Compton polarimeters laser system and fit procedures

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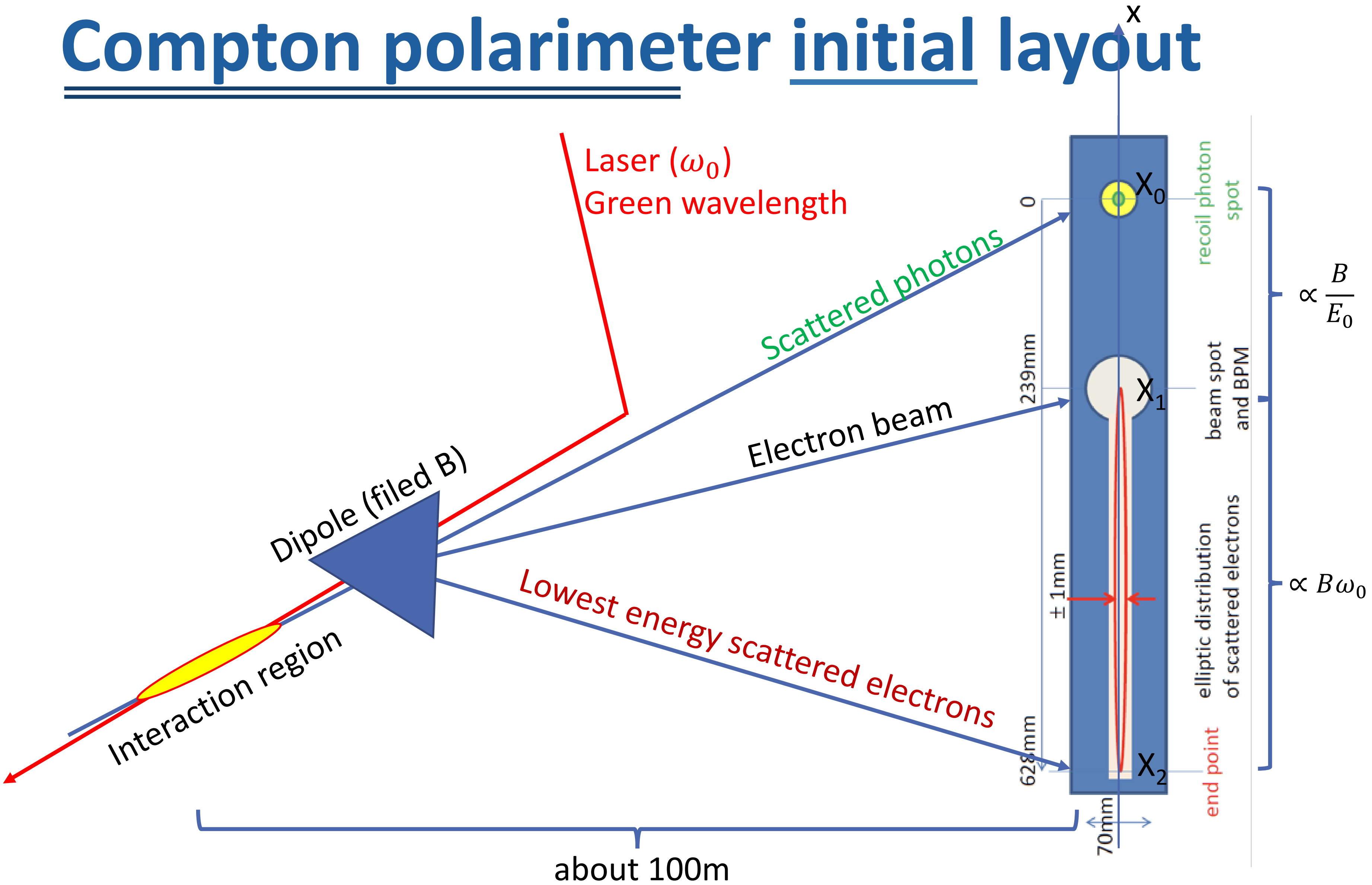
On behalf of FCC-ee FS EPOL group

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

Compton polarimeter initial layout



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

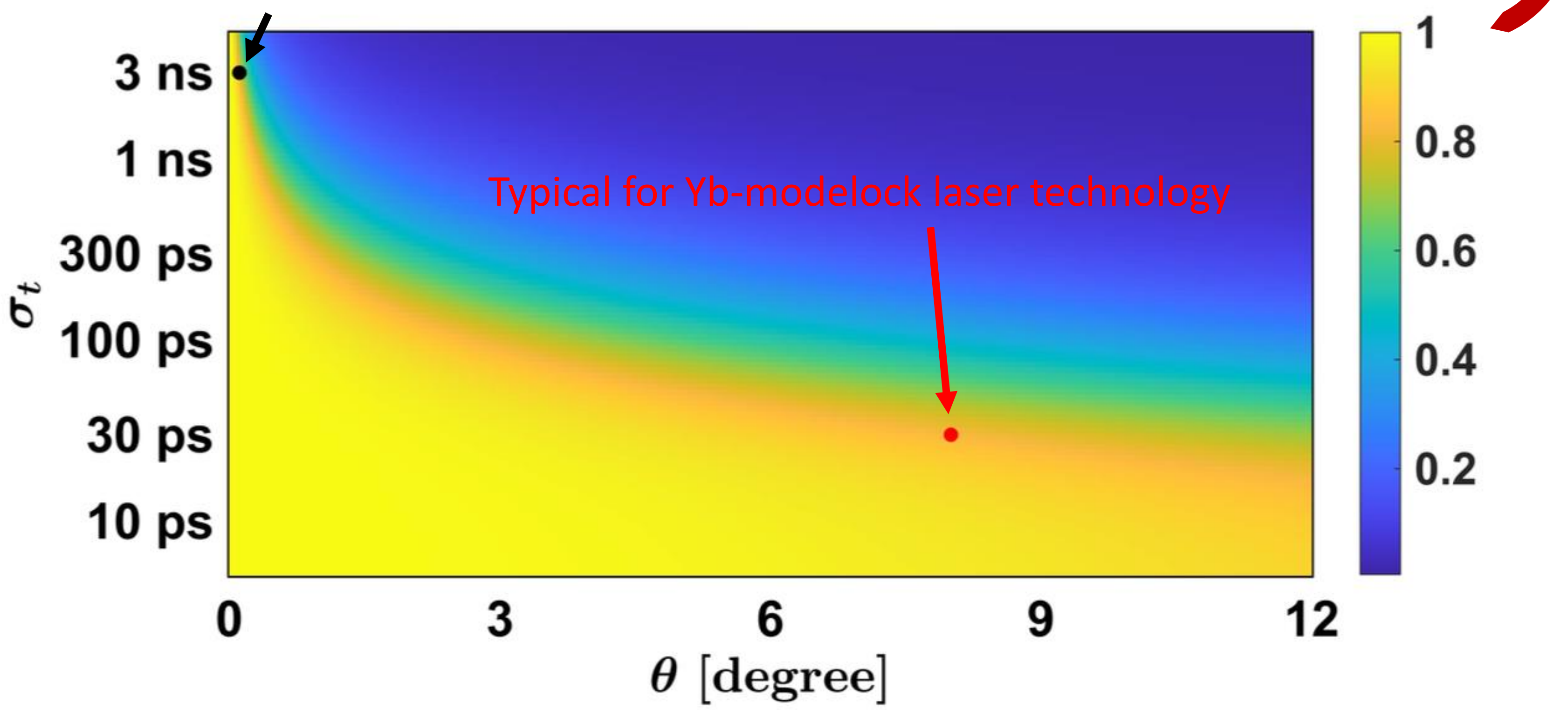
New concept (N. Yu Muchnoi) to measure all polarization parameters → 3D polarimeter

Electron beam parameters from lattice v24.3, in front of BL1.2

Acceptable pulse duration/crossing angle

$$\sigma_{x,y,z} = \sqrt{\sigma^2_{e,x,y,z} + \sigma^2_{l,x,y,z}}$$

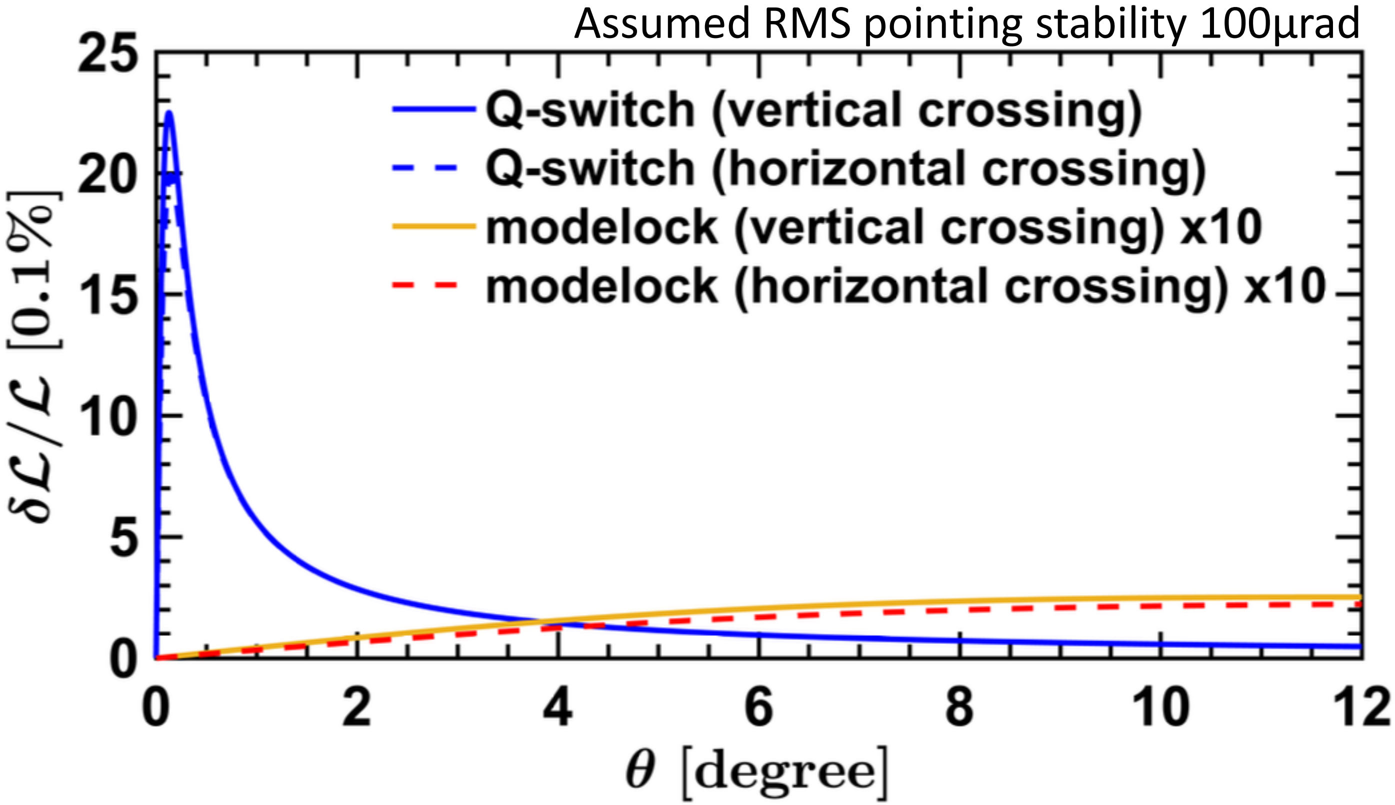
$$\mathcal{L} = \frac{f_{\text{rep}} N_l N_e}{2\pi\sigma_x\sigma_y \boxed{\sqrt{1+\frac{\sigma_z^2}{\sigma_x^2}\tan^2\frac{\theta}{2}}}}.$$



Typical for Q-switch laser technology

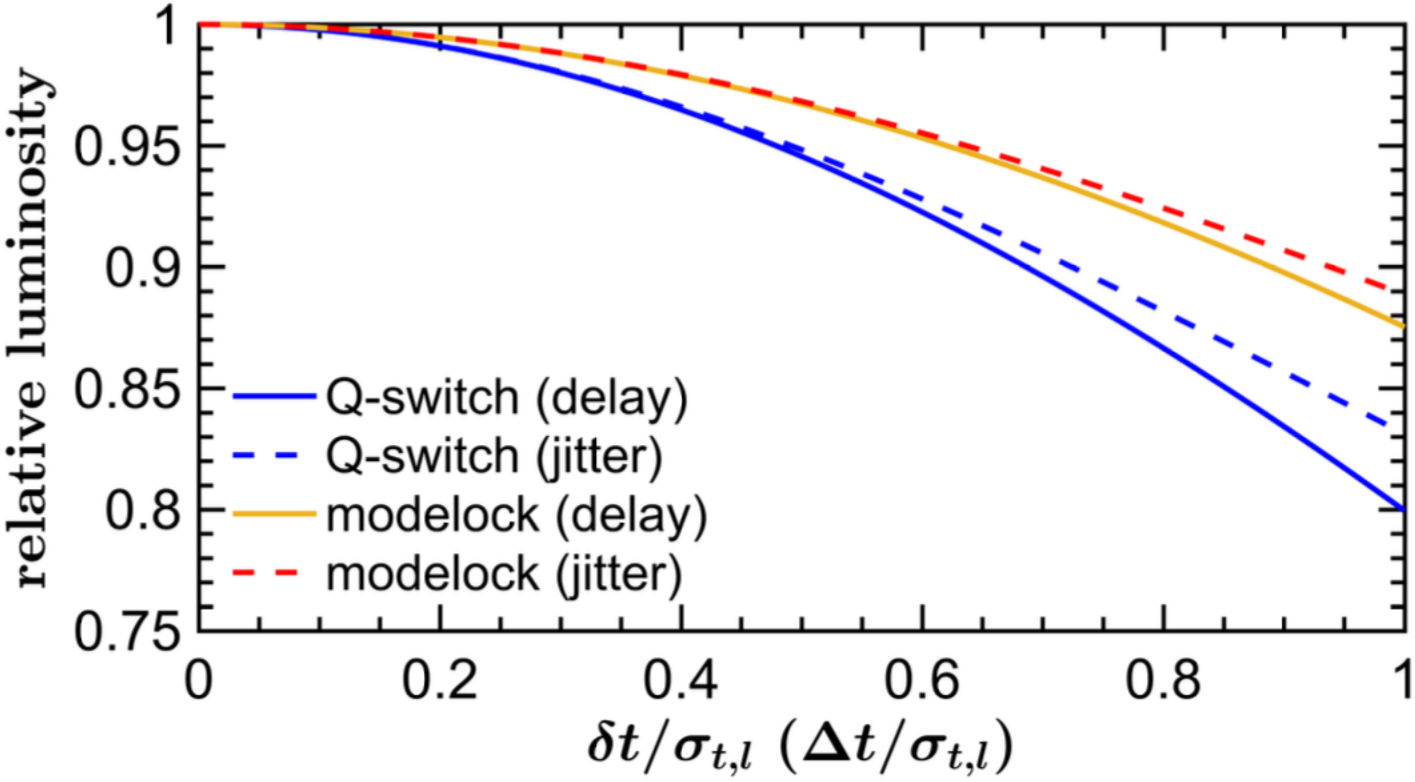
Typical for Yb-modelock laser technology

Luminosity fluctuations (pointing)



→ Luminosity very sensitive to laser pointing stability for Q-switch laser
→ below $2x10^{-4}$ for modelock laser

Luminosty fluctuations (jitter)



→ Jitter or bad timing is not expected to be a major issue for modelock laser

Expected yields (updated)

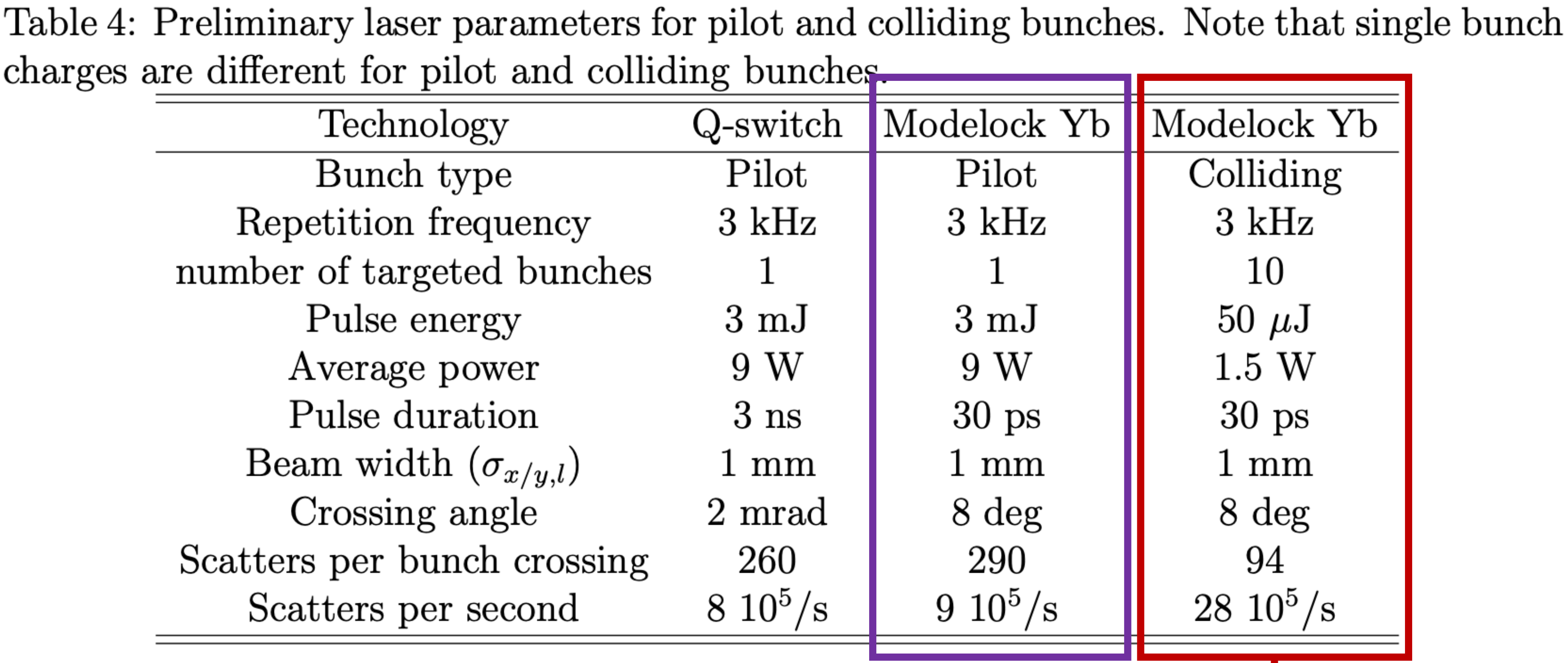


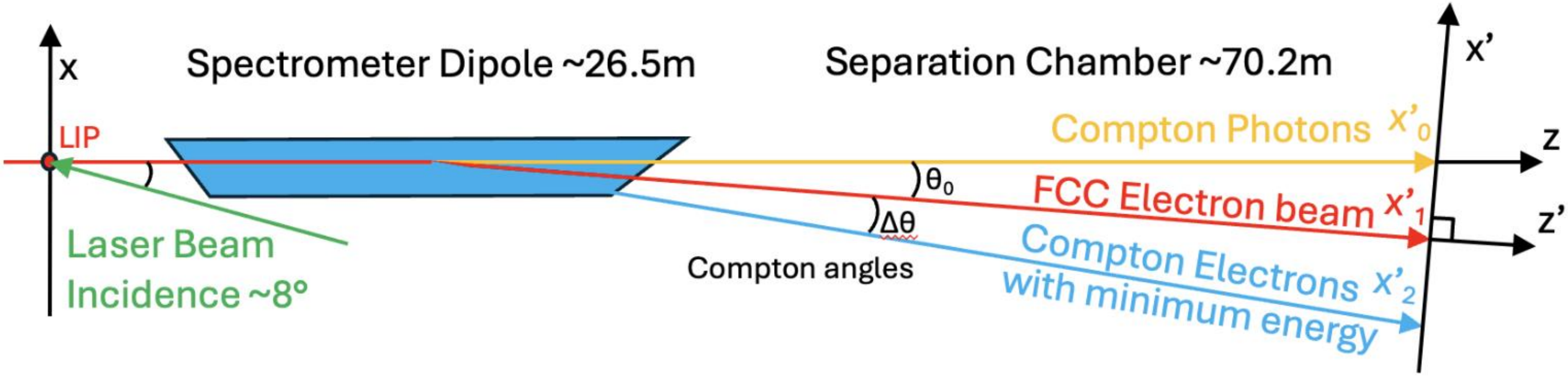
Table 4: Preliminary laser parameters for pilot and colliding bunches. Note that single bunch charges are different for pilot and colliding bunches.

Technology	Q-switch	Modelock Yb	Modelock Yb
Bunch type	Pilot	Pilot	Colliding
Repetition frequency	3 kHz	3 kHz	3 kHz
number of targeted bunches	1	1	10
Pulse energy	3 mJ	3 mJ	50 μJ
Average power	9 W	9 W	1.5 W
Pulse duration	3 ns	30 ps	30 ps
Beam width ($\sigma_{x/y,l}$)	1 mm	1 mm	1 mm
Crossing angle	2 mrad	8 deg	8 deg
Scatters per bunch crossing	260	290	94
Scatters per second	8 10^5/s	9 10^5/s	28 10^5/s

Our baseline technology

Illustrative at this stage, actual temporal pattern is flexible
→ will be constrained by today’s unknowns (actual background level and detector perf.)

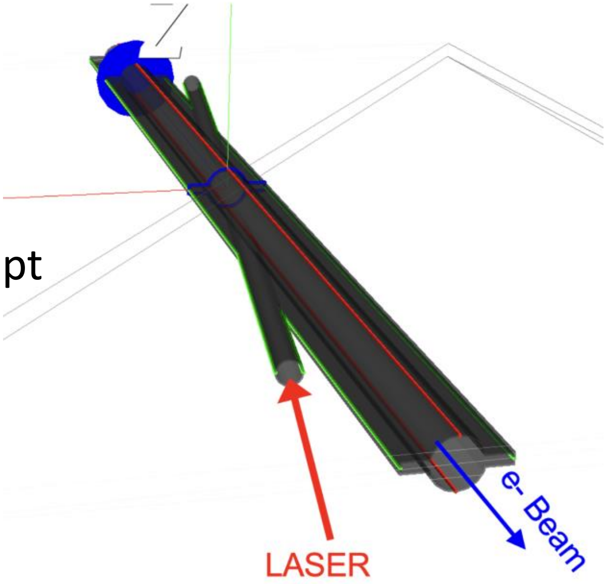
Impact on integration



Laser does not travel through dipole → easier integration (Q-switch would)

Vacuum chamber concept adapted from SuperKEKB concept

Validated for impedance budget



Laser requirements check list

24/7 operable Compton polarimeters (1/beam) with 95% up-time

- Reliable
- Remotely controled
- Versatile (laser intensity, temporal pattern)
- Simplified integration

Prefer Yb-modelock technology

- Laser access (beam on) for maintenance vs redundancy
- Short laser transport between optical room and IP
- Minimize radiation field delivered to optical elements

Careful evaluation required
Pre-TDR
Careful integration

High precision polarimetry

- Laser polarization real-tiem monitoring
- Absolute laser polarization calibration

Careful study for pre-TDR

- Minimize number of optical elements
- Minimize environmental fluctuations (Temp, pressure, vibrations)

Careful integration

- Avoid large average laser power — Compromise with statistics
- Homogeneity of electron beam sampling — Laser parameters, tunability for systematics
- Laser beam quality and stability — Further studies needed

Initial work of N. Munchnoi

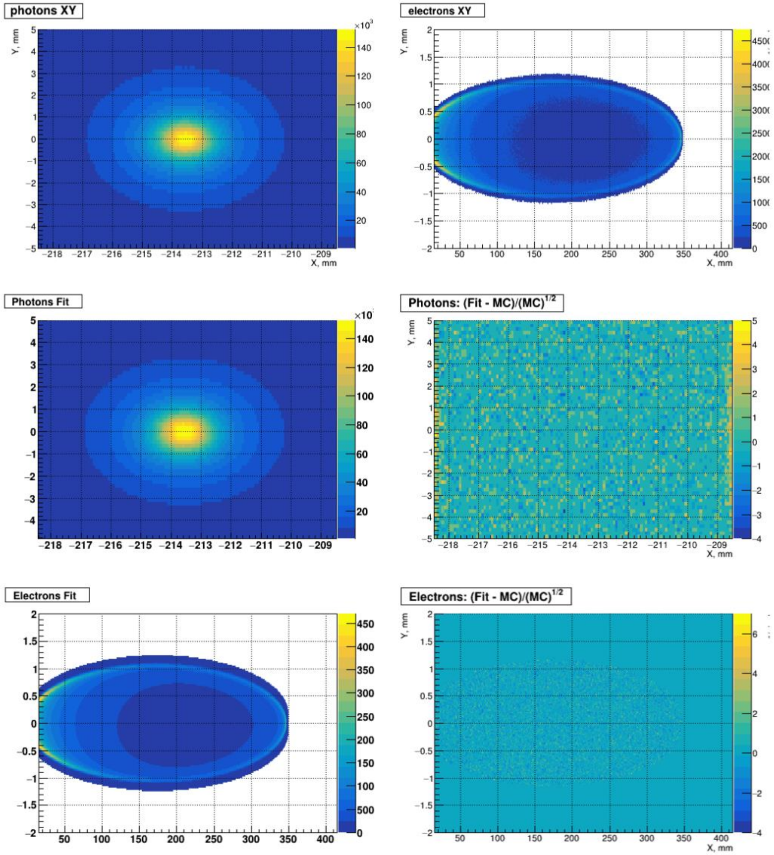
Typically obtained in 30s for a single bunch

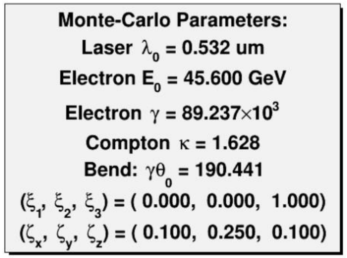
Typical result – fit of distributions

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

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

$$\frac{d\sigma}{du d\varphi} = \frac{d\sigma_0}{du d\varphi} + \xi_1 \frac{d\sigma_1}{du d\varphi} + \xi_2 \frac{d\sigma_2}{du d\varphi} + \xi_3 \left(\zeta_x \frac{d\sigma_x}{du d\varphi} + \zeta_y \frac{d\sigma_y}{du d\varphi} + \zeta_z \frac{d\sigma_z}{du d\varphi} \right)$$





Monte-Carlo Parameters:

Laser λ_0 = 0.532 um

Electron E_0 = 45.600 GeV

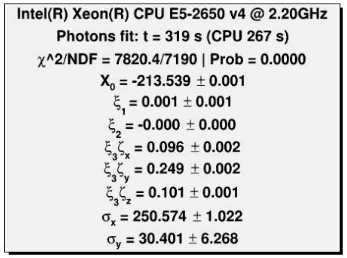
Electron γ = 89.237×10³

Compton κ = 1.628

Bend: $\gamma\theta_0$ = 190.441

(ξ_1, ξ_2, ξ_3) = (0.000, 0.000, 1.000)

$(\zeta_x, \zeta_y, \zeta_z)$ = (0.100, 0.250, 0.100)



Intel(R) Xeon(R) CPU E5-2650 v4 @ 2.20GHz

Photons fit: t = 319 s (CPU 267 s)

χ^2/NDF = 7820.4/7190 | Prob = 0.0000

X_0 = -213.539 ± 0.001

ξ_1 = 0.001 ± 0.001

ξ_2 = -0.000 ± 0.000

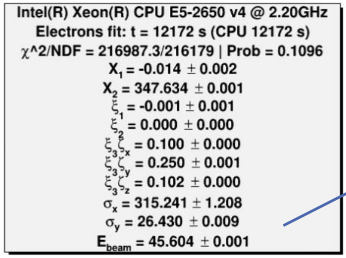
$\xi_3\zeta_x$ = 0.096 ± 0.002

$\xi_3\zeta_y$ = 0.249 ± 0.002

$\xi_3\zeta_z$ = 0.101 ± 0.001

σ_x = 250.574 ± 1.022

σ_y = 30.401 ± 6.268



Intel(R) Xeon(R) CPU E5-2650 v4 @ 2.20GHz

Electrons fit: t = 12172 s (CPU 12172 s)

χ^2/NDF = 216987.3/216179 | Prob = 0.1096

X_1 = -0.014 ± 0.002

X_2 = 347.634 ± 0.001

ξ_1 = -0.001 ± 0.001

ξ_2 = 0.000 ± 0.000

$\xi_3\zeta_x$ = 0.100 ± 0.000

$\xi_3\zeta_y$ = 0.250 ± 0.001

$\xi_3\zeta_z$ = 0.102 ± 0.000

σ_x = 315.241 ± 1.208

σ_y = 26.430 ± 0.009

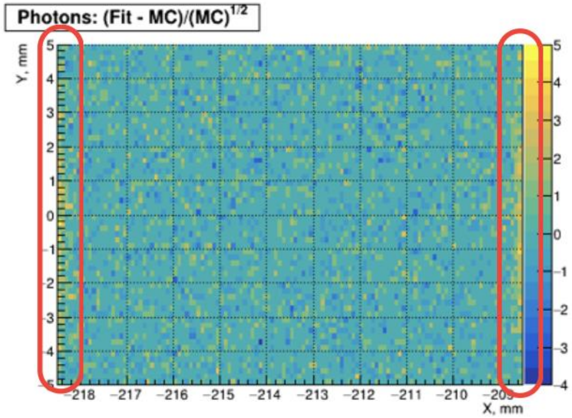
E_{beam} = 45.604 ± 0.001

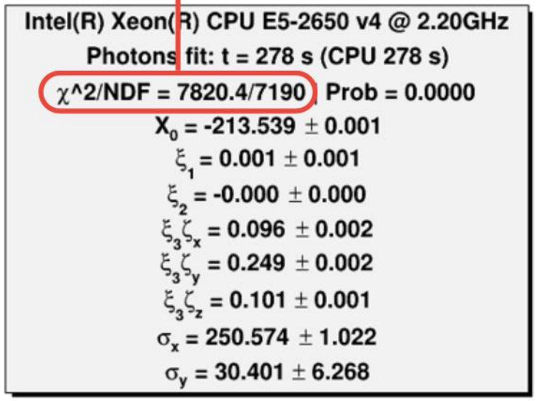
All components extracted with ~0.001 precision in few seconds

Beam energy may be extracted too! → redundancy with RDP

More about detector: Kieffer (previous talk)

Fit refinements





Intel(R) Xeon(R) CPU E5-2650 v4 @ 2.20GHz

Photons fit: t = 278 s (CPU 278 s)

χ^2/NDF = 7820.4/7190 | Prob = 0.0000

X_0 = -213.539 ± 0.001

ξ_1 = 0.001 ± 0.001

ξ_2 = -0.000 ± 0.000

$\xi_3\zeta_x$ = 0.096 ± 0.002

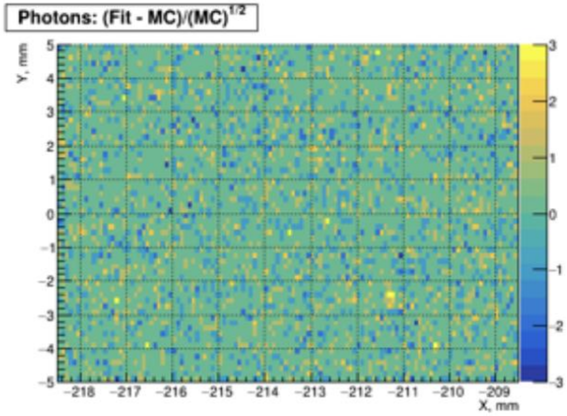
$\xi_3\zeta_y$ = 0.249 ± 0.002

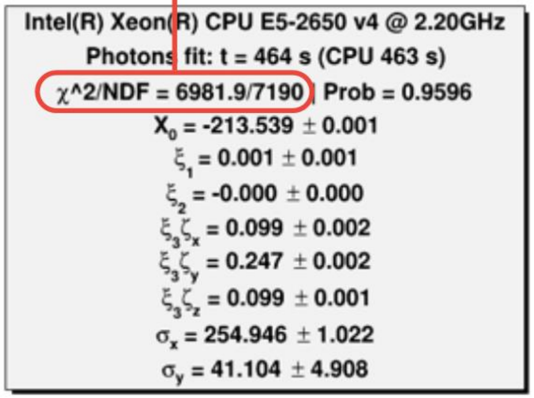
$\xi_3\zeta_z$ = 0.101 ± 0.001

σ_x = 250.574 ± 1.022

σ_y = 30.401 ± 6.268

χ2/NDF = 7820.4/7190





Intel(R) Xeon(R) CPU E5-2650 v4 @ 2.20GHz

Photons fit: t = 464 s (CPU 463 s)

χ^2/NDF = 6981.9/7190 | Prob = 0.9596

X_0 = -213.539 ± 0.001

ξ_1 = 0.001 ± 0.001

ξ_2 = -0.000 ± 0.000

$\xi_3\zeta_x$ = 0.099 ± 0.002

$\xi_3\zeta_y$ = 0.247 ± 0.002

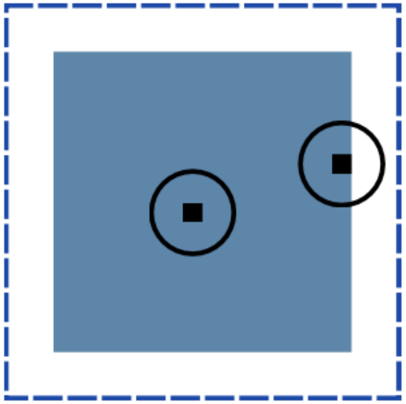
$\xi_3\zeta_z$ = 0.099 ± 0.001

σ_x = 254.946 ± 1.022

σ_y = 41.104 ± 4.908

χ2/NDF = 6981.9/7190

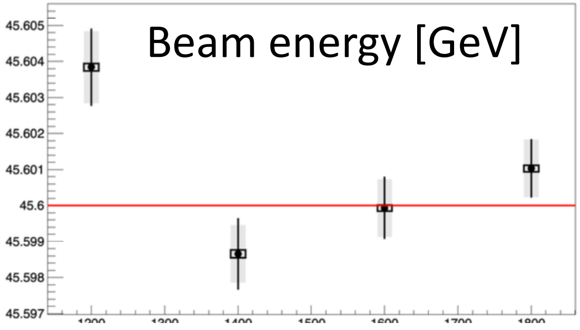
Convolution



Extend calculation over extended range beyond sensitive area see also J. Tamazirt poster

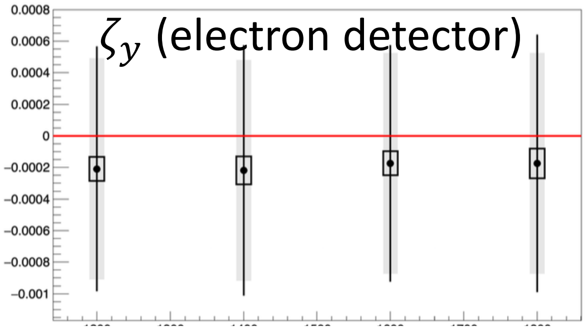
Updated toy study

A toy MonteCarlo procedure is applied (100 experiments, 10^8 events each

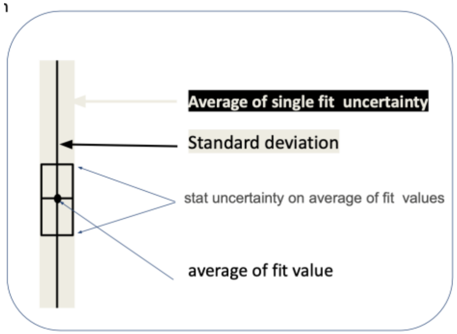


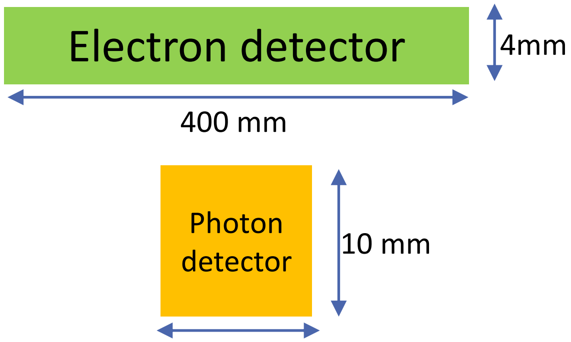
X: 1200 1400 1600 1800
Y: 40 60 80 100

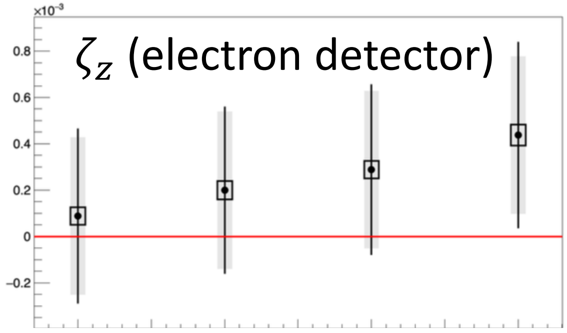
Npixels for electrons



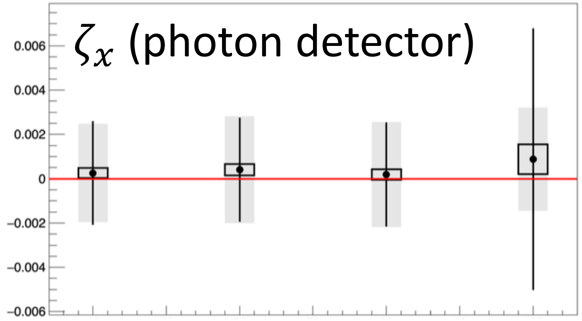
X: 1200 1400 1600 1800
Y: 40 60 80 100







X: 1200 1400 1600 1800
Y: 40 60 80 100
Npixels for electron detector

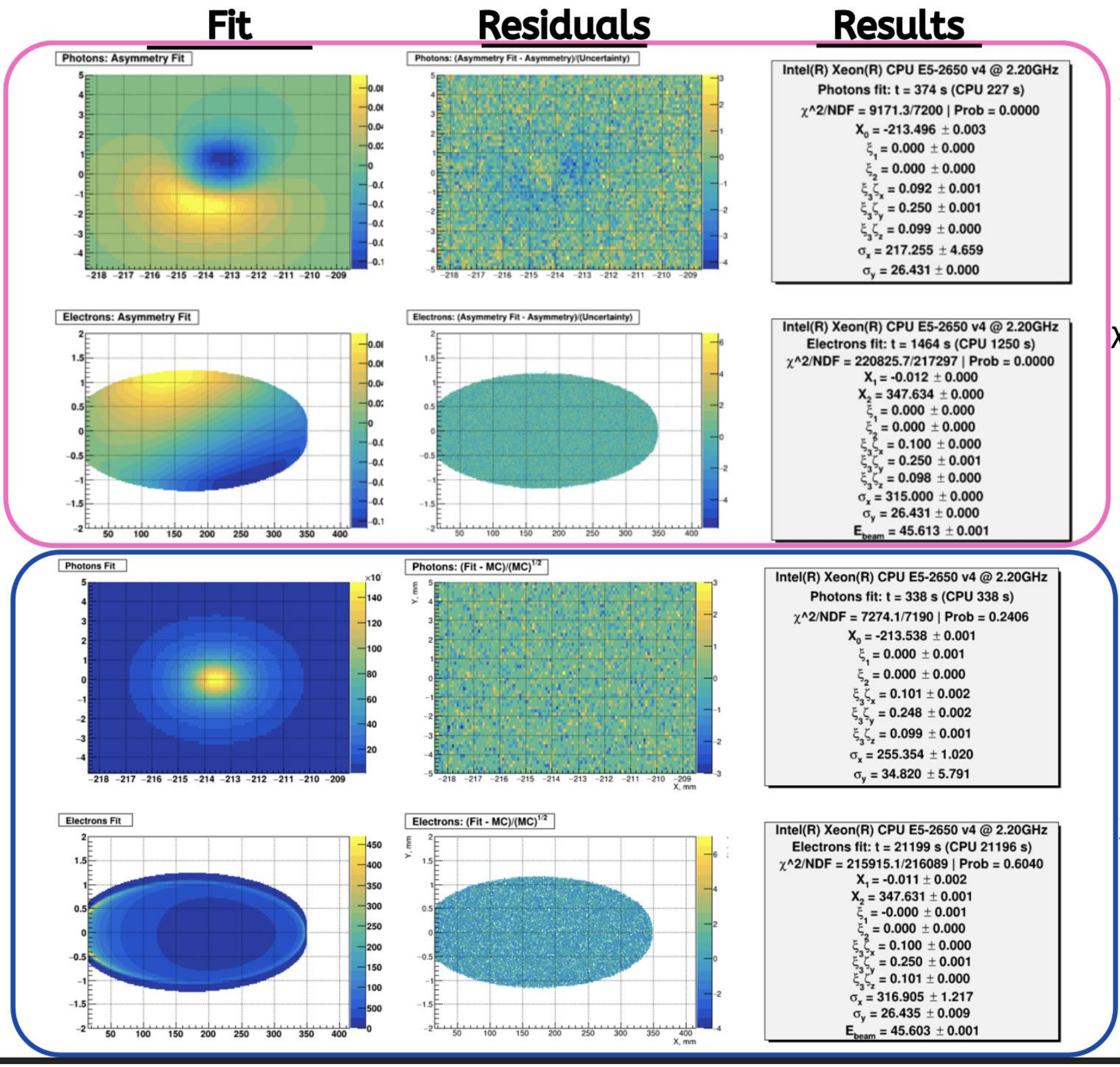


X: 40 60 80 100
Y: 40 60 80 100
Npixels for photon detector

Residual biases (1-5 10^{-4}) under investigation
Combined fit to be investigated

Asymmetry fit (preliminary)

$$\frac{\frac{d\sigma^+}{dud\varphi}-\frac{d\sigma^-}{dud\varphi}}{\frac{d\sigma^+}{dud\varphi}+\frac{d\sigma^-}{dud\varphi}}=\frac{\left(\zeta_x\frac{d\sigma_x}{dud\varphi}+\zeta_y\frac{d\sigma_y}{dud\varphi}+\zeta_z\frac{d\sigma_z}{dud\varphi}\right)}{\frac{d\sigma_0}{dud\varphi}+\xi_1\cancel{\frac{d\sigma_x}{dud\varphi}}+\xi_2\cancel{\frac{d\sigma_z}{dud\varphi}}}$$



Intel(R) Xeon(R) CPU E5-2650 v4 @ 2.20GHz
Photons fit: t = 374 s (CPU 227 s)
χ^2/NDF = 9171.3/7200 | Prob = 0.0000
$X_0 = -213.496 \pm 0.003$
$\xi_1 = 0.000 \pm 0.000$
$\xi_2 = 0.000 \pm 0.000$
$\xi_3\zeta_x = 0.092 \pm 0.001$
$\xi_3\zeta_y = 0.250 \pm 0.001$
$\xi_3\zeta_z = 0.099 \pm 0.000$
$\sigma_x = 217.255 \pm 4.659$
$\sigma_y = 26.431 \pm 0.000$

Intel(R) Xeon(R) CPU E5-2650 v4 @ 2.20GHz
Electrons fit: t = 1464 s (CPU 1250 s)
χ^2/NDF = 220825.7/217297 | Prob = 0.0000
$X_1 = -0.012 \pm 0.000$
$X_2 = 347.634 \pm 0.000$
$\xi_1 = 0.000 \pm 0.000$
$\xi_2 = 0.000 \pm 0.000$
$\xi_3\zeta_x = 0.100 \pm 0.000$
$\xi_3\zeta_y = 0.250 \pm 0.001$
$\xi_3\zeta_z = 0.098 \pm 0.000$
$\sigma_x = 315.000 \pm 0.000$
$\sigma_y = 26.431 \pm 0.000$
$E_{beam} = 45.613 \pm 0.001$

Intel(R) Xeon(R) CPU E5-2650 v4 @ 2.20GHz
Photons fit: t = 338 s (CPU 338 s)
χ^2/NDF = 7274.1/7190 | Prob = 0.2406
$X_0 = -213.538 \pm 0.001$
$\xi_1 = 0.000 \pm 0.001$
$\xi_2 = 0.000 \pm 0.000$
$\xi_3\zeta_x = 0.101 \pm 0.002$
$\xi_3\zeta_y = 0.248 \pm 0.002$
$\xi_3\zeta_z = 0.099 \pm 0.001$
$\sigma_x = 255.354 \pm 1.020$
$\sigma_y = 34.820 \pm 5.791$

Intel(R) Xeon(R) CPU E5-2650 v4 @ 2.20GHz
Electrons fit: t = 21199 s (CPU 21196 s)
χ^2/NDF = 215915.1/216089 | Prob = 0.6040
$X_1 = -0.011 \pm 0.002$
$X_2 = 347.631 \pm 0.001$
$\xi_1 = -0.000 \pm 0.001$
$\xi_2 = 0.000 \pm 0.000$
$\xi_3\zeta_x = 0.100 \pm 0.000$
$\xi_3\zeta_y = 0.250 \pm 0.001$
$\xi_3\zeta_z = 0.101 \pm 0.000$
$\sigma_x = 316.905 \pm 1.217$
$\sigma_y = 26.435 \pm 0.009$
$E_{beam} = 45.603 \pm 0.001$

χ2/NDF = 9171.3/7200

Photons

Preliminary
More investigations ongoing

Asymmetry

χ2/NDF = 220825.7/217297

Electrons

χ2/NDF = 7274.1/7190

Photons

Distribution

χ2/NDF = 215915.1/216089

Electrons

6

Narvaez, EPOL meeting

Conclusion & prospects

24/7 operable Compton polarimeters (1/beam) with 95% up-time

High precision polarimetry

Key requirements

Key pre-TDR phase subjects to be investigated:

- Laser robustness on long term
- Laser beam transport design and integration
- Laser polarization real-time monitoring R&D
- high-accuracy laser polarization calibration R&D
- Start to end simulation for e-beam polarization parameters extraction

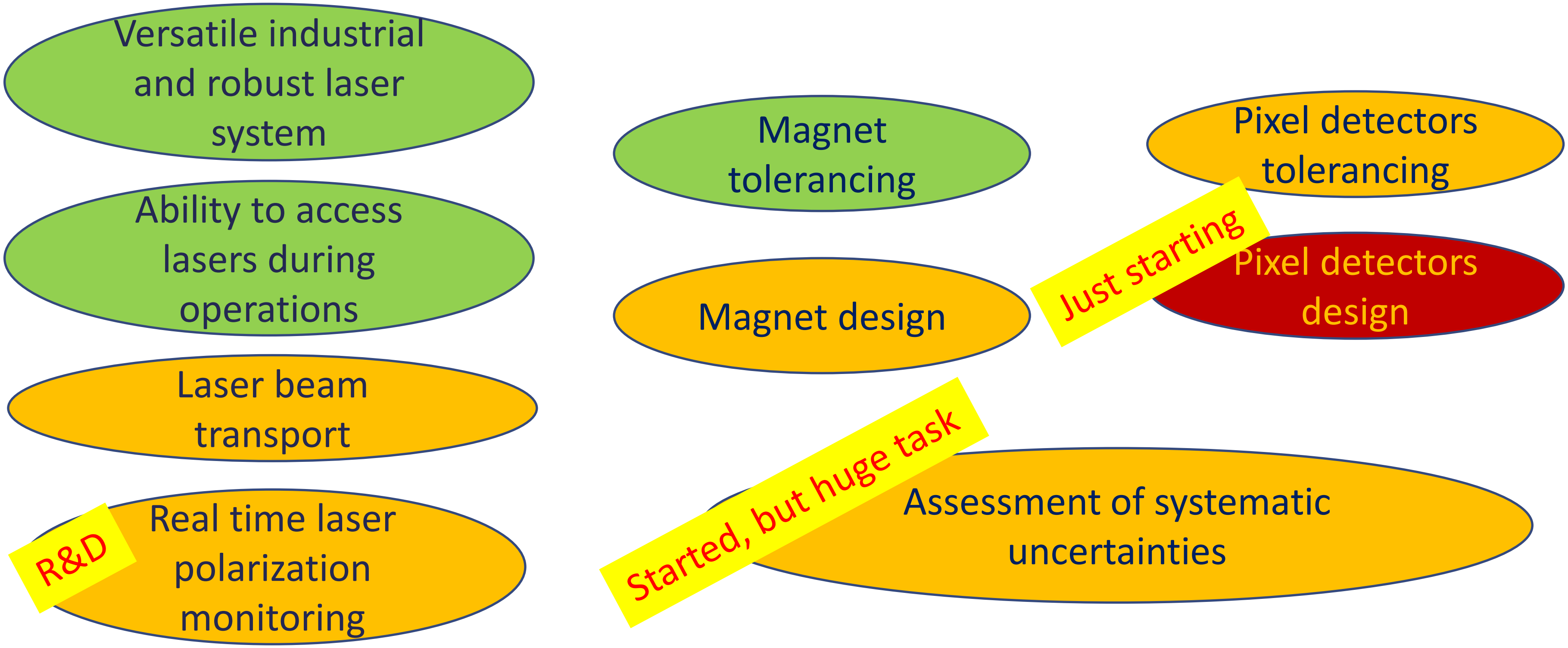
Current limitations:

- Personnel (detailed simulations, phd or fellows work)
- Hardware (mostly laser related, possibly detector tests)

backup

Conclusion & prospects

High accuracy and precision beam energy measurement with pilots
24/7 operable Compton polarimeters (1/beam)



Versatile industrial and robust laser system

Ability to access lasers during operations

Laser beam transport

Real time laser polarization monitoring

R&D

Magnet tolerancing

Magnet design

Pixel detectors tolerancing

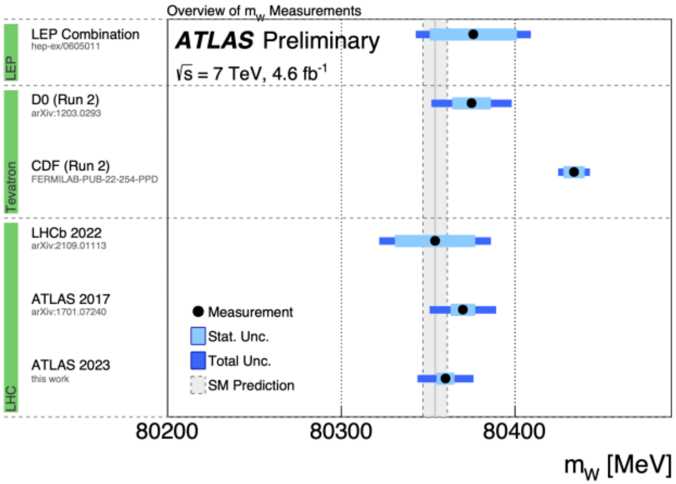
Pixel detectors design

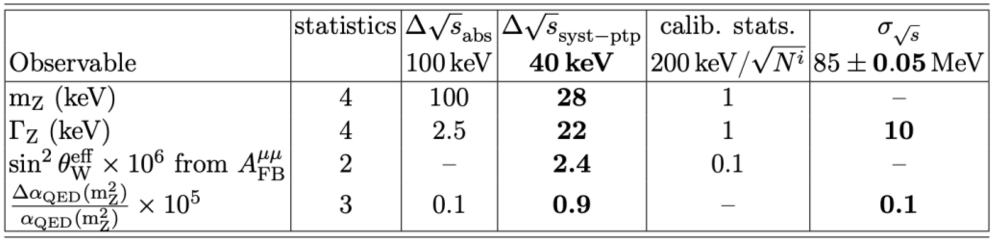
Just starting

Assessment of systematic uncertainties

Started, but huge task

Physics requirements





Observable	statistics	$\Delta\sqrt{s}_{\text{abs}}$ 100 keV	$\Delta\sqrt{s}_{\text{syst-ptp}}$ **40 keV**	calib. stats. 200 keV$/\sqrt{N^i}$	$\sigma_{\sqrt{s}}$ 85 ± **0.05** MeV
m_Z (keV)	4	100	**28**	1	–
Γ_Z (keV)	4	2.5	**22**	1	**10**
$\sin^2\theta_W^{\text{eff}} \times 10^6$ from $A_{FB}^{\mu\mu}$	2	–	**2.4**	0.1	–
$\frac{\Delta\alpha_{QED}(m_Z^2)}{\alpha_{QED}(m_Z^2)} \times 10^5$	3	0.1	**0.9**	–	**0.1**

Required accuracy of <1ppm

High reproductibility 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 (de-)polarization

Blondel et al., arXiv:1909.12245

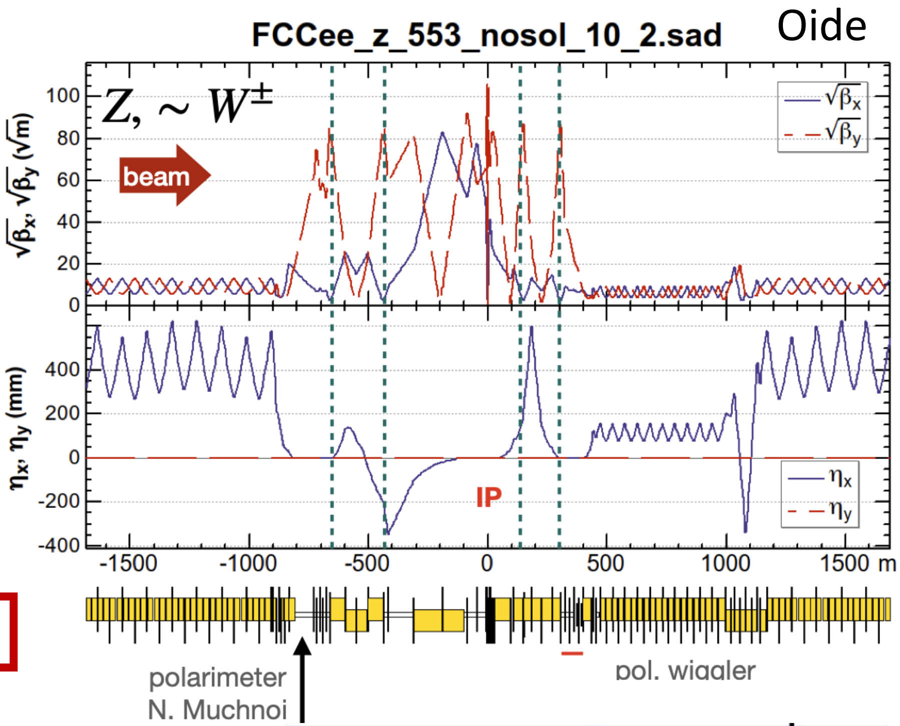
Integration

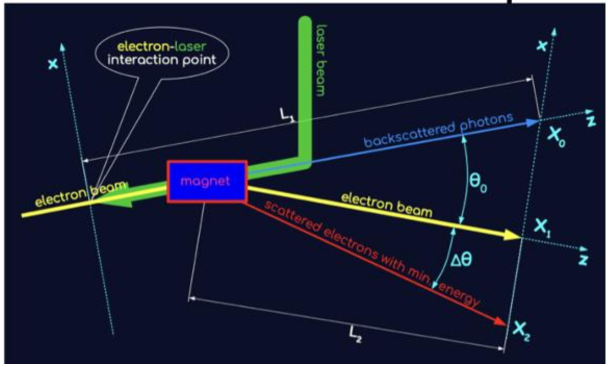
Polarimeter integrated close to experiments IP
1/beam (baseline)

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

Robust laser technology is available nowadays

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

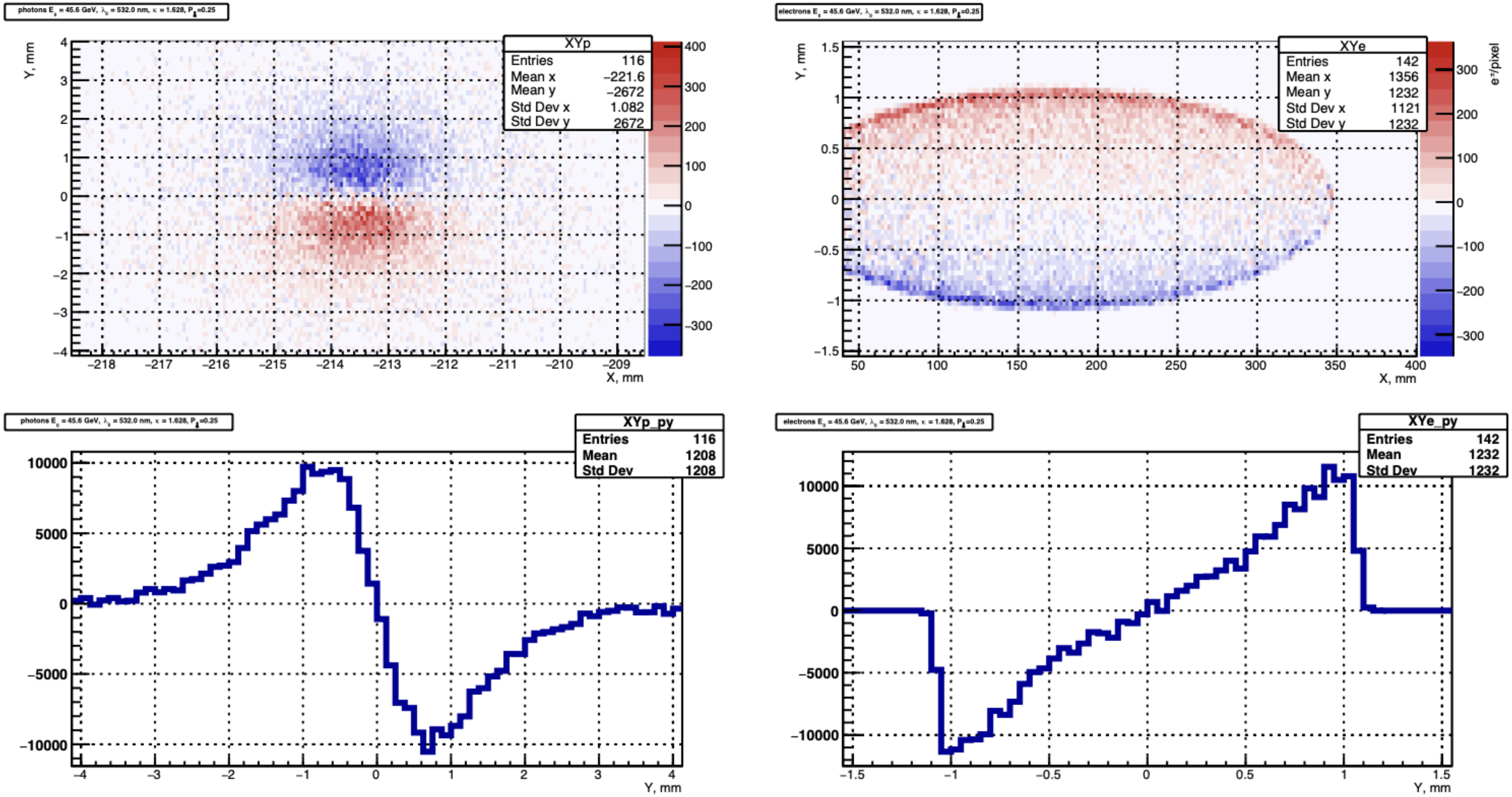




Oide, https://indico.cern.ch/event/1237189

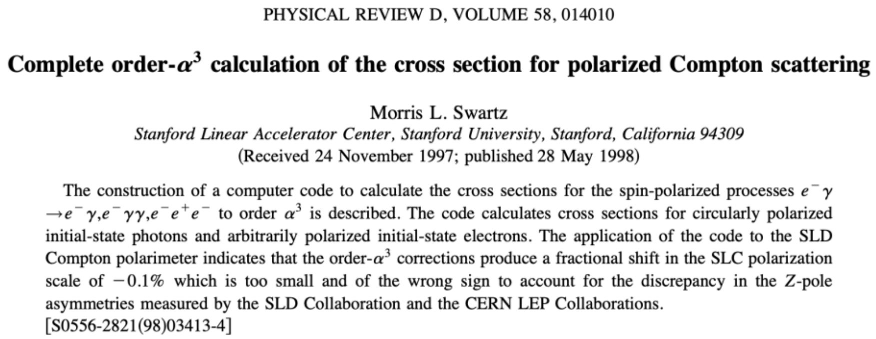
Laser helicity asymmetries

Blondel et al., arXiv:1909.12245



Reproductible and well known laser helicity flip is required

QED corrections



PHYSICAL REVIEW D, VOLUME 58, 014010

Complete order-α^3 calculation of the cross section for polarized Compton scattering

Morris L. Swartz

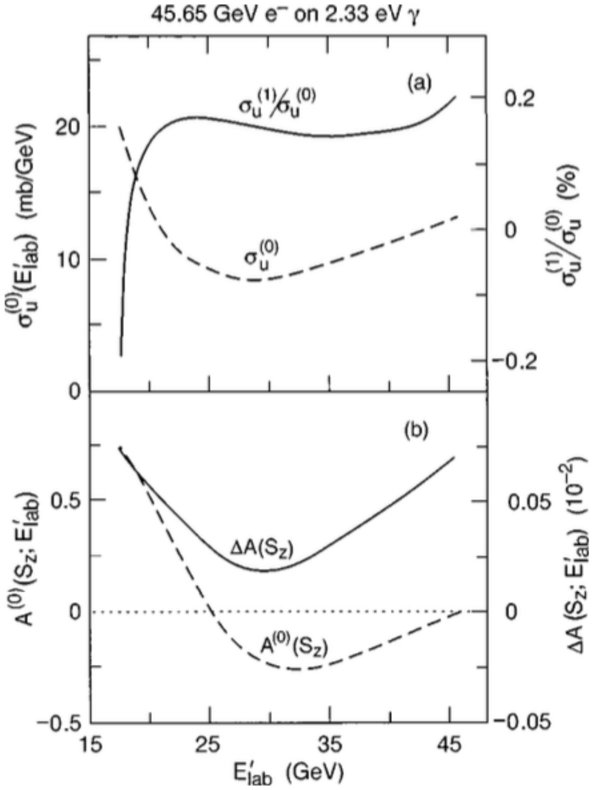
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309

(Received 24 November 1997; published 28 May 1998)

The construction of a computer code to calculate the cross sections for the spin-polarized processes $e^-\gamma \to e^-\gamma, e^-\gamma\gamma, e^-e^+e^-$ to order α^3 is described. The code calculates cross sections for circularly polarized initial-state photons and arbitrarily polarized initial-state electrons. The application of the code to the SLD Compton polarimeter indicates that the order-α^3 corrections produce a fractional shift in the SLC polarization scale of -0.1% which is too small and of the wrong sign to account for the discrepancy in the Z-pole asymmetries measured by the SLD Collaboration and the CERN LEP Collaborations.

[S0556-2821(98)03413-4]

- Studied in details at SLD



Measurement of transverse polarization at FCCee :

photons $\frac{\delta P}{P} \approx 1 \times 10^{-3}$ (0.5×10^{-3}) at 45 (80) GeV

electrons $\frac{\delta P}{P} \approx 4 \times 10^{-3}$ (10×10^{-3}) at 45 (80) GeV

Measurement of longitudinal polarization at FCCee :

$\frac{\delta P}{P} \approx 1 \times 10^{-3}$ at 45 GeV

If and only if laser helicity asymmetries are measured

Denner & Dittmaier Nucl. Phys. B 540 (1999) 58, Swartz Phys. Rev. D 58 014010 (1998), Veltman Phys. Rev. D 40 2810 (1989), Veltman Phys. Rev D 42 1856E (1990); A. Martens et al 2023 JINST 18 P10001

Magnetic field tolerancing

Many potential sources of ‘bending angle’ uncertainties (for instance genuine inhomogeneities of B-field, short-/long-term fluctuations of currents, temperatures, alignments)

Over the useful aperture of the magnet: $\frac{\sigma(\int B_y dl)}{\int B_y dl} \ll 2 \times 10^{-4}$

Fringe fields also may affect performance of polarimeter

$$\int B_x dl \ll \frac{\sigma_y \gamma}{L_2} \frac{mc}{q} \approx 1.1 \times 10^{-4} \text{ T.m and}$$
$$\int B_z dl \ll \frac{\sigma_y \gamma}{L_2 \kappa \theta_0} \frac{mc}{q} \approx 3.2 \times 10^{-2} \text{ T.m.}$$

Nominal vertical field for reference:

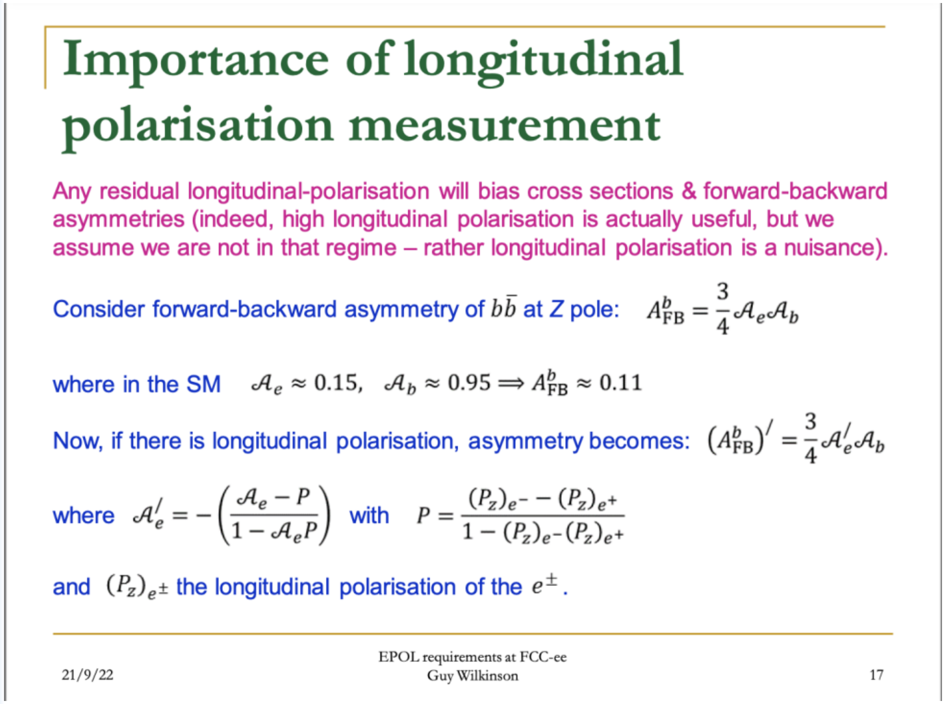
$$\int B_y dl = \theta_0 \gamma \frac{mc}{q} \approx 0.3 \text{ T.m.}$$

By product: angular alignment

$$\delta_B \ll \frac{\sigma_y \gamma}{L_2 \int B_y dl} \frac{mc}{q} \approx 370 \ \mu\text{rad.}$$

NB: Requirements not met → not a show-stopper but detailed studies required

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: $A^b_{\mathrm{FB}} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_b$

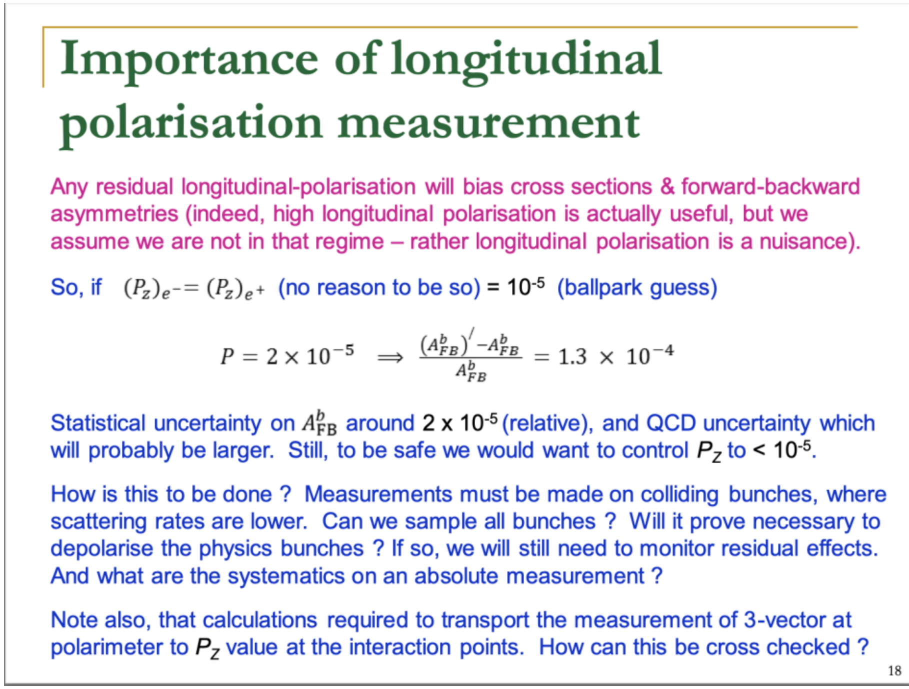
where in the SM $\mathcal{A}_e \approx 0.15, \quad \mathcal{A}_b \approx 0.95 \Longrightarrow A^b_{\mathrm{FB}} \approx 0.11$

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

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 17



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)

$$P = 2\times 10^{-5} \Longrightarrow \frac{(A^b_{FB})' - A^b_{FB}}{A^b_{FB}} = 1.3 \times 10^{-4}$$

Statistical uncertainty on A^b_{FB} around 2 x 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 ?

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Wilkinson at EPOL workshop https://indico.cern.ch/event/1181966

High accuracy longitudinal polarization measurement is needed

→ Naturally small at IPs but with what accuracy ?

→ Measure it !

Berestskii & Lfshitz QED textbook

Compton cross-section

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

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

The Compton cross-section averaged over scattered particles spins:

Differential cross-section

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

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

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

Electron beam polarization independent

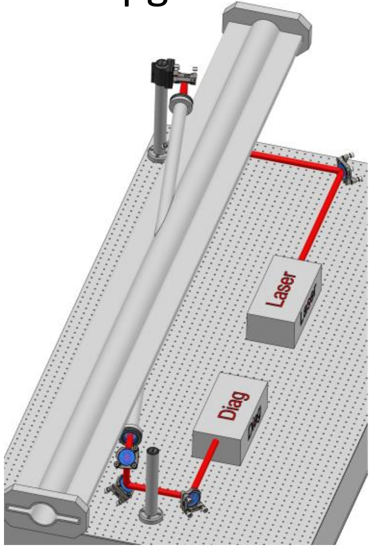
Electron beam polarization dependent

⚠ But small opening angle of scattered particles:

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

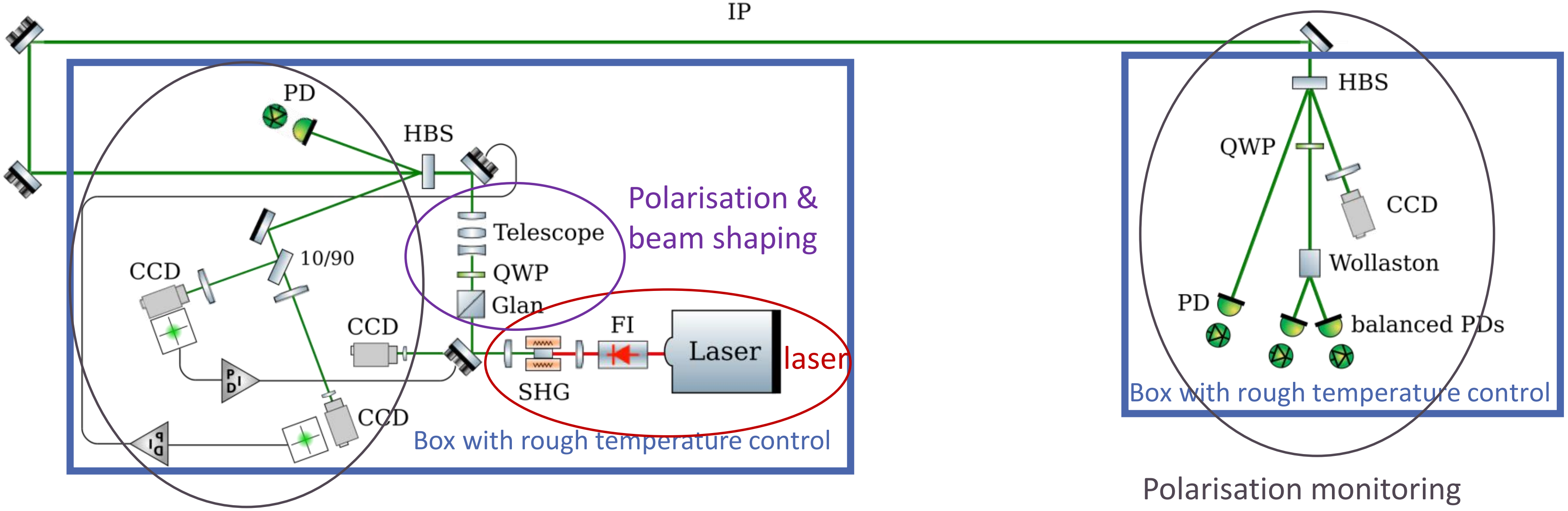
Laser integration

SuperKEKB upgrade concept



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)

Versatile Yb system

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	3x10^5/s (*)	3x10^5/s (****)	4x10^7/s (****)
Scattering rate per bunch	3x10^5/s (*)	3x10^5/s	4x10^5/s

adaptable

Same oscillator may be used but two different amplification schemes

(*) crossing angle ~ 2mrad

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

(***) Can be increased to typically ~100W (nowadays) but requires operational validation

(****) not limited by Piwinski contribution → can be several degrees without affecting rate

Scattering rates

Laser-beam single pulse energy

Compton cross-section

Electron bunch charge
(25nC for colliding bunches,
1.5nC for pilots)

Geometrical factor

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

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

Transverse beam sizes:

- $\sigma_{x,y,z} = \sqrt{\sigma^2_{x,y,z,laser} + \sigma^2_{x,y,z,e-}}$
- $\sigma_{x,laser} = \sigma_{y,laser}$=1000µm
- $\sigma_{x,e-}$ = 500µm, $\sigma_{y,e-}$=10µm, $\sigma_{z,e-} \sim$10mm

Laser photon energy
(2.4eV for 0.5µm wavelengths)

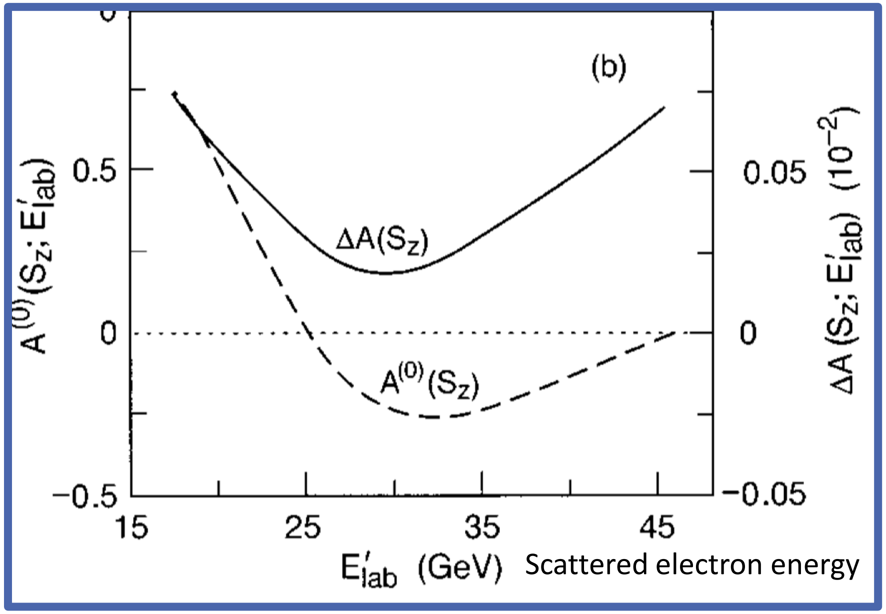
Involved processes $e\gamma \to e\gamma$, $e\gamma \to eee$, $e\gamma \to e\gamma\gamma$

QED corrections

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

Denner & Dittmaier Nucl. Phys. B 540 (1999) 58, Swartz Phys. Rev. D 58 014010 (1998), Veltman Ophys. Rev. D 40 2810 (1989), Veltman Phys. Rev D 42 1856E (1990)

QED corrections<0.001 @ 45 GeV



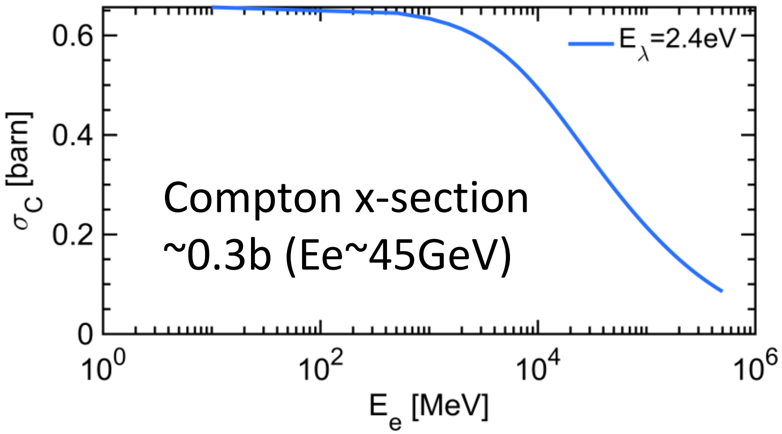
Scattered electron energy

Need to be eventually included in simulations…

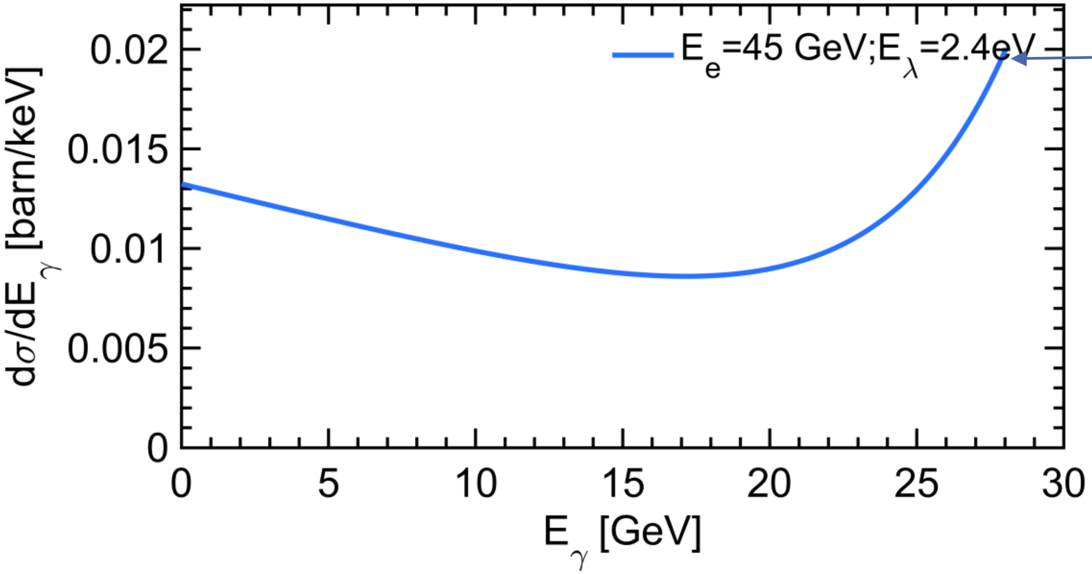
The Compton process

Klein O. and Nishina Y., Z. Phys. 52(1929) 853; Ginzburg I. et al., Nucl. Instr. Methods in Phys. Research 219 (1984) 5, V. B. Berestetskii, E. M. Lifshitz, L. P. Pitaevskii (1982). Quantum Electrodynamics. Vol. 4 (2nd ed.)

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



Compton x-section ~0.3b (Ee~45GeV)



Kinematic edge