Laser polarimetry for Compton polarimeter

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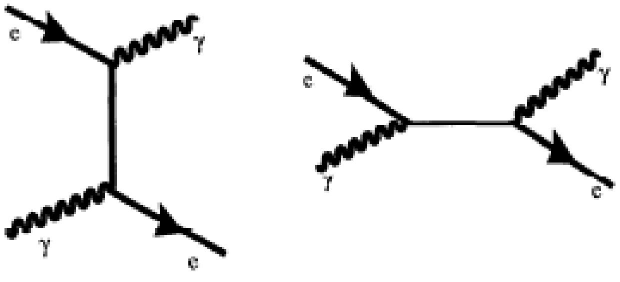
Compton cross-section



$$x = \frac{2E_0\omega_0}{m^2}(1+\cos\theta_0) \qquad y = \frac{E_\gamma}{E_0}$$

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

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

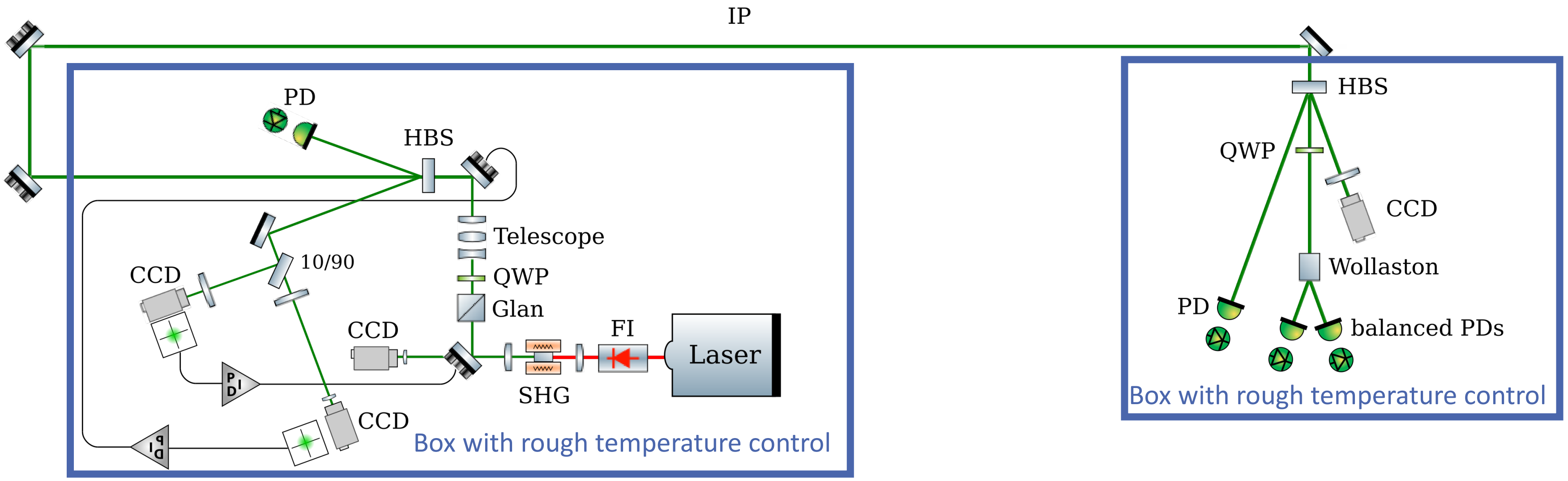
Electron beam polarization independent

Electron beam polarization dependent

⚠ Precise control and monitoring of laser polarization requested:

- Difficult to extract laser polarisation from scattered particles → transverse distribution must be precisely extracted
- An optical technique is needed

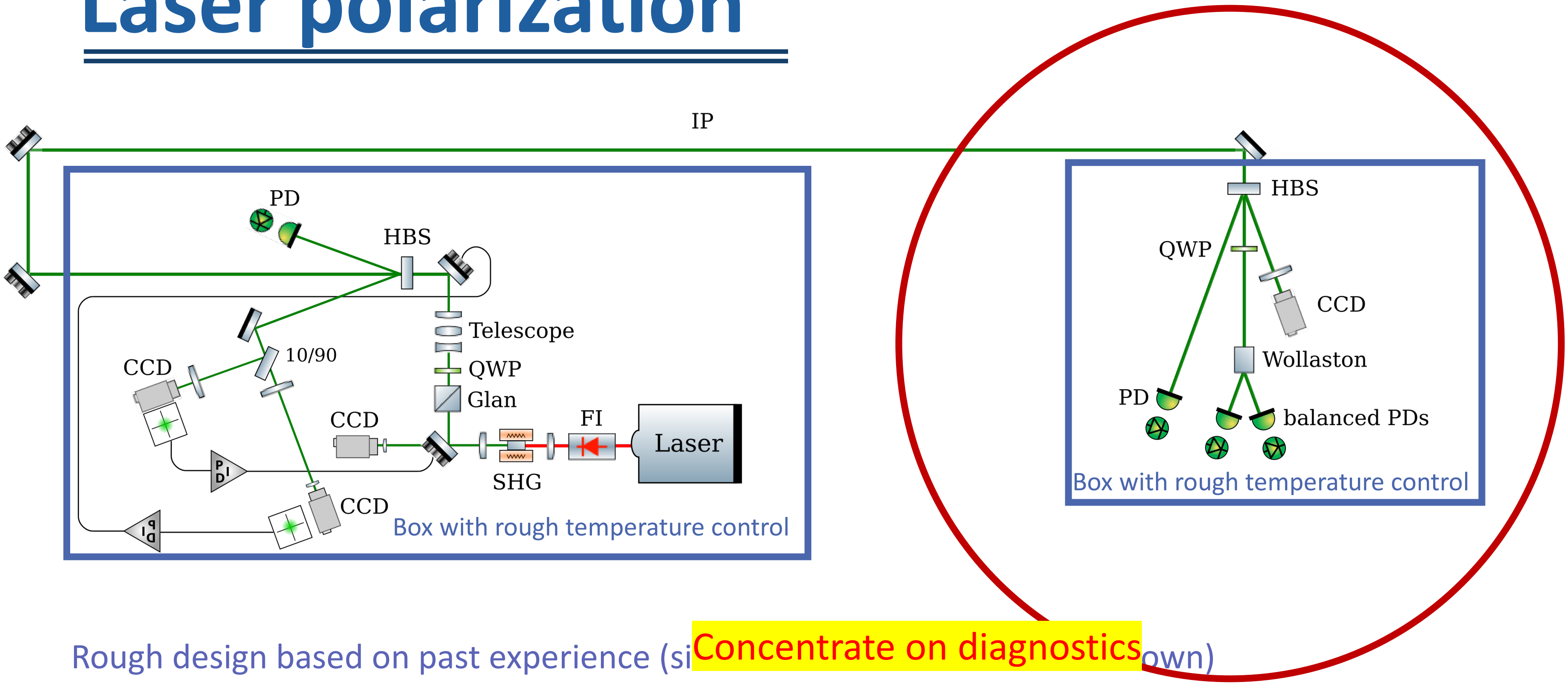
Laser polarization



Rough design based on past experience (similar to what D. Gaskell has shown)
In multi-photonic mode, average power can be large, prefer reflective optics..
300µm beam size shall not be a problem (Rayleigh range of 1m)
Elliptic beam can be delivered with cylindrical lenses/mirrors

NB: actual reasonable values are constrained by integration-related issues

Laser polarization



Concentrate on diagnostics

Rough design based on past experience (si own)
In multi-photonic mode, average power can be large, prefer reflective optics..
300µm beam size shall not be a problem (Rayleigh range of 1m)
Elliptic beam can be delivered with cylindrical lenses/mirrors

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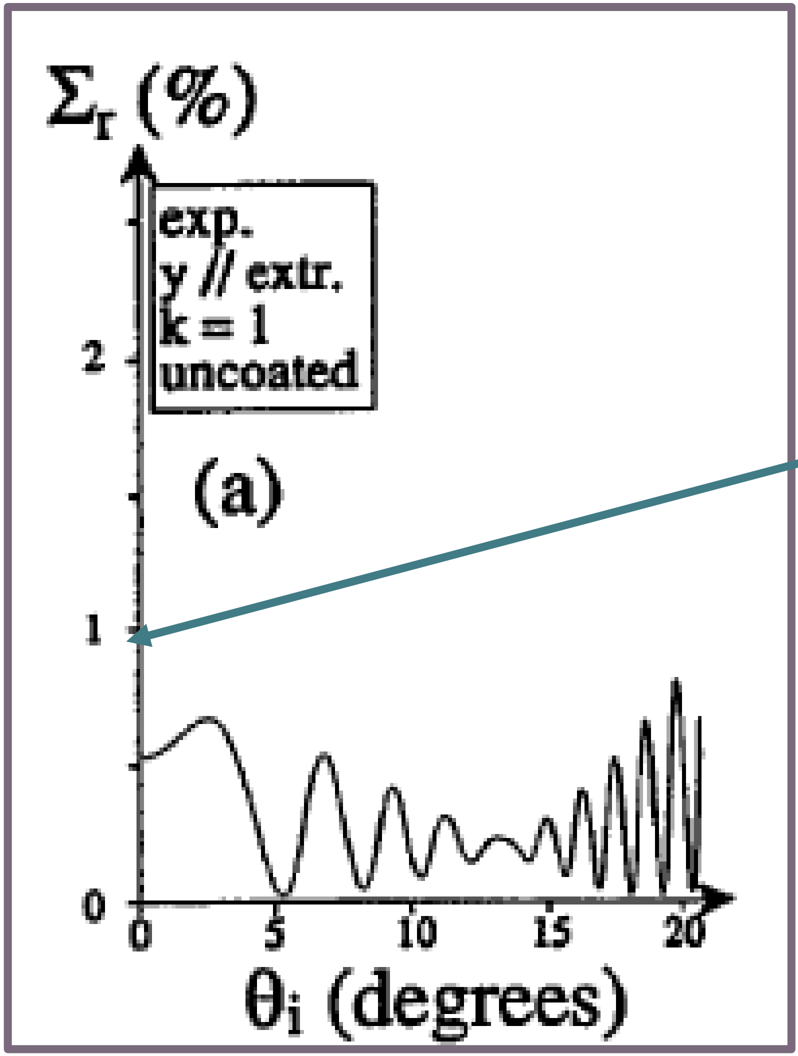
Defects in QWP

Brisson JINST 5 P06006 (2010), Zomer HDR (2003), Jacquet HDR (2009), Baudrand PhD thesis (2007)



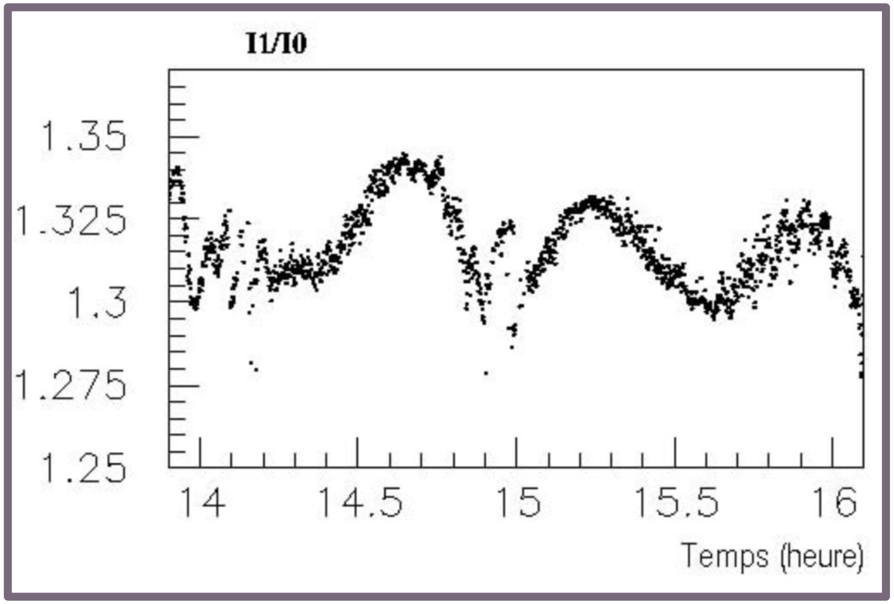
Residual wrong polarization vs QWP tilt angle

About 1 percent contribution from wrong polarization

Fine modeling of beam transport is required

Brisson JINST 5 P06006 (2010), Zomer HDR (2003), Jacquet HDR (2009), Baudrand PhD thesis (2007)

Laser beam polarization control



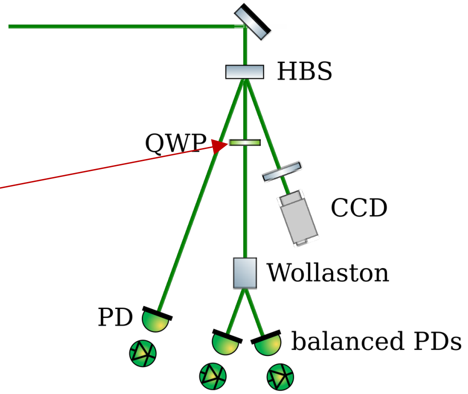
Example of time dependent measurement at HERA

- Remaining 0.3% fluctuations

- More frequent measurements ?
- Modulation of circular polarization to avoid DC fluctuations ?

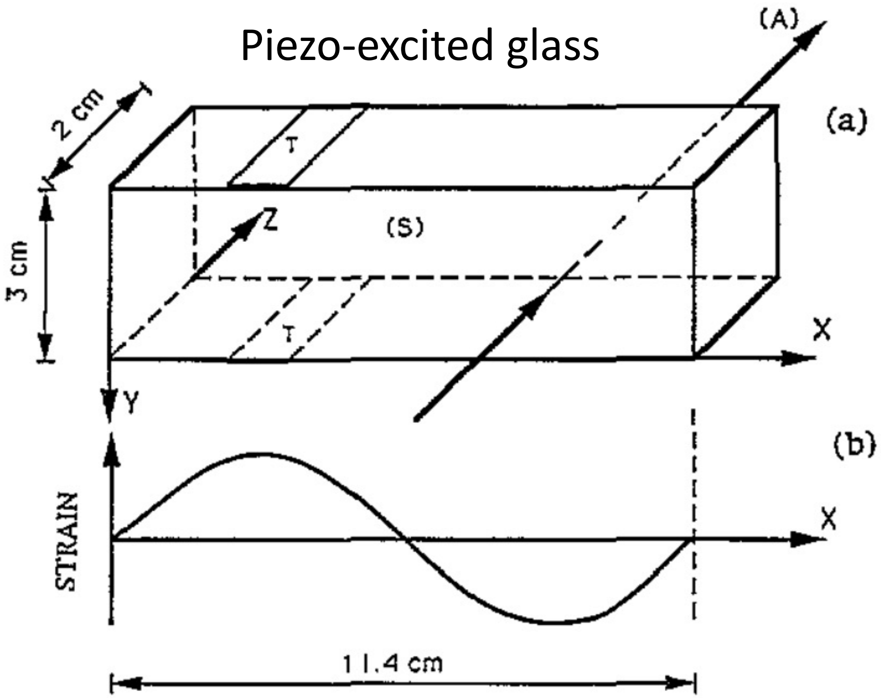
Photo-elastic modulator

D. Yang et al., J. Optics (Paris) **26** (1995) 151



Replace motorized QWP by PEM

Piezo-excited glass



$$n_x \# \; n_0\left[1-\frac{n_0^2}{2}\left(p_{11}\,U_{xx}+p_{12}(U_{yy}+U_{zz})\right)\right]$$

$$n_y \# \; n_0\left[1-\frac{n_0^2}{2}\left(p_{12}(U_{xx}+U_{zz})+p_{11}\,U_{yy}\right)\right] \qquad (2)$$

Modulated difference of refraction indices

Modulation of phase of waveplate

PEM: principle for polarimetry

O. Acher et al., Rev. Sci.Instrum. **60** (1989) 65

The detected intensity[7–9] takes the general form

$$I(t) = I\{I_0 + I_s \sin[\delta(t)] + I_c \cos[\delta(t)]\},$$

Intensity modulation on Photodetectors

$$\delta = \delta_0 + \mathscr{A} \sin \omega t.$$

Static birefringence

Harmonic contribution may also be required

To the first order in δ_0,

$$\begin{aligned}\sin[\delta(t)] &= \delta_0 J_0(\mathscr{A}) + 2J_1(\mathscr{A})\sin(\omega t)\\ &\quad + \delta_0 2J_2(\mathscr{A})\cos(2\omega t)\\ &\quad + \cdots (\text{higher harmonics})\\ \cos[\delta(t)] &= J_0(\mathscr{A}) - \delta_0 2J_1(\mathscr{A})\sin(\omega t)\\ &\quad + 2J_2(\mathscr{A})\cos(2\omega t)\\ &\quad + \ldots (\text{higher harmonics}).\end{aligned}$$

Characteristic bessel expansion

More harmonics may be used

$$\begin{pmatrix} S_0 \\ S_\omega \\ S_{2\omega} \end{pmatrix} = I \begin{pmatrix} 1 & \delta_0 J_0(\mathscr{A}) & J_0(\mathscr{A}) \\ 0 & 2J_1(\mathscr{A}) & -\delta_0 2J_1(\mathscr{A}) \\ 0 & \delta_0 2J_2(\mathscr{A}) & 2J_2(\mathscr{A}) \end{pmatrix} \begin{pmatrix} I_0 \\ I_s \\ I_c \end{pmatrix}.$$

PEM calibration setup

https://www.hindsinstruments.com/products/photoelastic-modulators/pem-200/

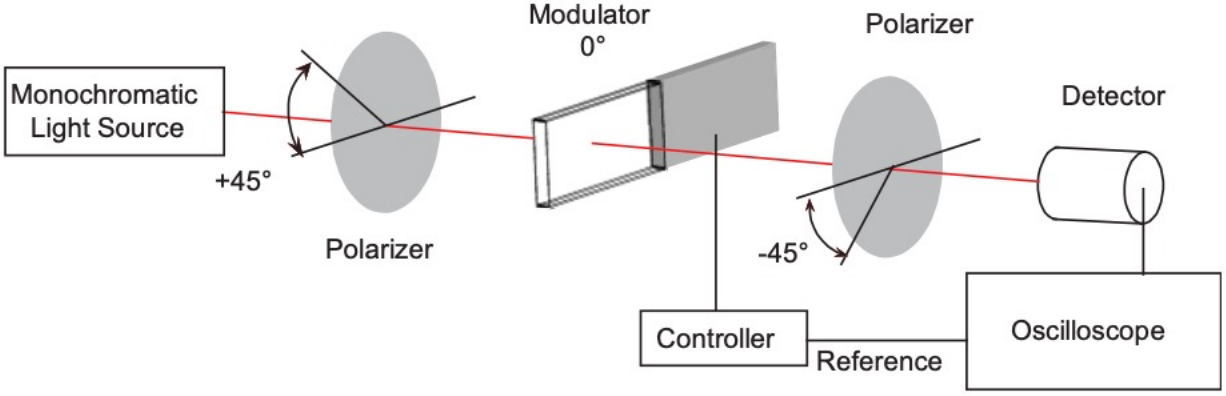
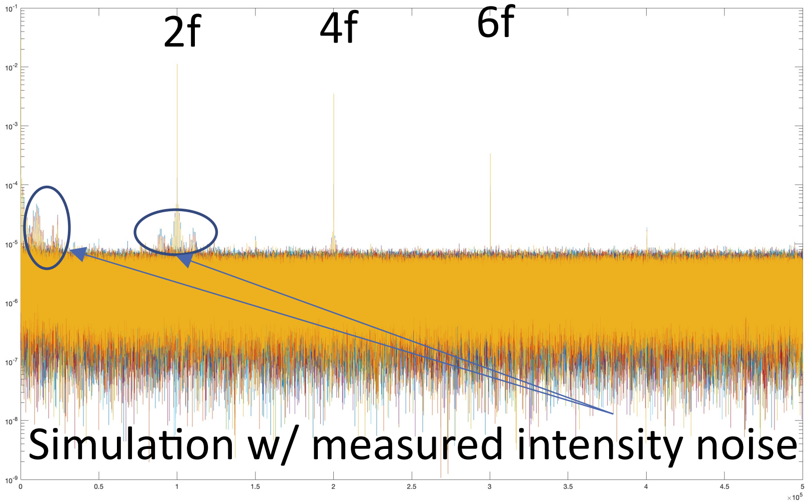


Figure A.1 Typical Optical Setup

Acquire waveforms and then DFT

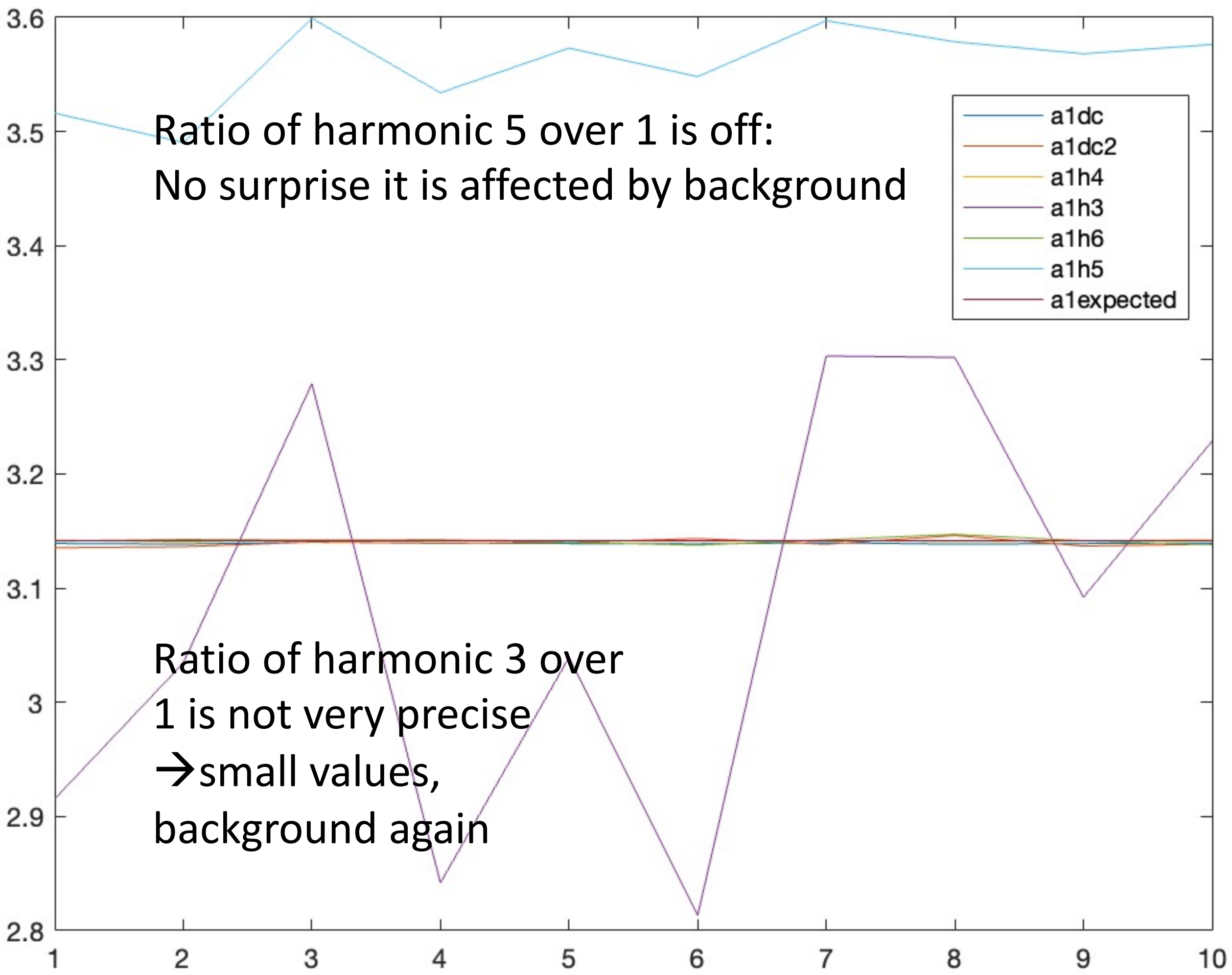


Simulation w/ measured intensity noise

Expected results (simulation)

A

$$\delta = \mathscr{A} \sin \omega t.$$

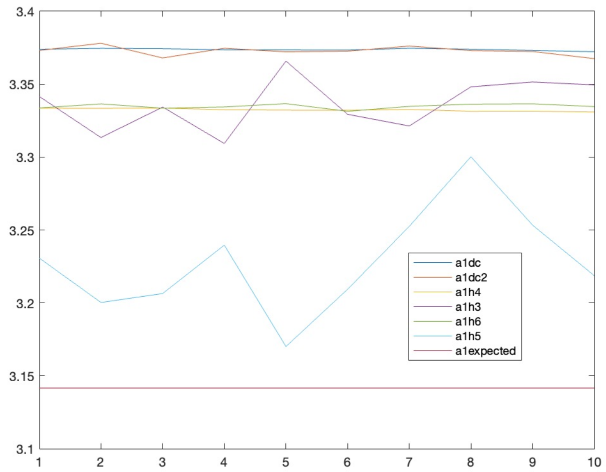


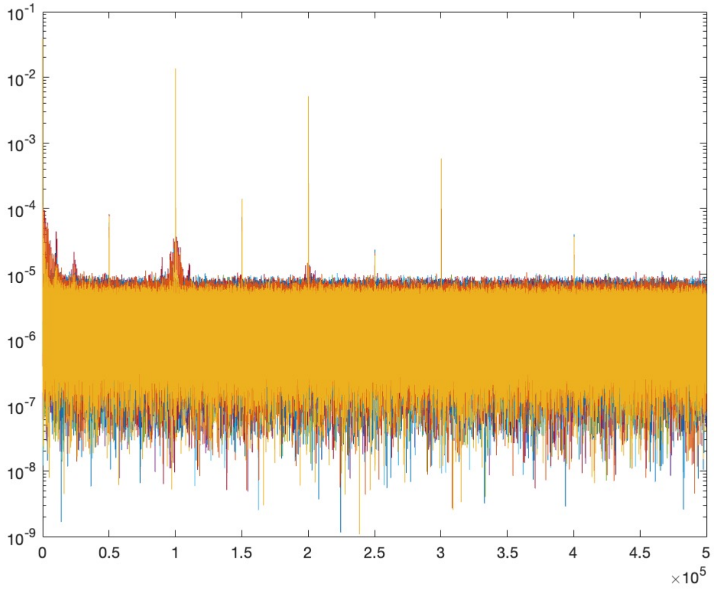
Ratio of harmonic 5 over 1 is off:
No surprise it is affected by background

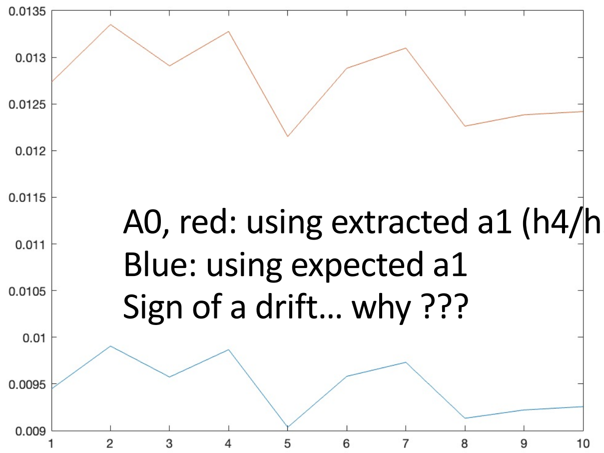
Ratio of harmonic 3 over 1 is not very precise
→small values, background again

Data

A1 precision (repeatability) ~0.03%
Accuracy comparing h4/h2 and h2/dc ~ 1%
Accuracy of calibration (?) ~ 6%







A0, red: using extracted a1 (h4/h2)
Blue: using expected a1
Sign of a drift… why ???

First results

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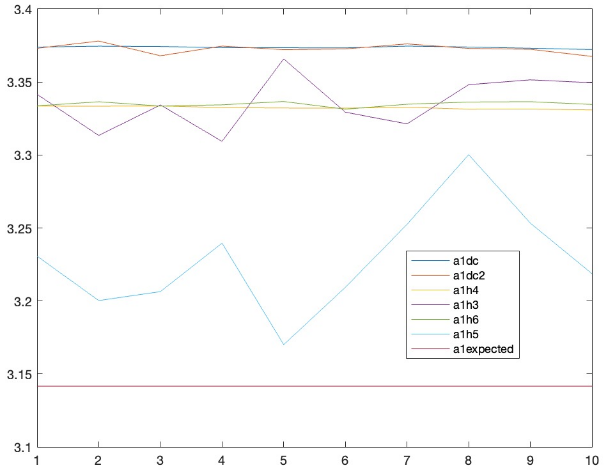
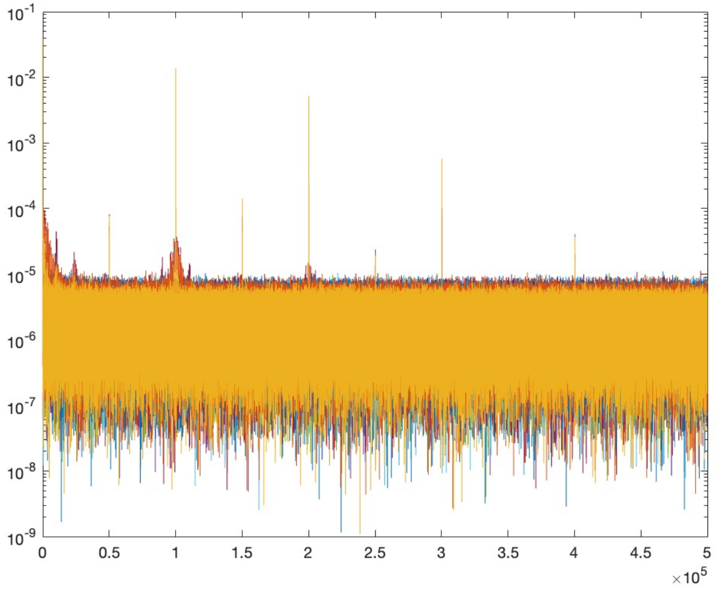
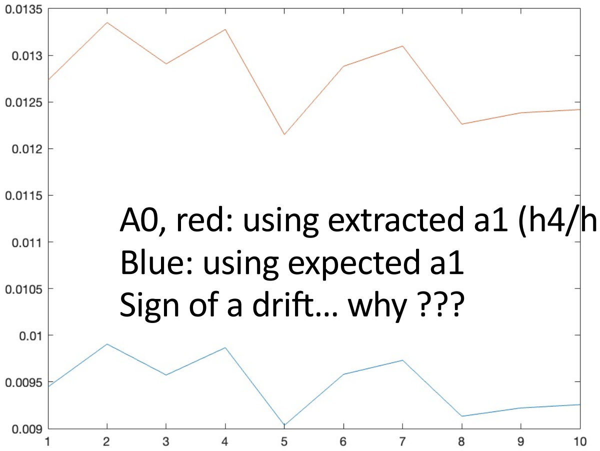
Accuracy comparing h4/h2 and h2/dc ~ 1%
Accuracy of calibration (?) ~ 6%







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Conclusion

Introduced the use of photo-elastic modulators for real-time laser polarization monitoring

- Interesting in the context of SuperKEKB (250MHz laser)
- Modulates polarization at harmonics of 50kHz
- More robust against DC fluctuations

First tests performed

- Sign of (relatively) large static birefringence
- Likely inhomogeneous on the PEM surface

Next steps

- Scan surface to make a static birefringence map
- Investigate in detail the effect on anharmonicities in the modulation
- Slowing progressing based on short-term undergrads training periods