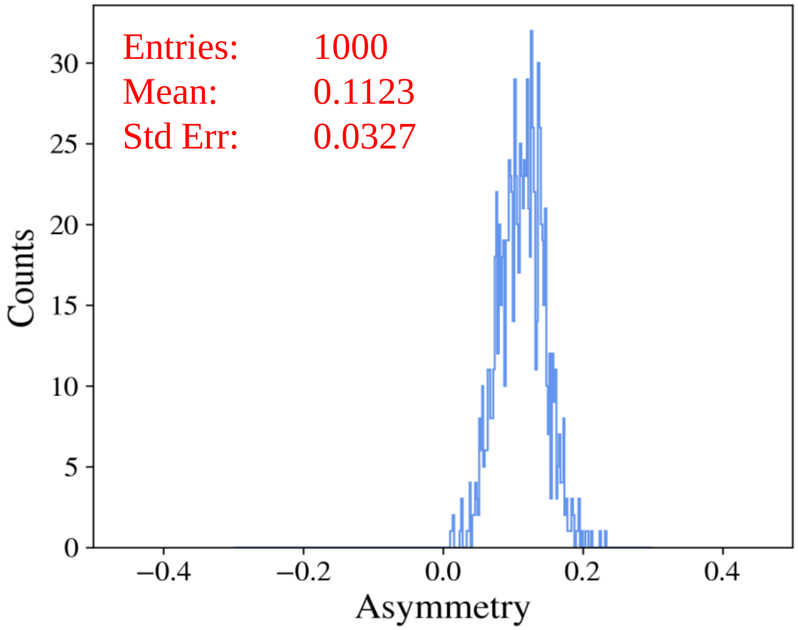


Histogram displaying the asymmetry in the Compton electron distribution for a single bunch crossing i.e. 1000 events

Polarimeter performance

- Performed analysis of the **electron sensor** at a bunch-by-bunch (1000 Compton events) measurement, found relative error on the polarisation of **~29%.**
- Far too high to be useful for RDP, however we can predict that to reach a 1% error would take **~0.28s**, which is well within our requirements.
- A similar analysis for the **photon sensor** yielded a **~23%** relative error on a bunch-by-bunch measurement, and **~0.17s** data taking time to reach a 1% error.
- However, this analysis was performed for a 100% polarised beam with no backgrounds considered, so the true time is expected to be higher.

100% Polarised Beam



Histogram displaying the asymmetry in the Compton electron distribution for a single bunch crossing i.e. 1000 events

Summary

- The FCC-ee requires a calibration of the centre-of-mass collision energy to within a relative error of $\sim 10^{-7}$.
- This can be achieved via resonant depolarisation, which in turn requires a precise measurement of the vertical beam polarisation.
- BDSIM can be used to simulate the FCCee polarimeter and predict its performance.
- Currently the electron and photon sensors yield an expected relative error of 29% and 23% respectively for a bunch-by-bunch measurement of a 100% vertically polarised beam.
- Extrapolating from this, to achieve a relative error of 1% the respective sensors would require 0.28s and 0.17s of data taking. This time increases for lower polarisations and many factors such as backgrounds have not yet been implemented in the model.

Next steps for the polarimeter design

- A careful evaluation of the expected **background** rates and their impact on the polarimeter performance needs to be made, this is likely the biggest factor impacting the uncertainties that we have not considered.
- Investigation of simulation methods to more completely model the **sensor behaviour and digitisation** is ongoing e.g. Allpix-squared. Possible benefit to having multiple layers of sensors, also to be investigated.
- First **hardware tests** with TimePix sensors are expected to be performed in the coming year.
- Investigate performance at longitudinal polarisation measurement on **colliding bunches**.

  => an even bigger challenge!

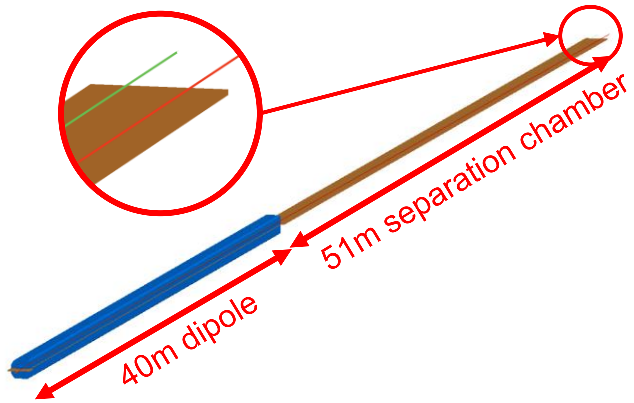
FCC

Thank you for your attention.

Backup slides

Simulating the polarimeter

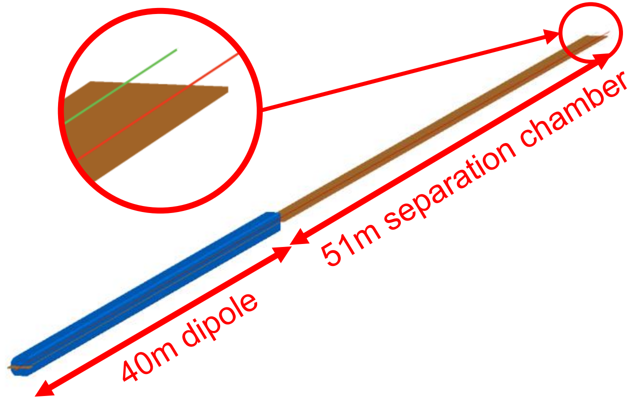
- Simulations were performed in two stages:



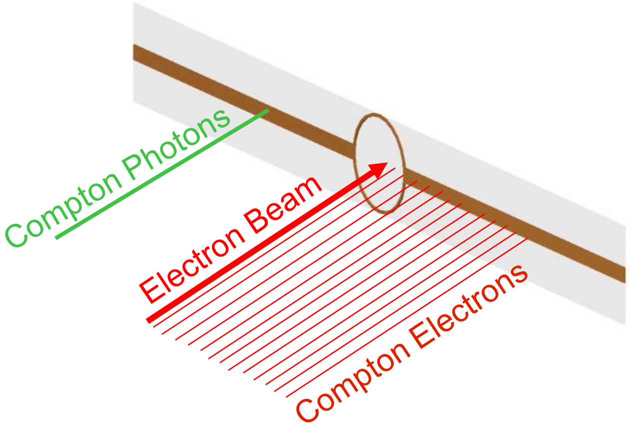
1) Compton interaction and dipole

Simulating the polarimeter

- Simulations were performed in two stages:



1) Compton interaction and dipole



2) Extraction window and sensors

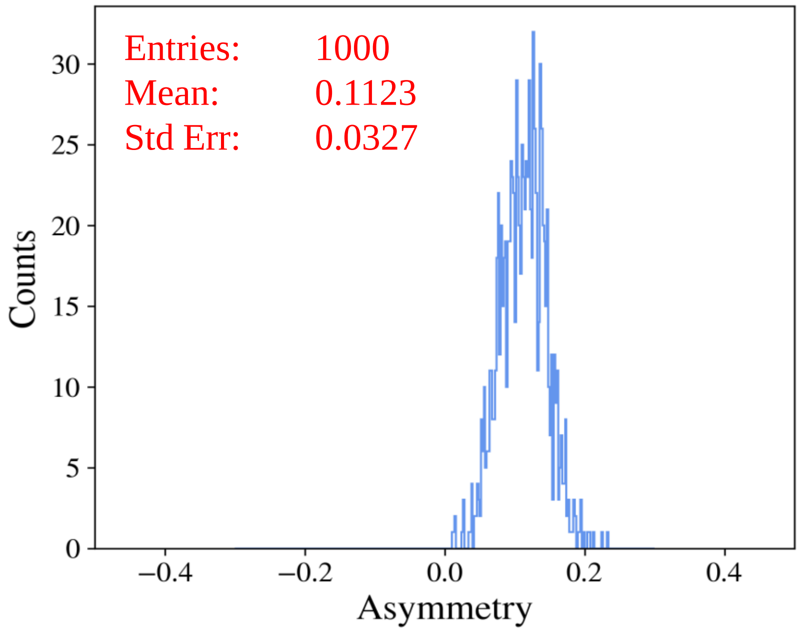
Electron Sensor

Measuring the polarisation (100% beam polarisation)

Error on the polarisation measurement taken bunch-by-bunch:

- Ran 1M Compton scattering events.
- For every 1000 events (1 bunch crossing), calculated the asymmetry of the incident Compton electrons.
- Repeated 1000 times, the error on the asymmetry histogram gives the relative error on the polarisation measurement.
- Can then estimate error for longer measurement times.

100% Polarised Beam (ideal)



Assuming $\sigma_A \propto \frac{1}{\sqrt{N}}$

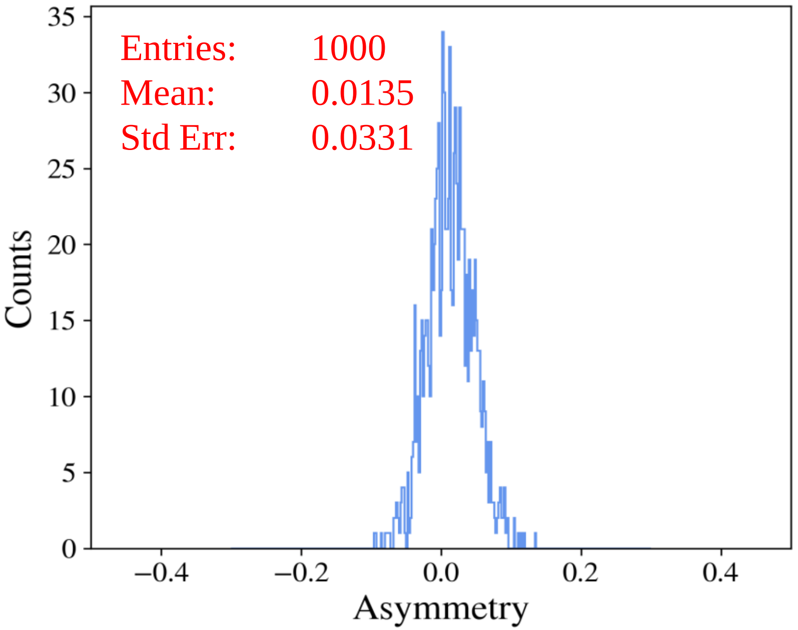
$$\text{Relative Error} = \frac{0.0327}{0.113} = \mathbf{29.1\%} \Rightarrow \text{To achieve 1\% error: } \frac{29.1^2}{1^2} \cdot 1000 \approx 8.5e5 \text{ evts} \Rightarrow \mathbf{0.28s} \text{ data taking}$$

Measuring the polarisation (10% beam polarisation)

Error on the polarisation measurement taken bunch-by-bunch:

- Ran 1M Compton scattering events.
- For every 1000 events (1 bunch crossing), calculated the asymmetry of the incident Compton electrons.
- Repeated 1000 times, the error on the asymmetry histogram gives the relative error on the polarisation measurement.
- Can then estimate error for longer measurement times.

10% Polarised Beam (more realistic)



Assuming $\sigma_A \propto \frac{1}{\sqrt{N}}$

$$\text{Relative Error} = \frac{0.0331}{0.0135} = \mathbf{245\%} \Rightarrow \text{To achieve 1\% error: } \frac{245^2}{1^2} \cdot 1000 \approx 6.0e7 \text{ evts} \Rightarrow \mathbf{20s} \text{ data taking}$$

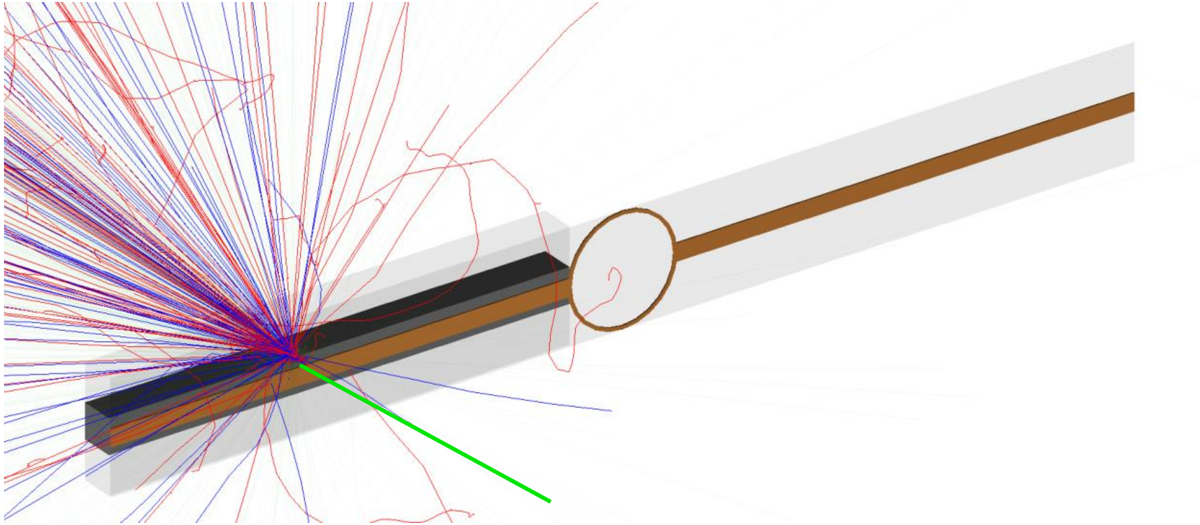
Photon Sensor

Photon Sensor Structure

- Silicon detectors can’t measure the high-energy photons directly, so we need to first convert them into charged particles using a layer of dense material e.g. lead, tungsten.
- BDSIM is able to simulate the required particle-matter interactions to predict the showers of secondary particles.

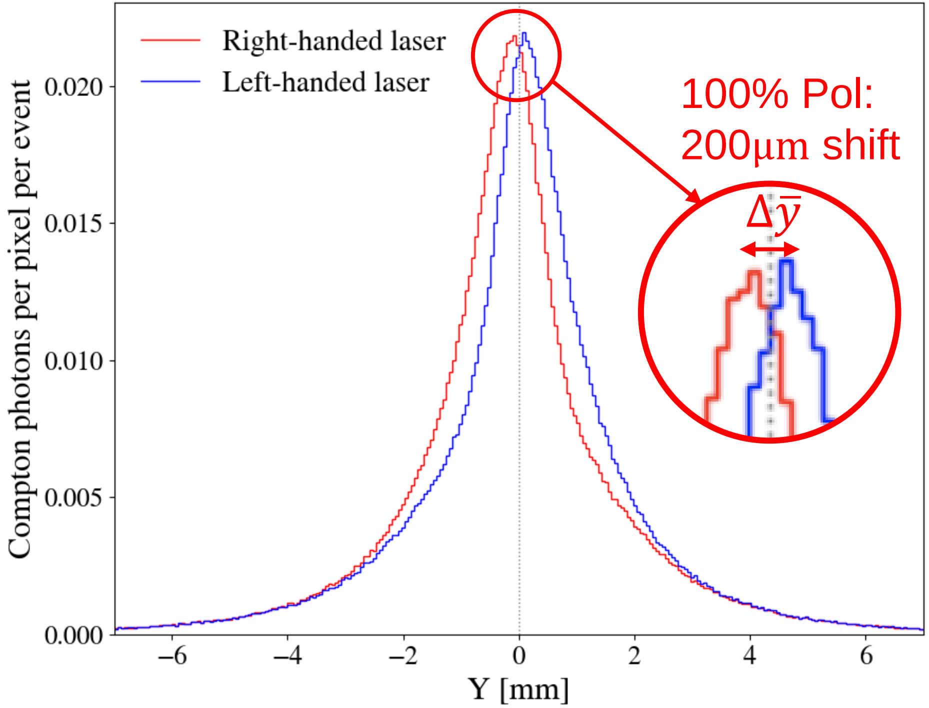
Photon Sensor Structure

- Silicon detectors can’t measure the high-energy photons directly, so we need to first convert them into charged particles using a layer of dense material e.g. lead, tungsten.
- BDSIM is able to simulate the required particle-matter interactions to predict the showers of secondary particles.
- For the following results a 20mm layer of tungsten was used to convert the photons to charged particles.



Measuring the polarisation

- How to deduce the polarisation from the on-screen photon distribution?
- Calculating asymmetry is less effective due to the conversion layer, instead find the **shift in the mean.**
- Alternate polarisation of the incident *laser.*
- Measure the shift in the mean of the profile $\Delta\bar{y}$.
- Polarisation of the electron beam is proportional to the vertical shift.



Measuring the polarisation (100% beam polarisation)

Error on the polarisation measurement taken bunch-by-bunch:

- Ran 1M Compton scattering events for both a left-handed (LH) and right-handed (RH) laser.
- For every 1000 LH events (1 bunch crossing), made a **Gaussian fit** to find the mean of the profile, then did the same for 1000 RH events and subtracted one from the other to find $\Delta\bar{y}$.

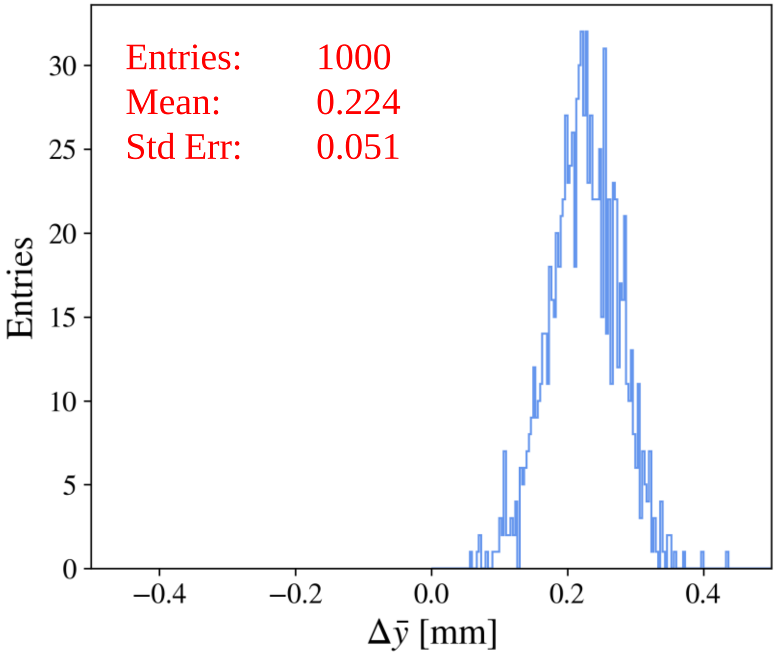
Measuring the polarisation (100% beam polarisation)

Error on the polarisation measurement taken bunch-by-bunch:

- Ran 1M Compton scattering events for both a left-handed (LH) and right-handed (RH) laser.
- For every 1000 LH events (1 bunch crossing), made a **Gaussian fit** to find the mean of the profile, then did the same for 1000 RH events and subtracted one from the other to find $\Delta\bar{y}$.
- Repeated 1000 times, the error on the $\Delta\bar{y}$ histogram gives the relative error on the polarisation measurement.

$$\text{Relative Error} = \frac{0.051}{0.224} = \mathbf{22.8\%}$$

100% Polarised Beam (ideal)

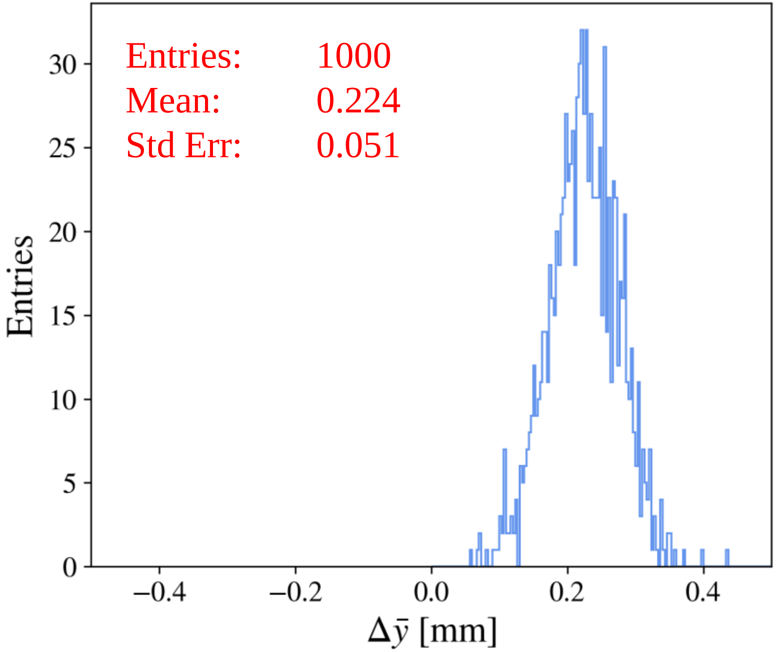


Measuring the polarisation (100% beam polarisation)

Error on the polarisation measurement taken bunch-by-bunch:

- Ran 1M Compton scattering events for both a left-handed (LH) and right-handed (RH) laser.
- For every 1000 LH events (1 bunch crossing), made a **Gaussian fit** to find the mean of the profile, then did the same for 1000 RH events and subtracted one from the other to find $\Delta\bar{y}$.
- Repeated 1000 times, the error on the $\Delta\bar{y}$ histogram gives the relative error on the polarisation measurement.
- Can then estimate error for longer measurement times.

100% Polarised Beam (ideal)



Assuming $\sigma_{\Delta\bar{y}} \propto \frac{1}{\sqrt{N}}$

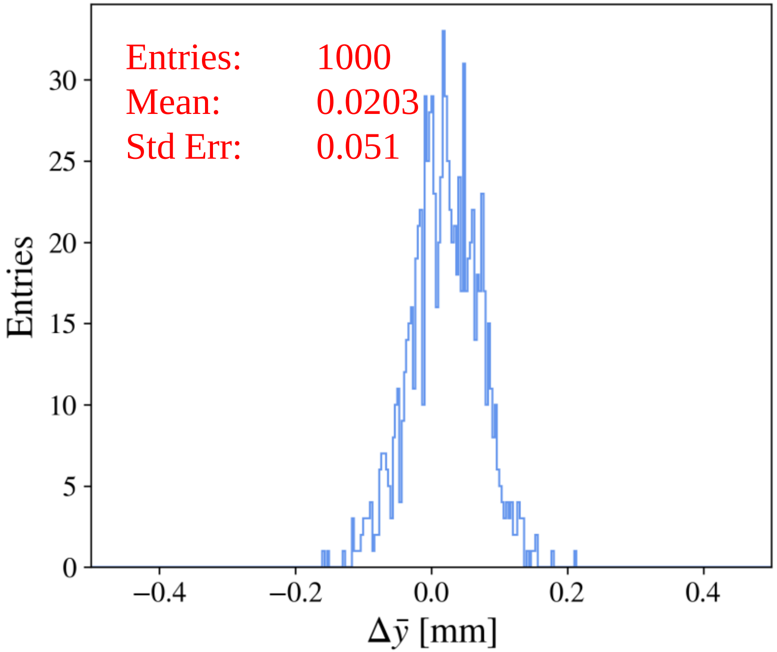
$$\text{Relative Error} = \frac{0.051}{0.224} = \mathbf{22.8\%} \Rightarrow \text{To achieve 1\% error: } \frac{22.8^2}{1^2} \cdot 1000 \approx 5.2e5 \text{ evts} \Rightarrow \mathbf{0.17s} \text{ data taking}$$

Measuring the polarisation (10% beam polarisation)

Error on the polarisation measurement taken bunch-by-bunch:

- Ran 1M Compton scattering events for both a left-handed (LH) and right-handed (RH) laser.
- For every 1000 LH events (1 bunch crossing), made a **Gaussian fit** to find the mean of the profile, then did the same for 1000 RH events and subtracted one from the other to find $\Delta\bar{y}$.
- Repeated 1000 times, the error on the $\Delta\bar{y}$ histogram gives the relative error on the polarisation measurement.
- Can then estimate error for longer measurement times.

10% Polarised Beam (more realistic)



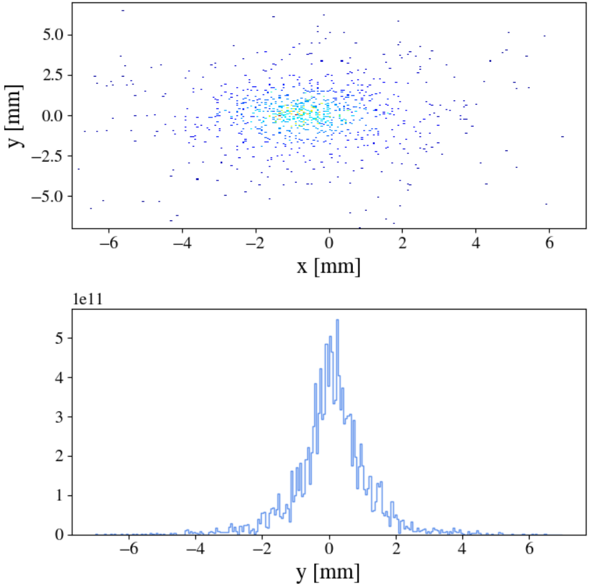
Assuming $\sigma_{\Delta\bar{y}} \propto \frac{1}{\sqrt{N}}$

$$\text{Relative Error} = \frac{0.051}{0.0203} = \mathbf{251\%} \Rightarrow \text{To achieve 1\% error: } \frac{251^2}{1^2} \cdot 1000 \approx 6.3\text{e}7 \text{ evts} \Rightarrow \mathbf{21s} \text{ data taking}$$

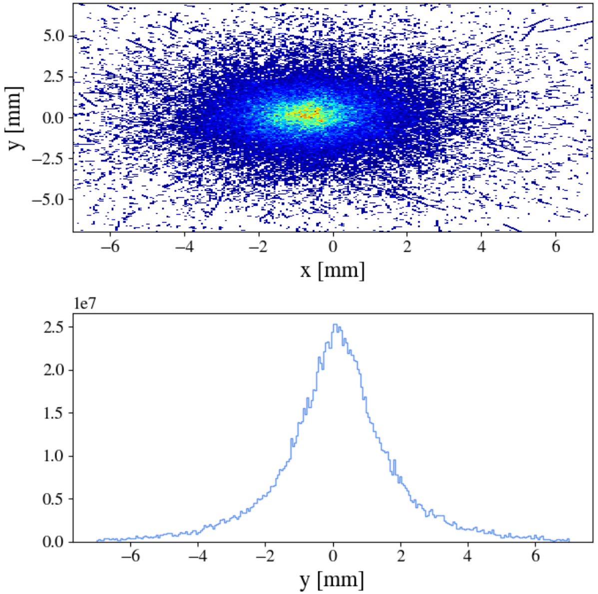
Comparison to sampler

- Placed a sampler *before* the tungsten layer to compare performance of sensor to recording the photon positions directly.
- For timepix3 layout of 256x256 pixels, observed a higher error in $\Delta\bar{y}$ with the *sampler* than with the more realistic sensor. A brief investigation revealed that it was clear this was merely a result of the sparse binning in the sampler:

Sampler before tungsten

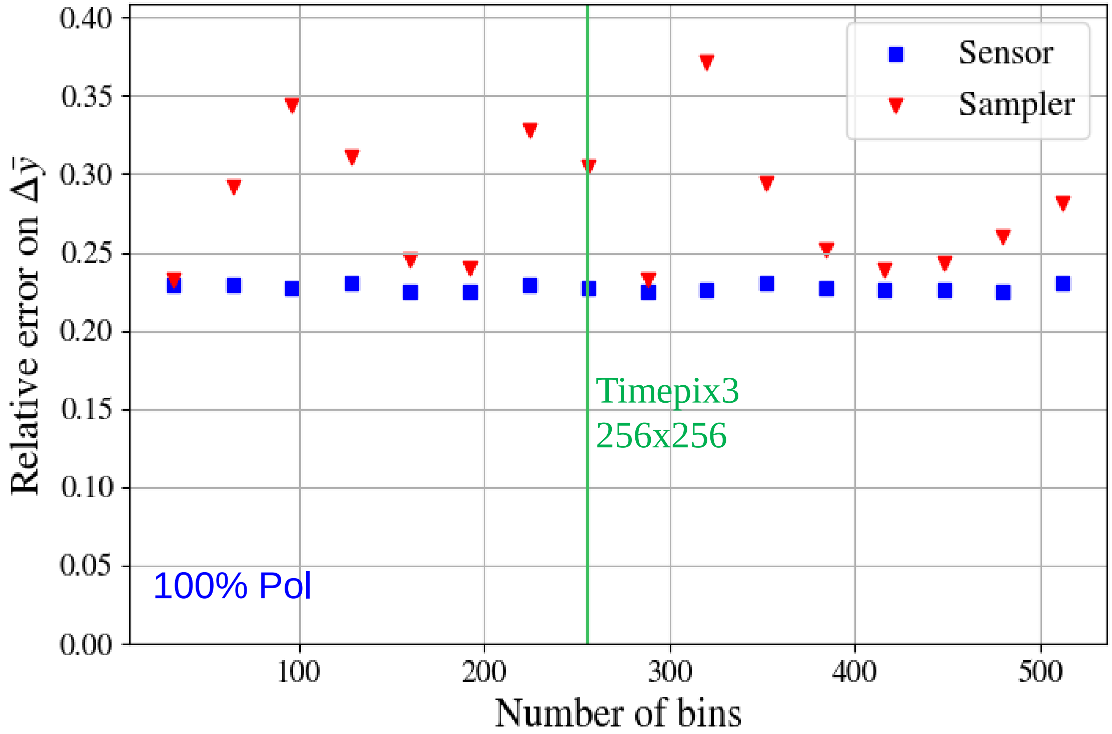


Sensor after tungsten



Comparison to sampler

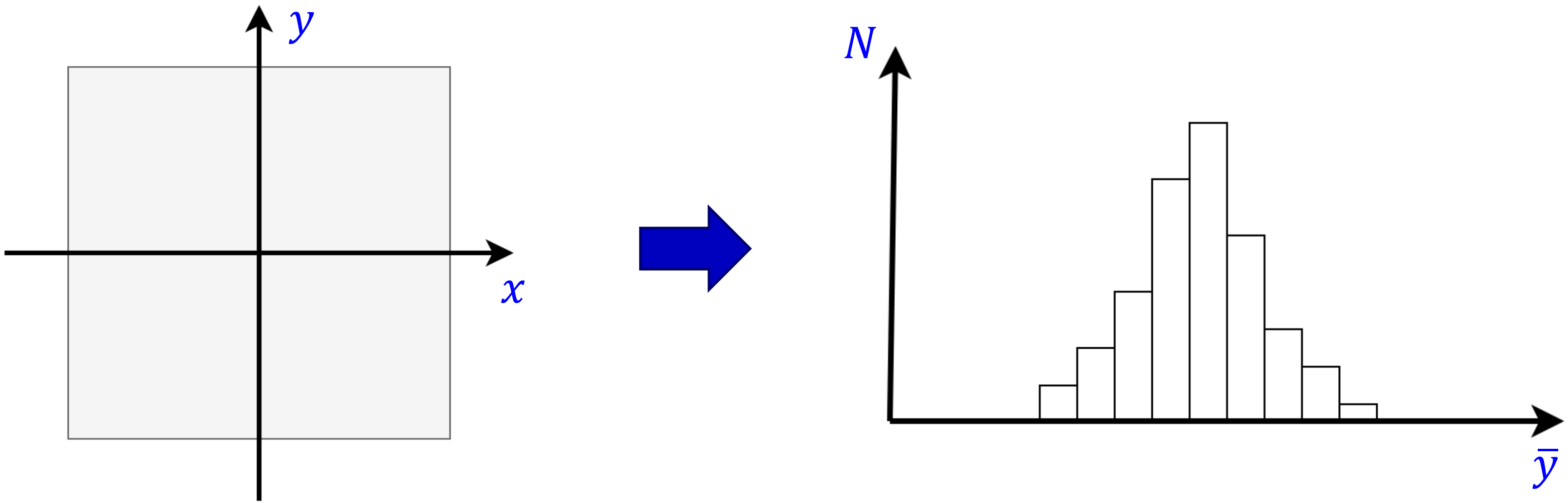
- Investigated the effect of changing the number of pixels in the sensor/sampler, looking at a range from 32x32 to 512x512:



- Pixel size not a limiting factor for *bunch-by-bunch* measurements.
- Convertor layer actually reduces error for bunch-by-bunch case due to improved statistics.

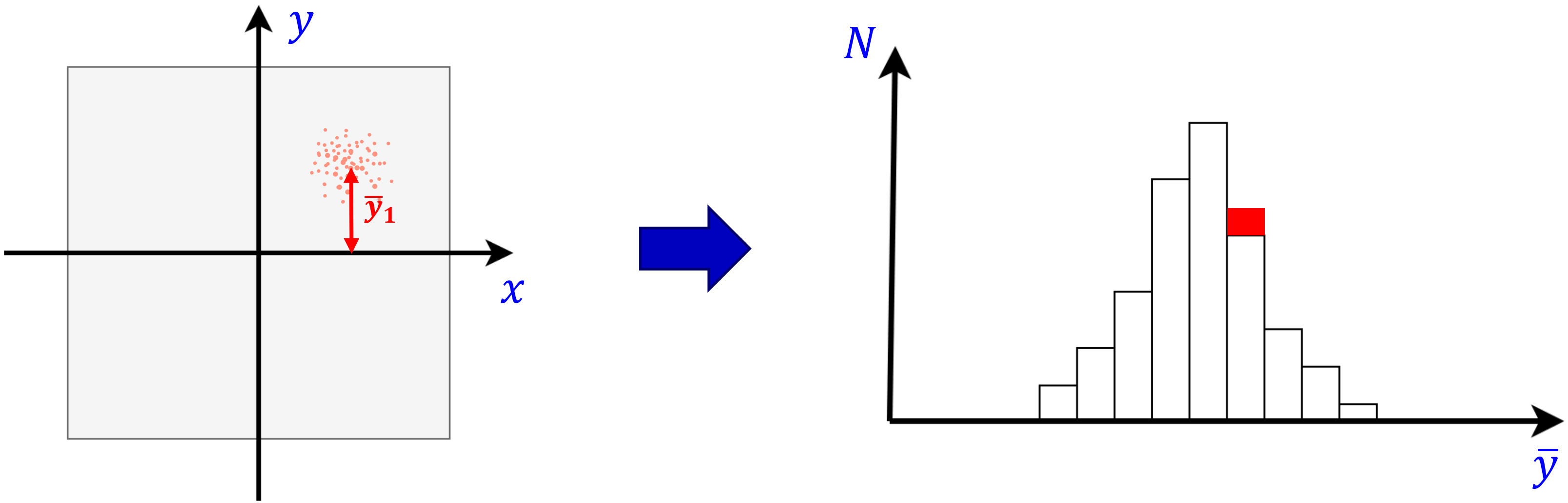
Analysis of the profile mean position

- Want to choose thickness of tungsten that minimises jitter in the secondary particles profile.
- We take the **average charged particle position** from an unpolarised bunch crossing **relative to the average Compton photon position**, and bin it to a histogram. Repeat this across many bunch crossings, and find the **standard error in this average position.**



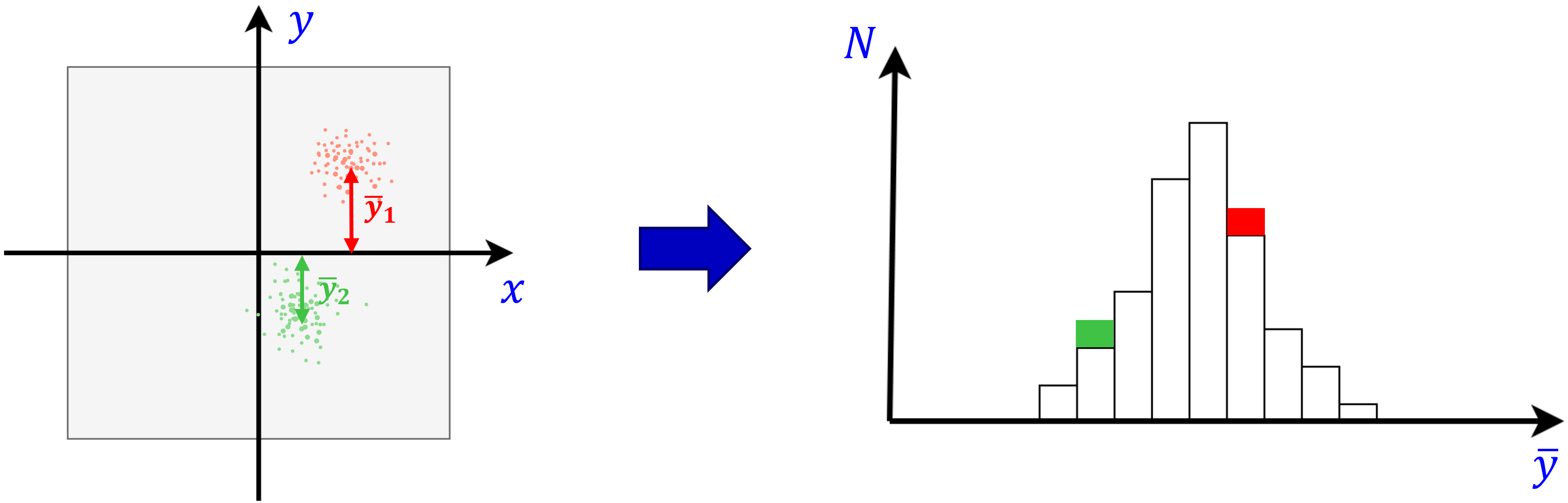
Analysis of the profile mean position

- Want to choose thickness of tungsten that minimises jitter in the secondary particles profile.
- We take the **average charged particle position** from an unpolarised bunch crossing **relative to the average Compton photon position**, and bin it to a histogram. Repeat this across many bunch crossings, and find the **standard error in this average position.**



Analysis of the profile mean position

- Want to choose thickness of tungsten that minimises jitter in the secondary particles profile.
- We take the **average charged particle position** from an unpolarised bunch crossing **relative to the average Compton photon position**, and bin it to a histogram. Repeat this across many bunch crossings, and find the **standard error in this average position.**



Polarisation error assumption

- We want to check that the assumption:

$$\sigma_{\Delta\bar{y}} \propto \frac{1}{\sqrt{N}}$$

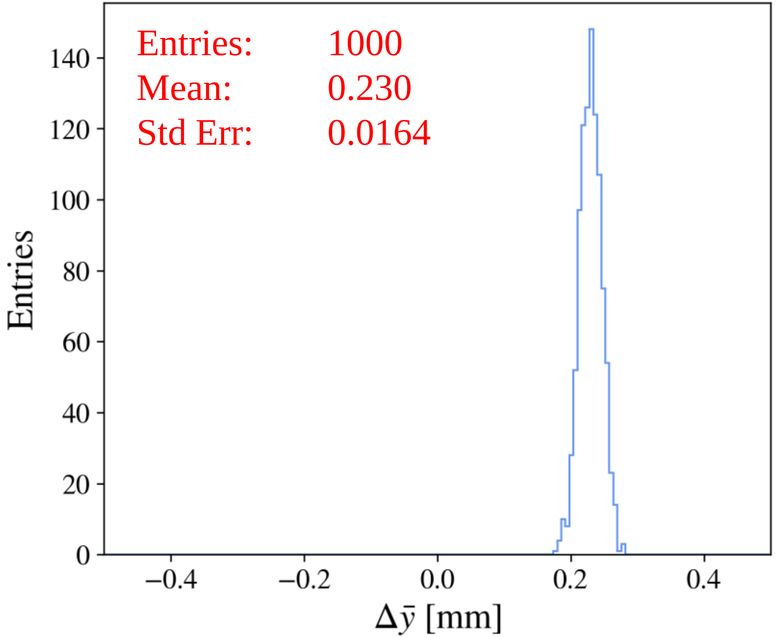
is valid.

- For measurements of 1000 Compton events at 100% polarisation we found $\sigma_{\Delta\bar{y}} = 0.051$.
- If the assumption holds then for 10000 Compton events we should get:

$$\sigma_{\Delta\bar{y}} = 0.051 \times \sqrt{\frac{1000}{10000}} = \frac{0.051}{\sqrt{10}} = 0.0161$$

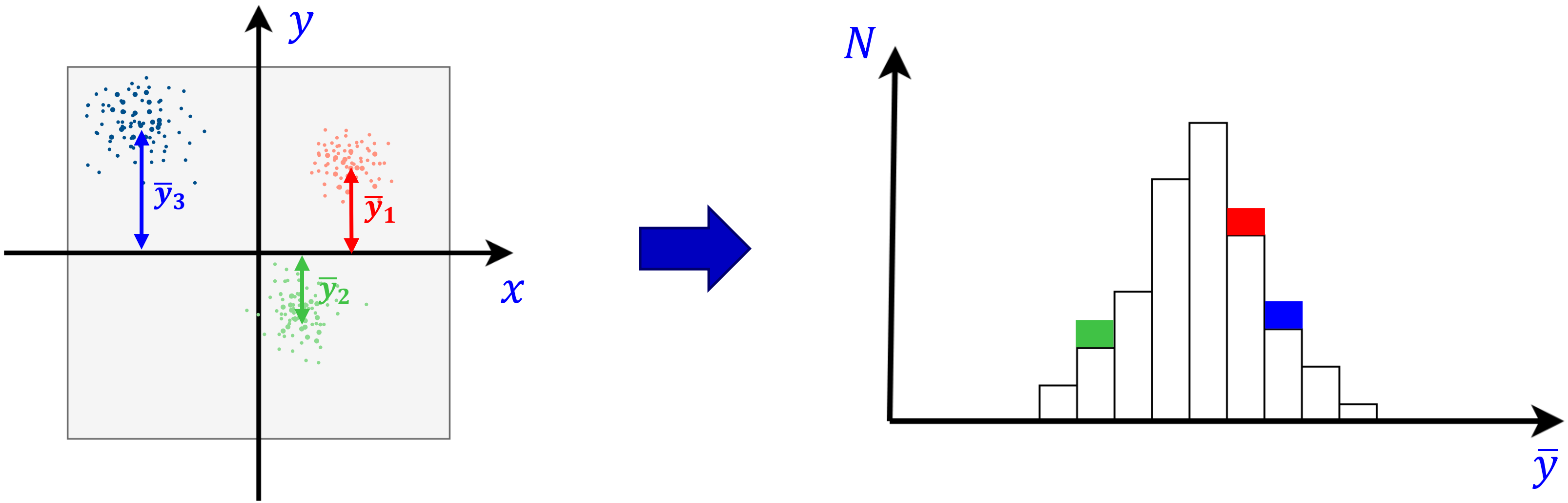
- When generating a histogram of 1000 samples of 10000 events each, we find that $\sigma_{\Delta\bar{y}} = 0.0164$
- **Assumption appears to hold up to 10000 events, equivalent to 3ms data taking.**

100% Polarised Beam (ideal)



Analysis of the profile mean position

- Want to choose thickness of tungsten that minimises jitter in the secondary particles profile.
- We take the **average charged particle position** from an unpolarised bunch crossing **relative to the average Compton photon position**, and bin it to a histogram. Repeat this across many bunch crossings, and find the **standard error in this average position.**



Analysis of the profile mean position

- Want to choose thickness of tungsten that minimises jitter in the secondary particles profile.
- We take the **average charged particle position** from an unpolarised bunch crossing **relative to the average Compton photon position**, and bin it to a histogram. Repeat this across many bunch crossings, and find the **standard error in this average position.**
- **Repeat across each layer** to find the thickness of tungsten with the smallest error.