

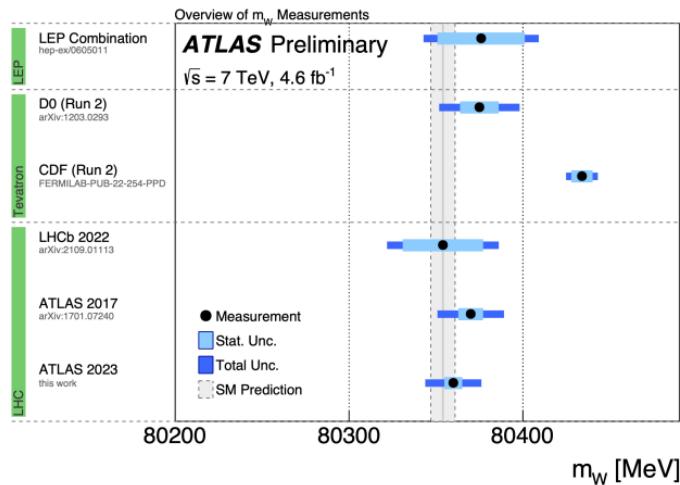
# Compton polarimeters

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On behalf of FCC-ee FS EPOL group

<https://indico.cern.ch/category/8678/>

# Physics requirements



Observable	statistics	$\Delta\sqrt{s}_{\text{abs}}$ 100 keV	$\Delta\sqrt{s}_{\text{syst-tpf}}$ 40 keV	calib. stats.	$\sigma_{\sqrt{s}}$ $200 \text{ keV}/\sqrt{N^i}$
$m_Z$ (keV)	4	100	<b>28</b>	1	—
$\Gamma_Z$ (keV)	4	2.5	<b>22</b>	1	<b>10</b>
$\sin^2 \theta_W^{\text{eff}} \times 10^6$ from $A_{\text{FB}}^{\mu\mu}$	2	—	<b>2.4</b>	0.1	—
$\frac{\Delta\alpha_{\text{QED}}(m_Z^2)}{\alpha_{\text{QED}}(m_Z^2)} \times 10^5$	3	0.1	<b>0.9</b>	—	<b>0.1</b>

Required accuracy of <1ppm

High reproducibility of measurements for various  $\sqrt{s}$  is critically needed

Extract as much information as possible from physics experiments themselves (crossing angle, luminosity,  $\sqrt{s}$  spread)

Beam-based measurements in real time, including beams energy with resonant depolarization

24/7 operable measurement of depolarization

# Physics requirements cont'd

## Importance of longitudinal polarisation measurement

Any residual longitudinal-polarisation will bias cross sections & forward-backward asymmetries (indeed, high longitudinal polarisation is actually useful, but we assume we are not in that regime – rather longitudinal polarisation is a nuisance).

Consider forward-backward asymmetry of  $b\bar{b}$  at Z pole:  $A_{FB}^b = \frac{3}{4}\mathcal{A}_e\mathcal{A}_b$

where in the SM  $\mathcal{A}_e \approx 0.15$ ,  $\mathcal{A}_b \approx 0.95 \Rightarrow A_{FB}^b \approx 0.11$

Now, if there is longitudinal polarisation, asymmetry becomes:  $(A_{FB}^b)' = \frac{3}{4}\mathcal{A}'_e\mathcal{A}_b$

where  $\mathcal{A}'_e = -\left(\frac{\mathcal{A}_e - P}{1 - \mathcal{A}_e P}\right)$  with  $P = \frac{(P_z)_{e^-} - (P_z)_{e^+}}{1 - (P_z)_{e^-} - (P_z)_{e^+}}$

and  $(P_z)_{e^\pm}$  the longitudinal polarisation of the  $e^\pm$ .

21/9/22

EPOL requirements at FCC-ee  
Guy Wilkinson

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## Importance of longitudinal polarisation measurement

Any residual longitudinal-polarisation will bias cross sections & forward-backward asymmetries (indeed, high longitudinal polarisation is actually useful, but we assume we are not in that regime – rather longitudinal polarisation is a nuisance).

So, if  $(P_z)_{e^-} = (P_z)_{e^+}$  (no reason to be so)  $= 10^{-5}$  (ballpark guess)

$$P = 2 \times 10^{-5} \Rightarrow \frac{(A_{FB}^b)' - A_{FB}^b}{A_{FB}^b} = 1.3 \times 10^{-4}$$

Statistical uncertainty on  $A_{FB}^b$  around  $2 \times 10^{-5}$  (relative), and QCD uncertainty which will probably be larger. Still, to be safe we would want to control  $P_z$  to  $< 10^{-5}$ .

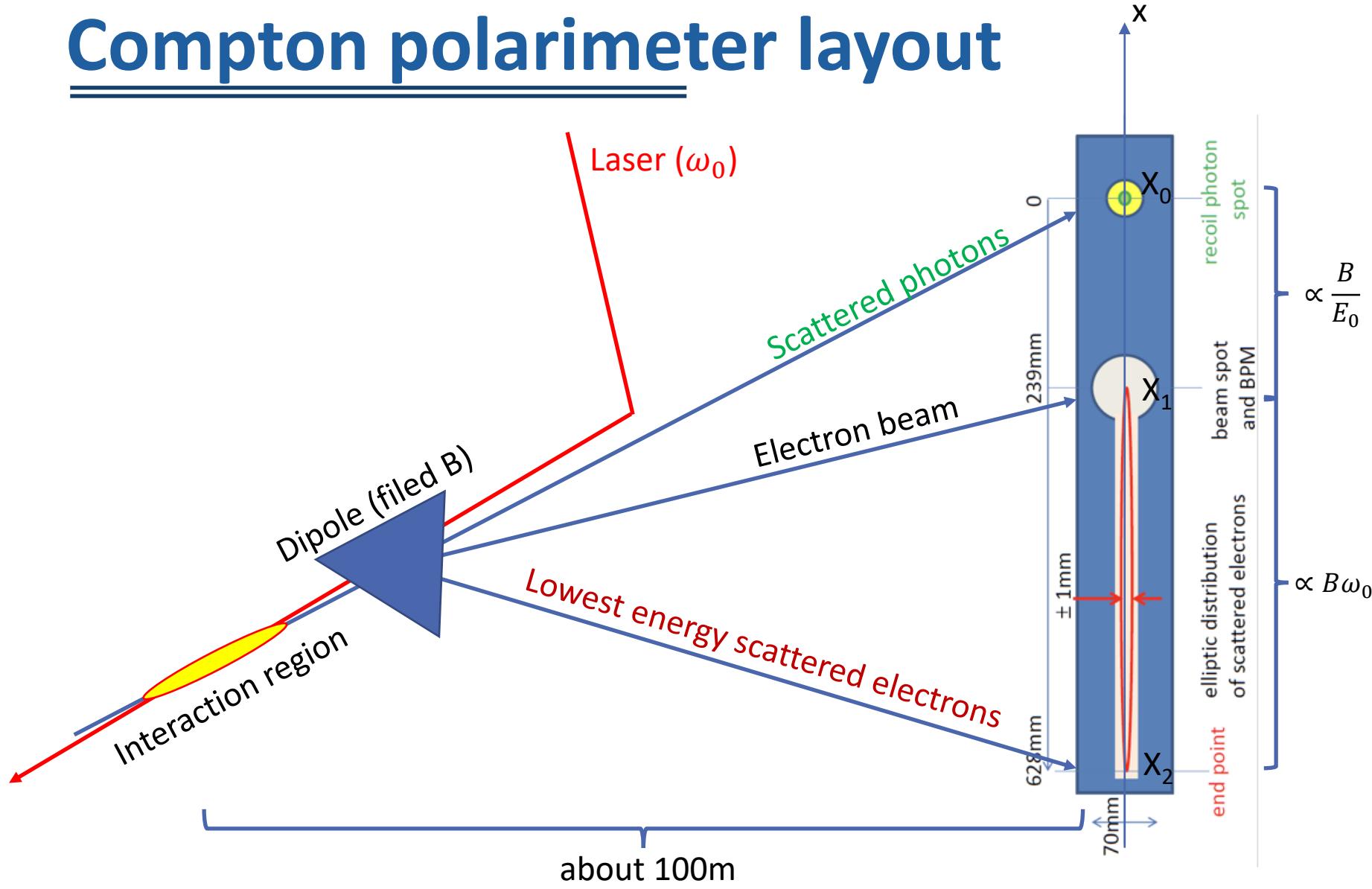
How is this to be done ? Measurements must be made on colliding bunches, where scattering rates are lower. Can we sample all bunches ? Will it prove necessary to depolarise the physics bunches ? If so, we will still need to monitor residual effects. And what are the systematics on an absolute measurement ?

Note also, that calculations required to transport the measurement of 3-vector at polarimeter to  $P_z$  value at the interaction points. How can this be cross checked ?

High accuracy longitudinal polarization measurement is needed  
 → Naturally small at IPs but with what accuracy ?  
 → Measure it !

# Compton polarimeter layout

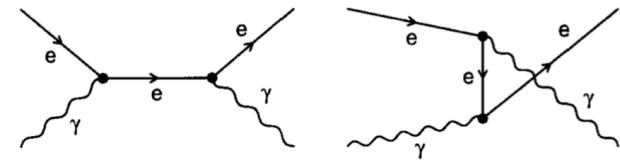
Blondel et al., arXiv:1909.12245; Muchnoi, INST 17 P10014 (2022)



New concept (N. Yu Muchnoi) to measure all polarization parameters → 3D polarimeter

# Compton cross-section

$$x = \frac{2E_0\omega_0}{m^2} (1 + \cos \alpha) \quad y = \frac{E_\gamma}{E_0}$$

Fig. 1. Tree diagrams for  $e^- \gamma \rightarrow e^- \gamma$ 

*The Compton cross-section averaged over scattered particles spins:*

Differential cross-section

Transverse laser polarisation: nuisance parameter to minimize and keep under control

$$\frac{d\sigma}{dy d\varphi_{obs}}(x, y) = \frac{d\sigma_0}{dy}(x, y) + \frac{d\sigma_\perp}{dy}(x, y) \cos(2(\varphi_{obs} - \varphi_{las})) \mathcal{P}_L^{las} + \frac{d\sigma_\parallel}{dy}(x, y) \mathcal{P}_C^{las} (P_T f_T(x, y) \cos(\varphi_{obs} - \varphi_{elec}) + P_z f_z(x, y))$$

*Electron beam polarization independent*

Transverse electron beam polarisation: intervenes as an asymmetry in the transverse plane

*Electron beam polarization dependent*

⚠ But small opening angle of scattered particles:

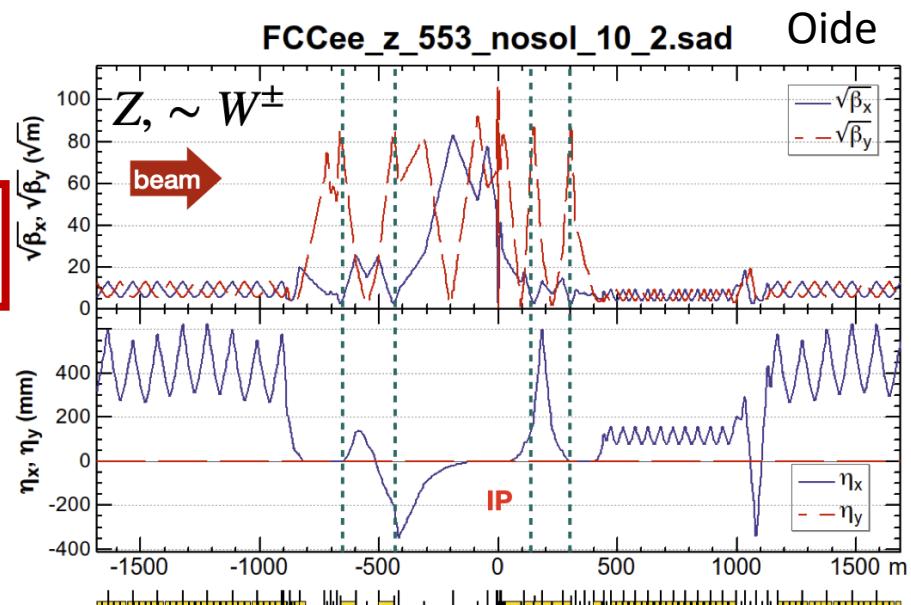
- Electrons → spectrometer
- Photons → difficult to measure asymmetric distribution of a narrow spot → long lever arm needed

# Integration

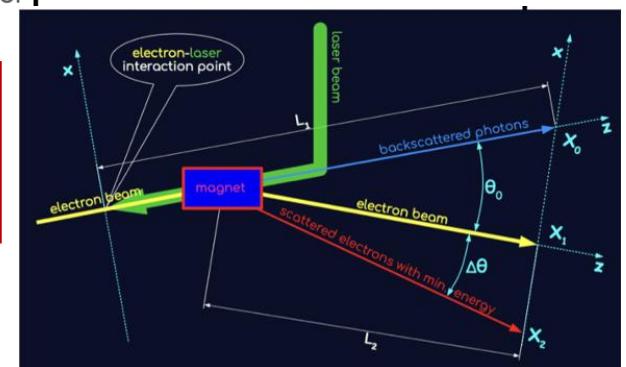
Polarimeter integrated close to experiments IP  
1/beam/IP

e-beam size at Compton IP :  
~500μm (horizontal)

Demanding operational constraints  
→ laser room in the parallel technical gallery  
→ 24/7 access to the laser system and related electronics



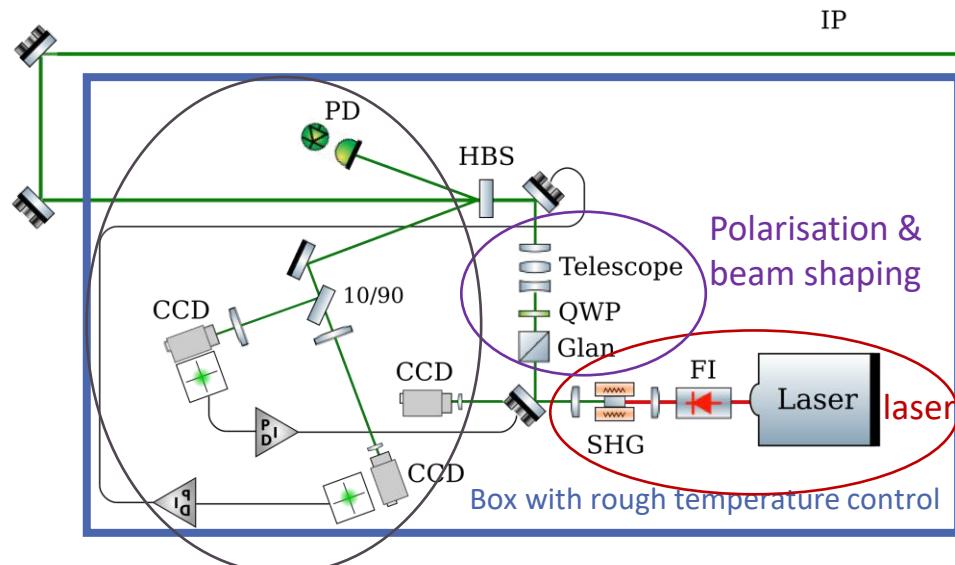
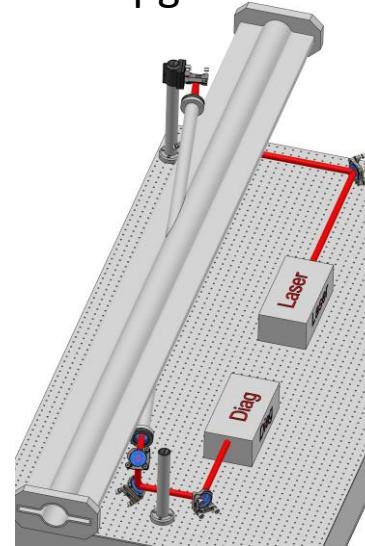
polarimeter  
N. Muchnoi



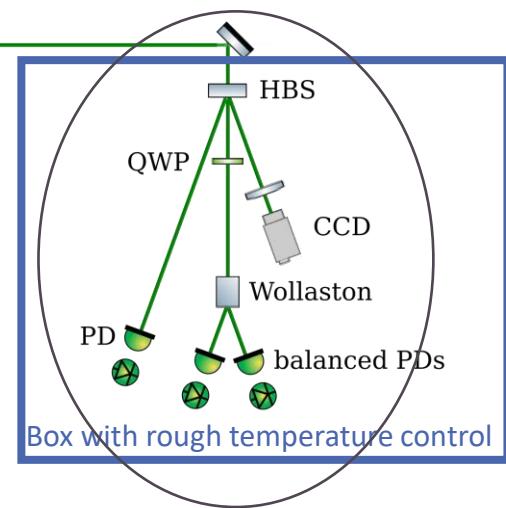
# Laser integration

## Some constraints

- Small crossing angles are preferred (cross-section, beam jitters) few mrad typically
- Beams crossing plane neither horizontal nor vertical
- beam impedance
- beam induced currents in metallic parts ← avoid
- mechanical stability
- ease of maintenance works



Position, pointing control and monitoring  
Polarisation independent intensity monitoring  
Optical spectrum monitoring possible



Polarisation monitoring  
Duplicated at injection  
Add Position and pointing monitoring  
R&D needed to reach required perf.

**24/7 operable laser system, with full monitoring, remote control**

# Some laser systems

Nikolai's baseline (Q-switch Nd-YAG)

Laser param.	1 pilot	1 pilot v2	All colliding bunches (at Z)
Repetition rate	3 kHz	3 kHz	30 kHz
Pulse energy	1 mJ	1 mJ	10x0.05mJ
Pulse duration	3 ns	30 ps (**)	30 ps
Average power	3 W	3 W	15 W (***)
Scattering rate	$3 \times 10^5 /s$ (*)	$3 \times 10^5 /s$ (****)	$4 \times 10^7 /s$ (****)
Scattering rate per bunch	$3 \times 10^5 /s$ (*)	$3 \times 10^5 /s$	$4 \times 10^5 /s$

Versatile Yb system

adaptable

Same oscillator may be used but two different amplification schemes

(\*) crossing angle  $\sim 2\text{mrad}$

(\*\*) related to optical bandwidth  $\leftarrow$  constrains resolution of 'direct' energy measurement from polarimeter

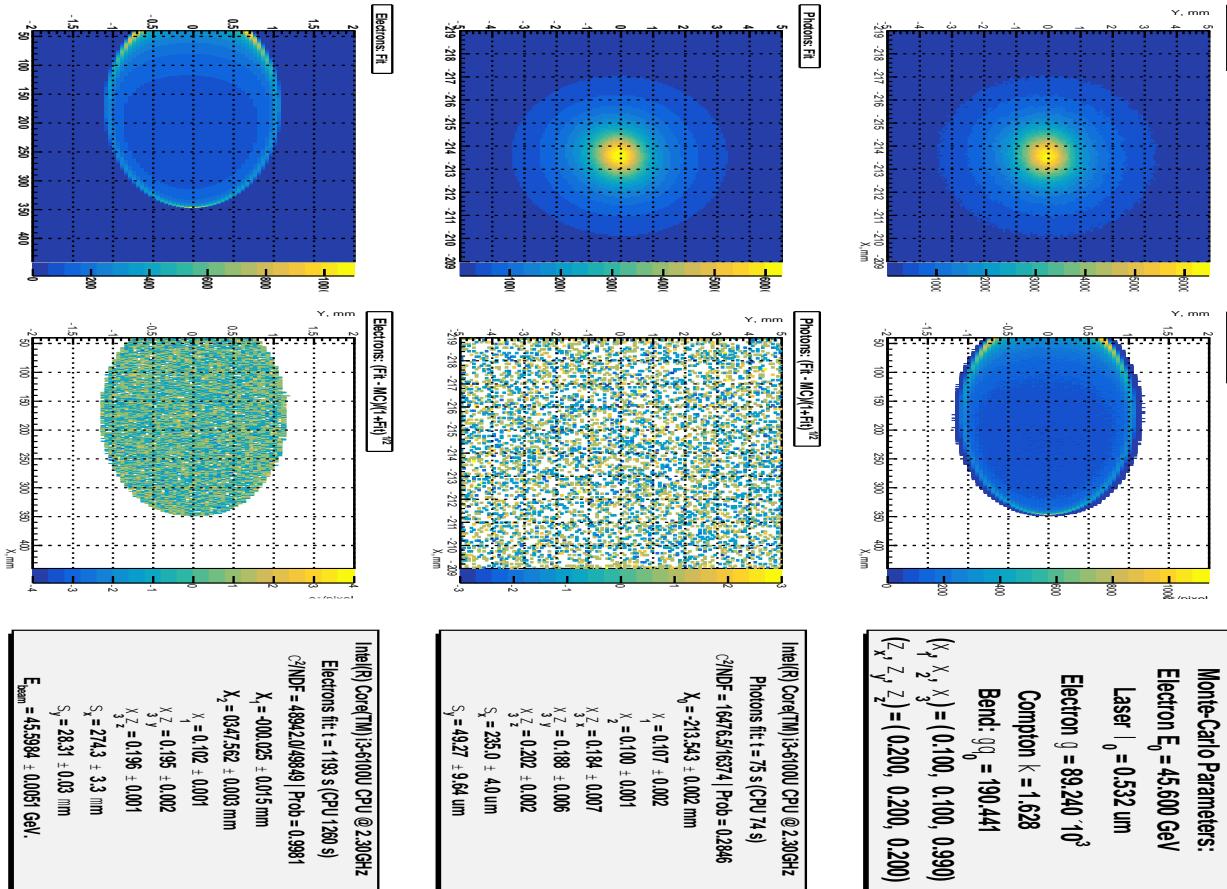
(\*\*\*) Can be increased to typically  $\sim 100\text{W}$  (nowadays) but requires operational validation

(\*\*\*\*) not limited by Piwinski contribution  $\rightarrow$  can be several degrees without affecting rate

Typically obtained in 30s for a single bunch

# Transverse distributions

Based on measurement of scattered particles transverse distributions (pixelized detectors)



All components extracted with  
~0.001 precision in few seconds

Beam energy may be extracted  
too! → redundancy with RDP

Realistic detector specifications (still) to be drawn

With the constraints of being tolerant to radiations

# Conclusion & prospects

High accuracy and precision beam energy measurement with pilots

High accuracy colliding bunches polarization monitoring



24/7 operable Compton polarimeters (1/beam/IP)

Versatile laser system

Industrial/robust lasers

Real time laser polarization monitoring

Ability to access lasers during operations

Pixel detectors design

Magnet design

Laser beam transport

Assessment of systematic uncertainties

# Scattering rates

$$\text{Photon rate} \quad n = \sigma_C \frac{\varepsilon}{E_\lambda} \frac{Q}{q} \frac{\mathcal{F}}{2\pi\sigma_y\sigma_x}$$

Compton cross-section

Laser photon energy  
( $2.4\text{eV}$  for  $0.5\mu\text{m}$  wavelengths)

Laser-beam single pulse energy

Electron bunch charge  
( $25\text{nC}$  for colliding bunches,  
 $1.5\text{nC}$  for pilots)

Geometrical factor

- $\mathcal{F}^{-1} = \sqrt{1 + \left(\frac{\sigma_z}{\sigma_x} \tan \frac{\theta_0}{2}\right)^2}$
- $\theta_0 \sim 2\text{mrad}$

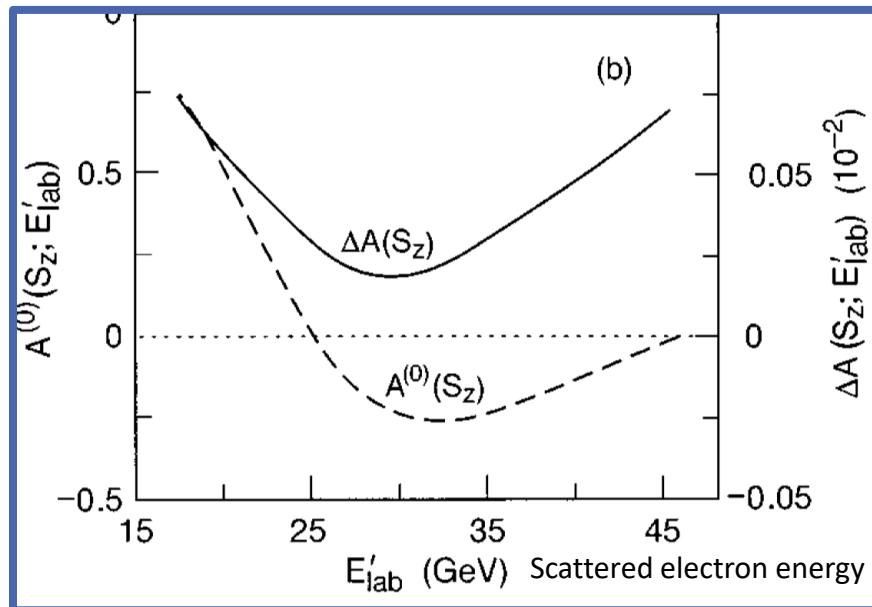
Transverse beam sizes:

- $\sigma_{x,y,z} = \sqrt{\sigma_{x,y,z,\text{laser}}^2 + \sigma_{x,y,z,e^-}^2}$
- $\sigma_{x,\text{laser}} = \sigma_{y,\text{laser}} = 1000\mu\text{m}$
- $\sigma_{x,e^-} = 500\mu\text{m}, \sigma_{y,e^-} = 10\mu\text{m}, \sigma_{z,e^-} \sim 10\text{mm}$

# QED corrections

$$\frac{d\sigma}{dE'}(E') \cong \frac{d\sigma_0}{dE'}(1 + \delta)[1 + \mathcal{P}_z \mathcal{P}_{C,las}(A + \Delta A)]$$

QED corrections < 0.001 @ 45 GeV



Need to be eventually included in simulations...

# The Compton process

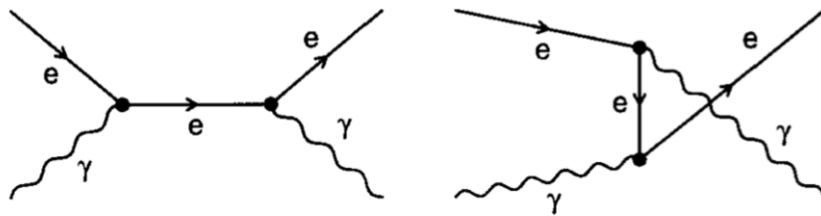
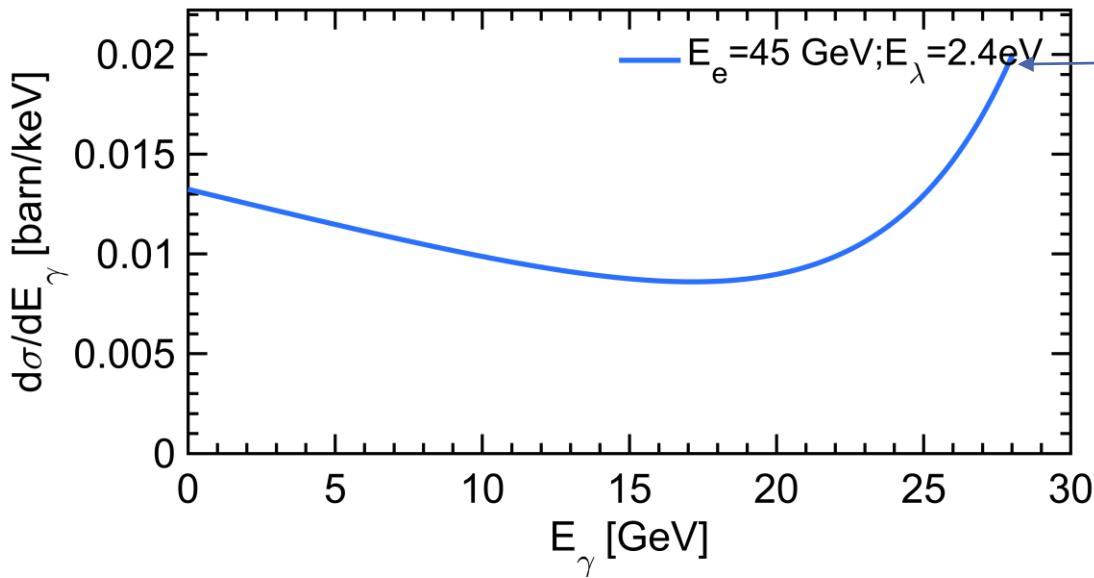
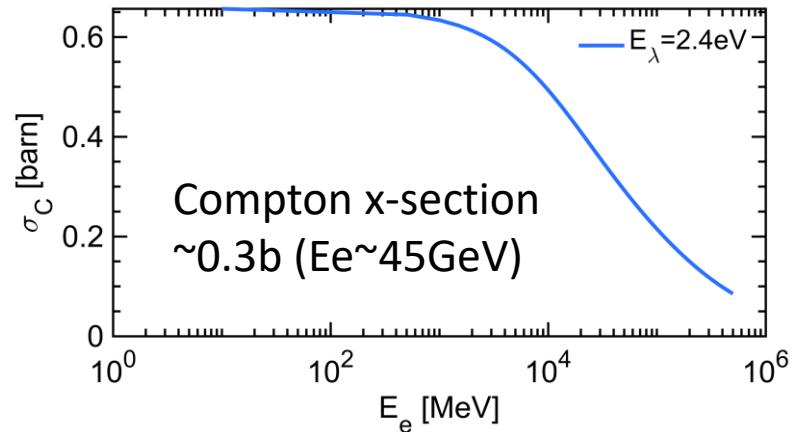
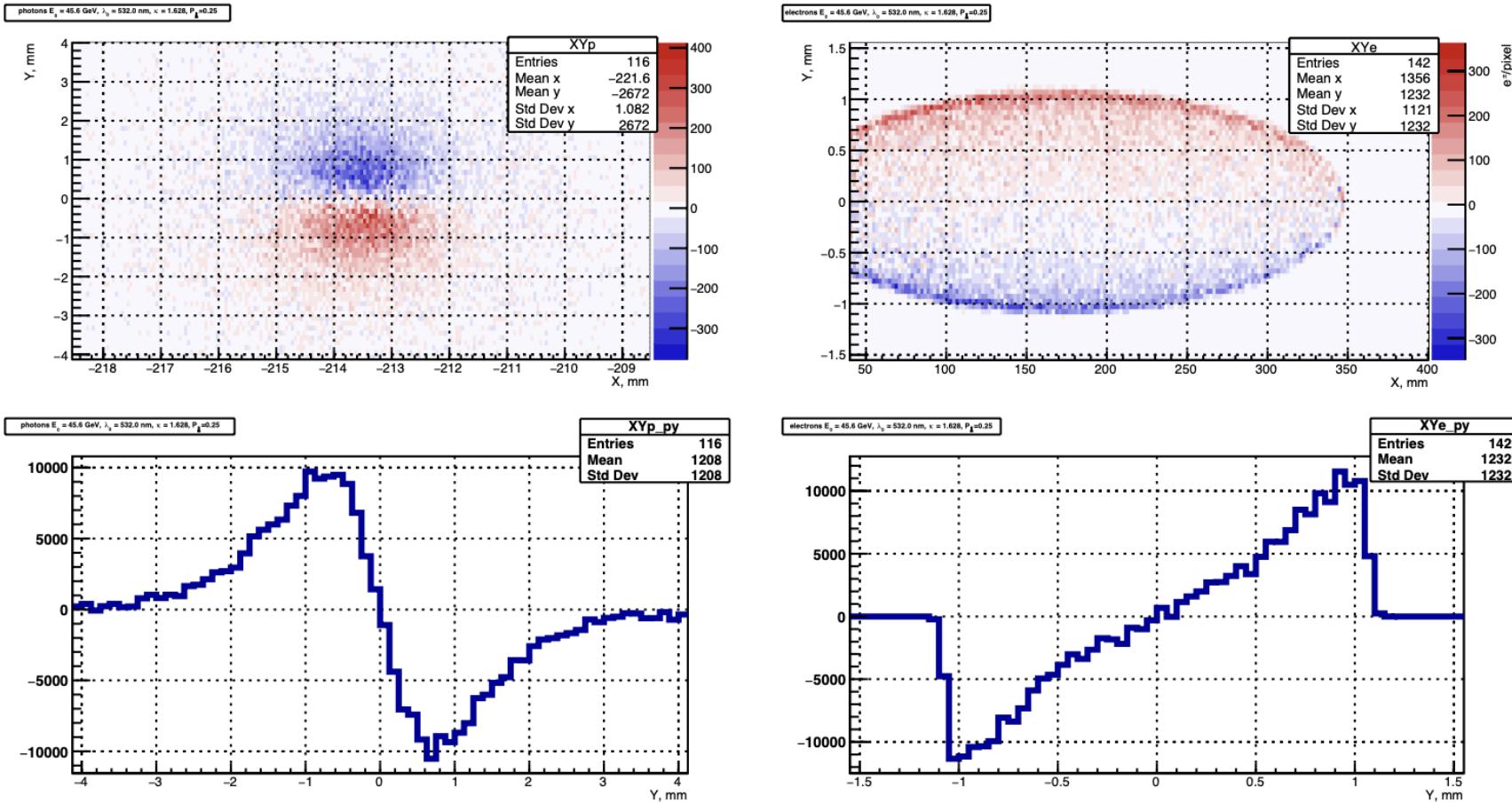


Fig. 1. Tree diagrams for  $e^- \gamma \rightarrow e^- \gamma$



# Laser helicity asymmetries



Reproducible and well known laser helicity flip is required