HERA LPOL2 laser system and polarization control

Introduction

The Compton cross-section averaged over scattered particles spins:

Differential cross-section

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

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

Electron beam polarization independent

Electron beam polarization dependent

$\mathcal{P}^{las}_{circ}$ and $\mathcal{P}^{las}_{lin}$ = degree of linear ans circular polarization of the laser beam

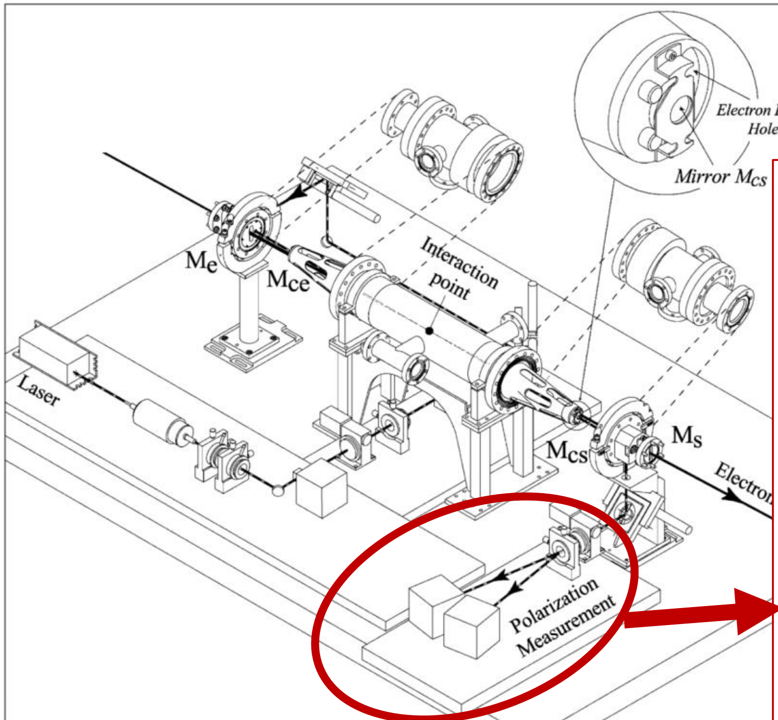
If one wants to determine P_L and P_T at the permille level, then it must be the same for laser beam polarization

Outlook

- (some) Basic & robust laser beam polarimetric setups used in the past
  - SLD (see M. Woods) & Jlab laser cavity setup (1999, N Falletto PhD.)
  - Hera lpol cavity setup 2004
  - Precision & Limit of the method
- Improvement for higher precision

N. Falletto et al. / Nuclear Instruments and Methods in Physics Research A 459 (2001) 412–425

JLAB(1999) polarimeter & SLD polarimeter



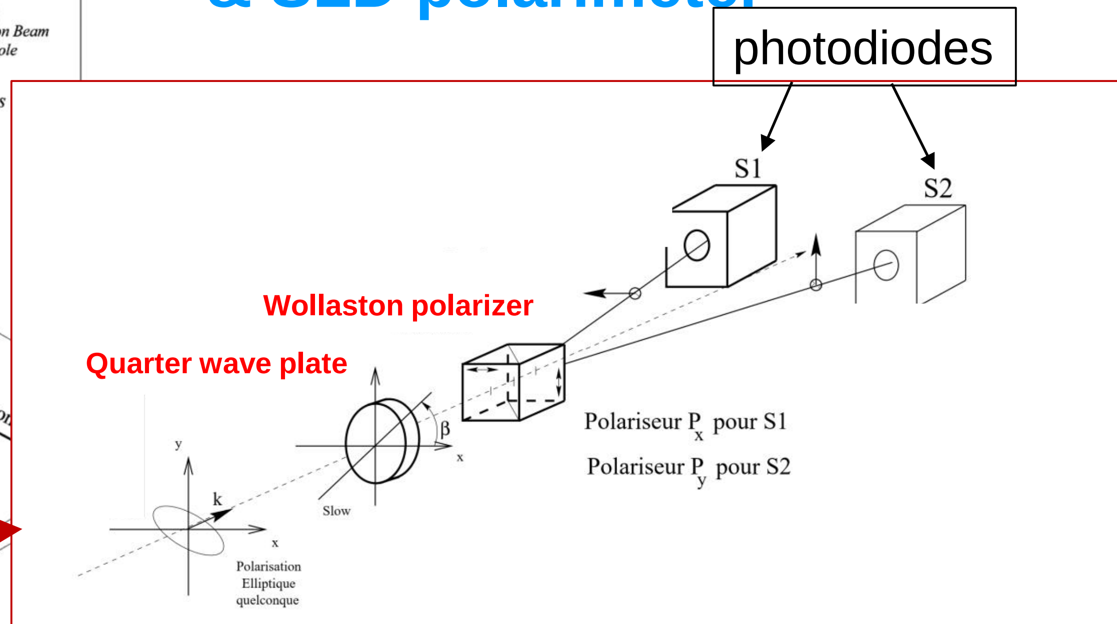


FIG. 4.12 - *Mesure de la polarisation sur le montage de TJNAF.*

Quarter wave plate : uniaxial quartz plate with optical axis in the plane of interface (β angle)
Thickness :

Wollaston polarizer: extinction ~10^{-5}

Laser beam wavelength ~1µm

$$e = \frac{\lambda}{4\Delta n}(4k+1), k = 0, \frac{1}{2}, 1, \ldots$$

Birefringence ~10^{-2} for quartz

'zero order plate' :
k=0 ➔ e~30µm
'few order', k=1/2
e~90µm

Assume the electric field of laser beam described by a plane wave :

Jones (Field components) formalism
 or Mueller (intensity components)
 formalism can be used
(see M. Woods yesterday)

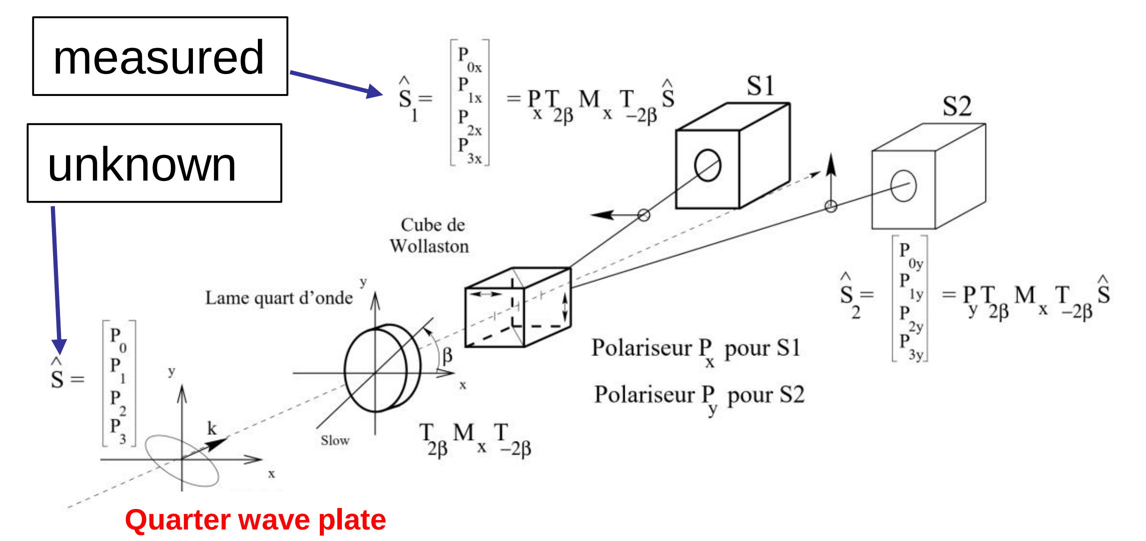


FIG. 4.12 - *Mesure de la polarisation sur le montage de TJNAF.*

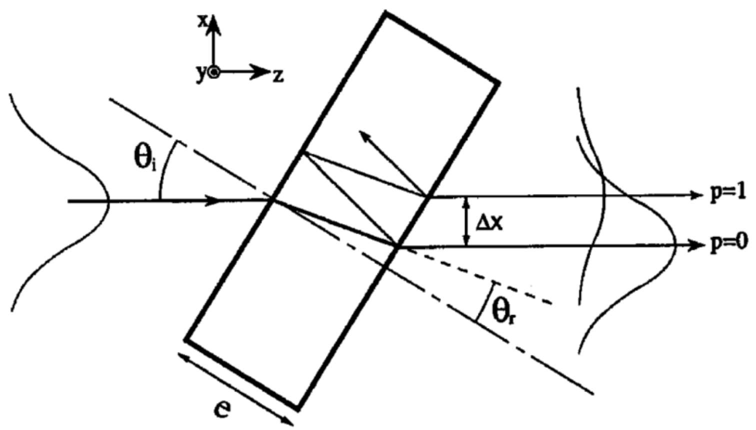
For 'perfect' QWP and polarizer :

$$P_{x/y} = \begin{pmatrix} 1 & 1/-1 & 0 & 0 \\ 1/-1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \quad , \quad T_{2\beta} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(2\beta) & -\sin(2\beta) & 0 \\ 0 & \sin(2\beta) & \cos(2\beta) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$M_x = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

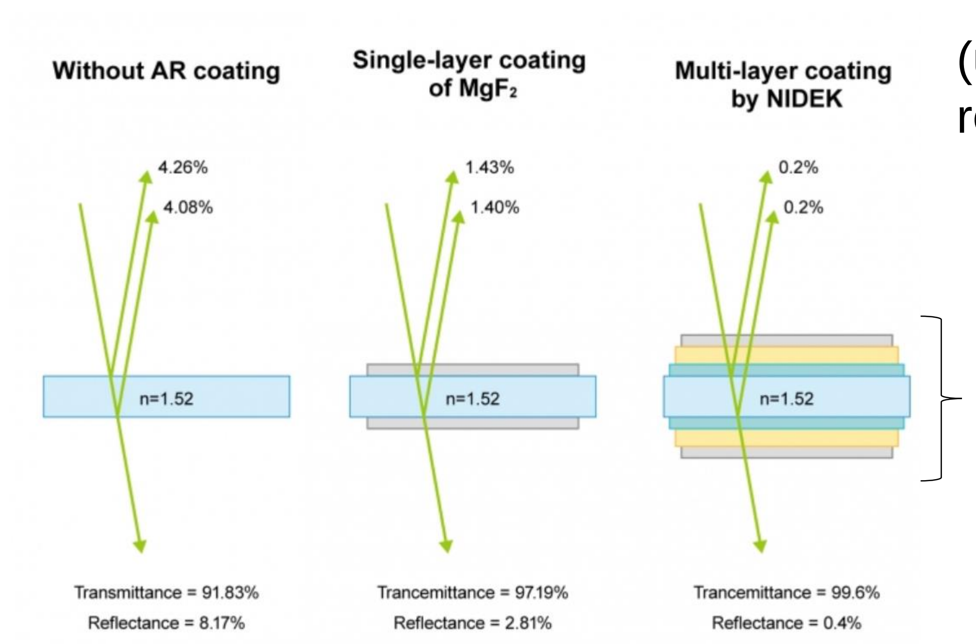
The laser beam polarization is measured by rotating (β angle) the QWP and fitting the intensity profiles S1, S2 after the polarizer using Mueller (or Jones) matrix .

However : multiple reflexions inside quartz plate are neglected in this model



[Paraxial Gaussian beam
Amplitude accounted for large tilts
➔modified Jones & Mueller matrix]

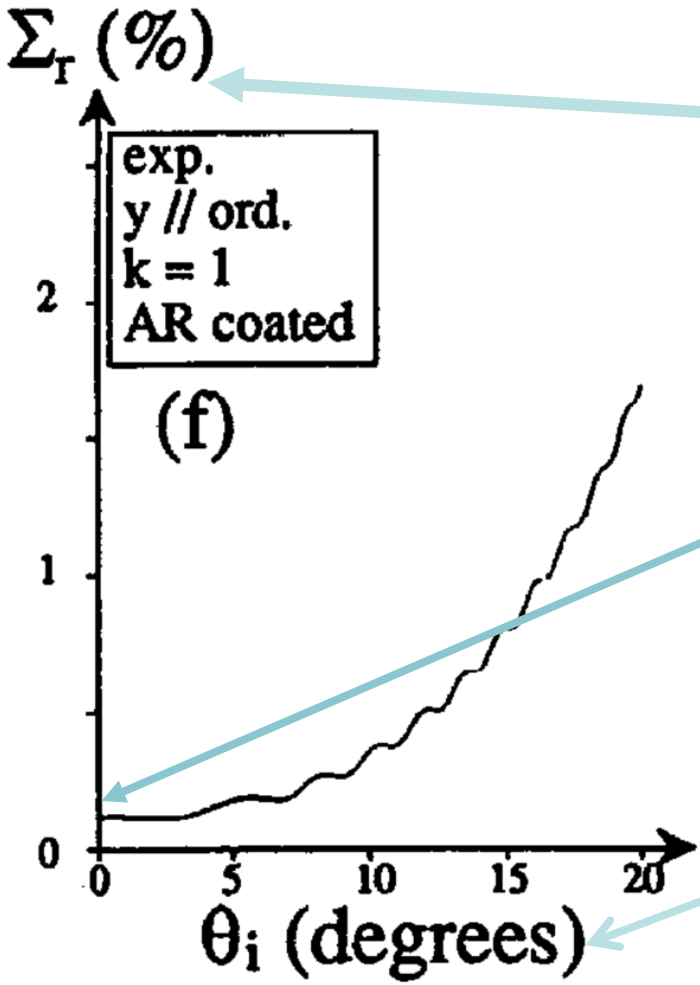
This is usually justified by using anti-reflexion coatings



(usually 0.2%-0.4% residual reflectance)

Complex system to model (thicknesses, optical indices…)

Residual effect of AR coating



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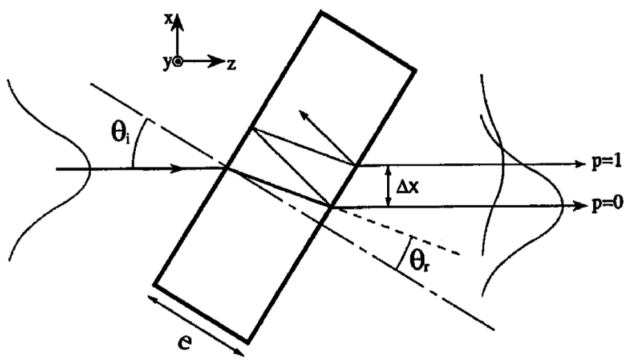
Residual wrong polarization vs QWP tilt angle
Σ_r sould by 0 at θ_i=0

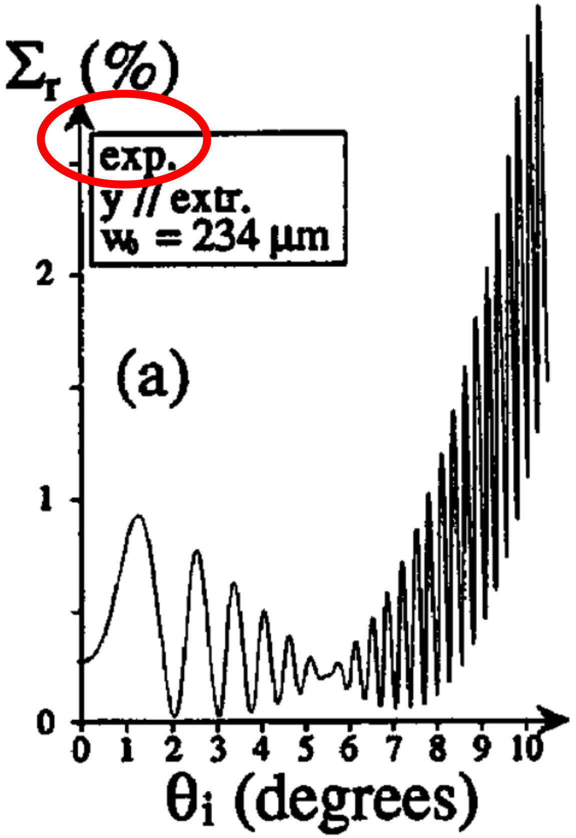
About 0.1 percent contribution from wrong polarization
➔ This gives a precision estimate on the model assumption

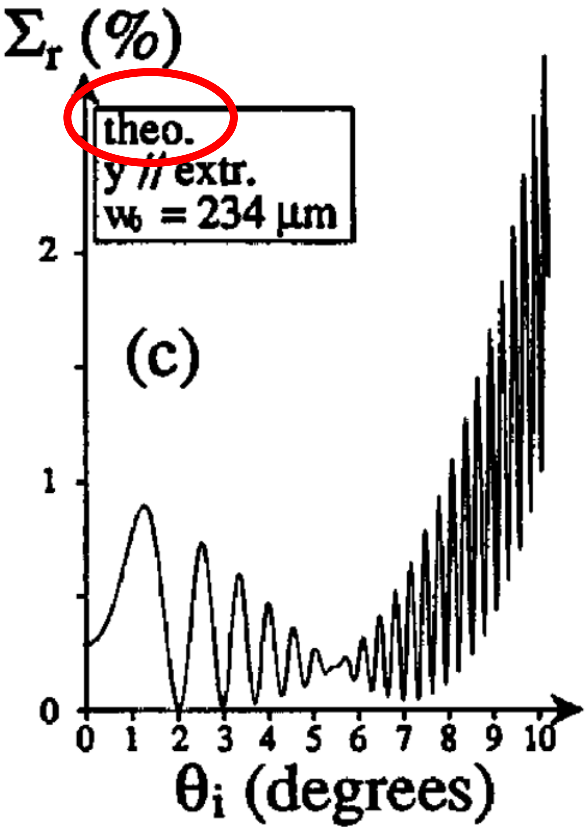


Precision strongly related to
AR coating performance & quartz thickness

While simple uncoated plate are well modeled

QWP thickness (~1mm) corrected by **~-7% @ 0.01%(~λ/500)** precision...





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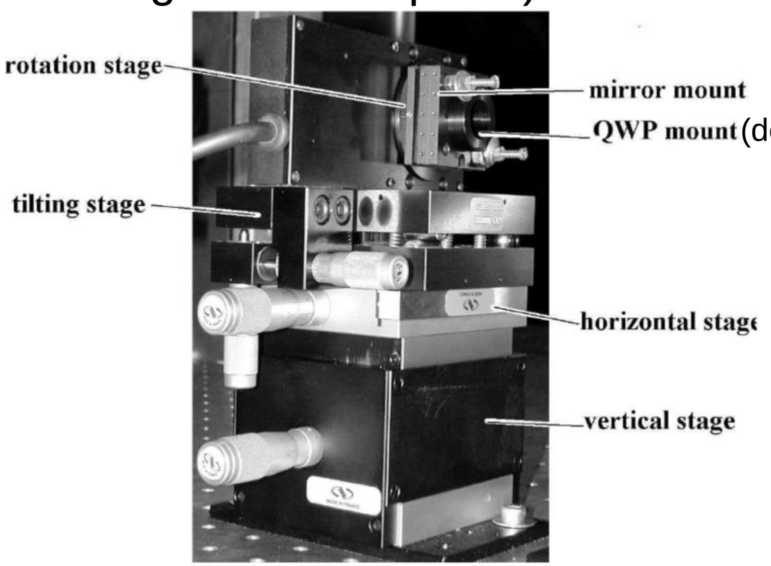
Hera cavity polarimeter: goal 0.1% precision

- We had had bad experience with various AR coated QWP (and little funding…)

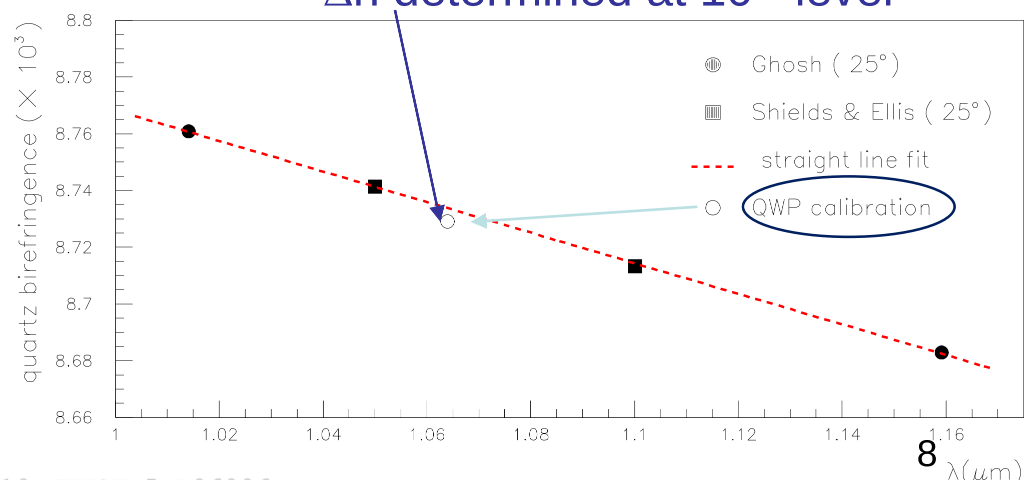
➔Same laser beam polarimeter as SLD&Jlab but with an uncoated quartz plate (e~90µm)

- Calibration by tilting and rotating 2 uncoated quartz plates (of diffrent thicknesses)
  - Fit parameters : thickness, various misalignments parameters, birefringence Δn as a control parameter
- Final precision : few per mille (limited by photodiode readout stability, easy to upgrade using lock-in amplifier)



(dedicated stress free mount)

Δn determined at 10^{-6} level



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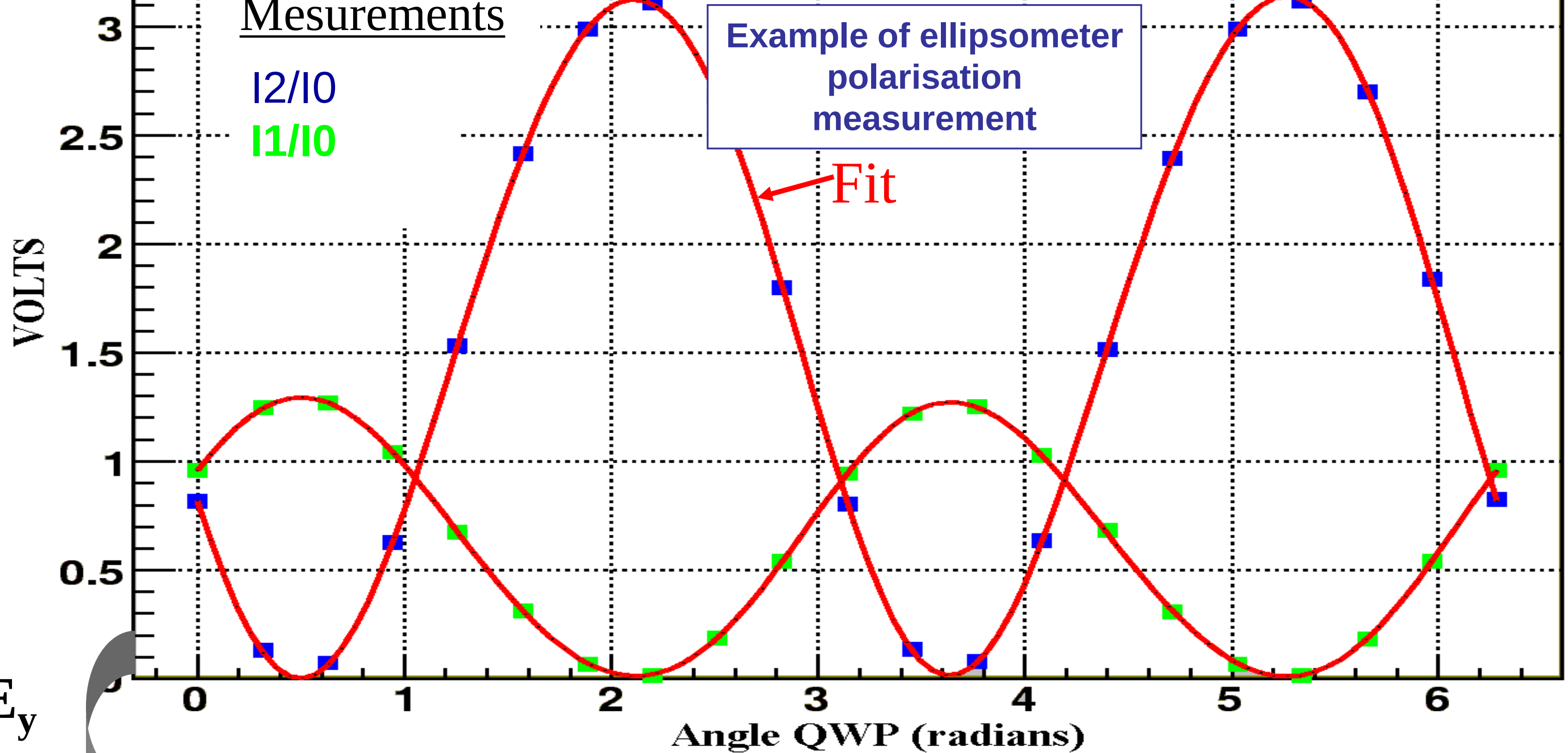
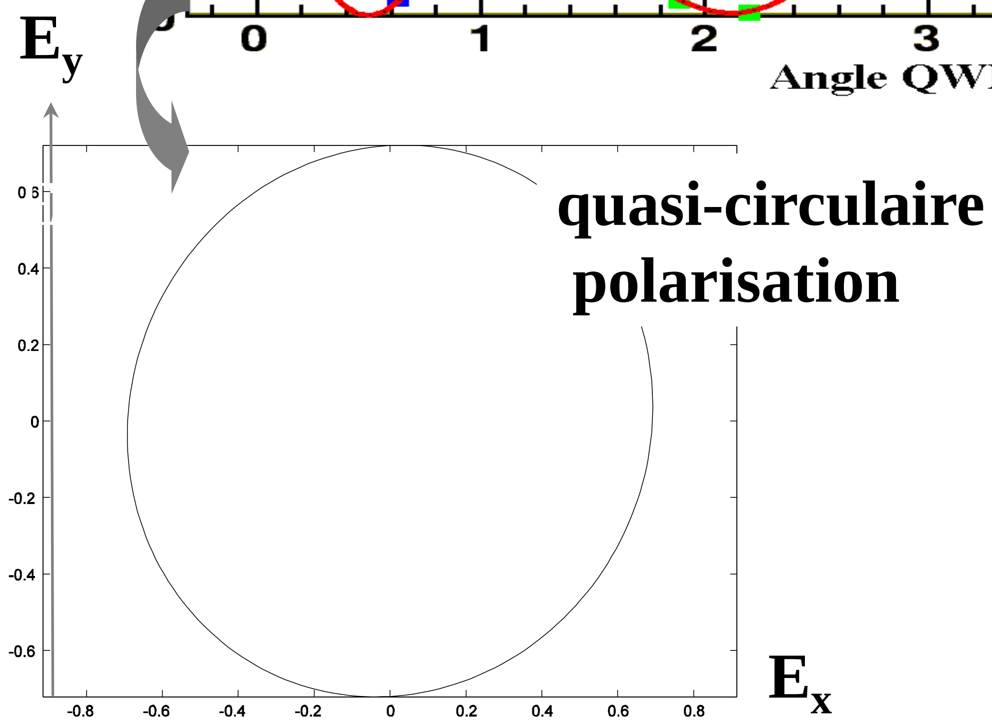
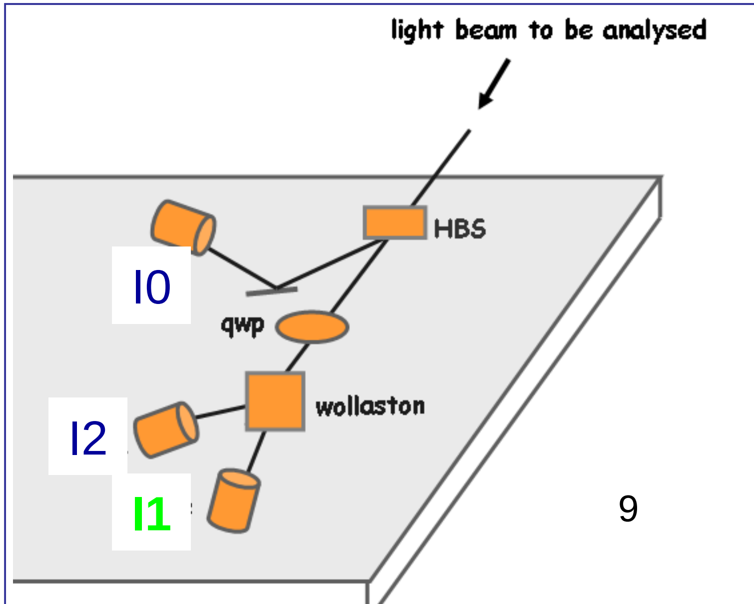
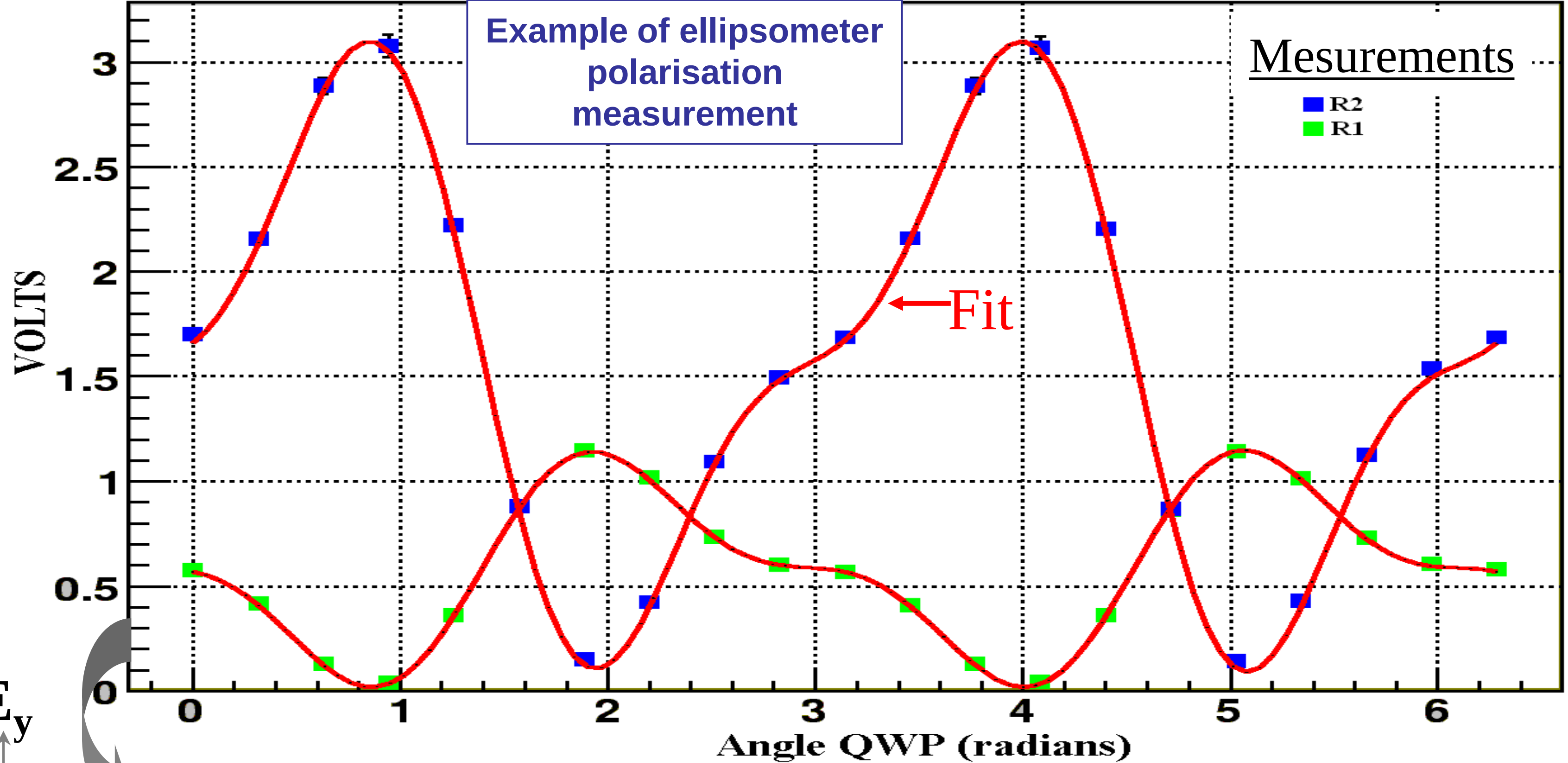
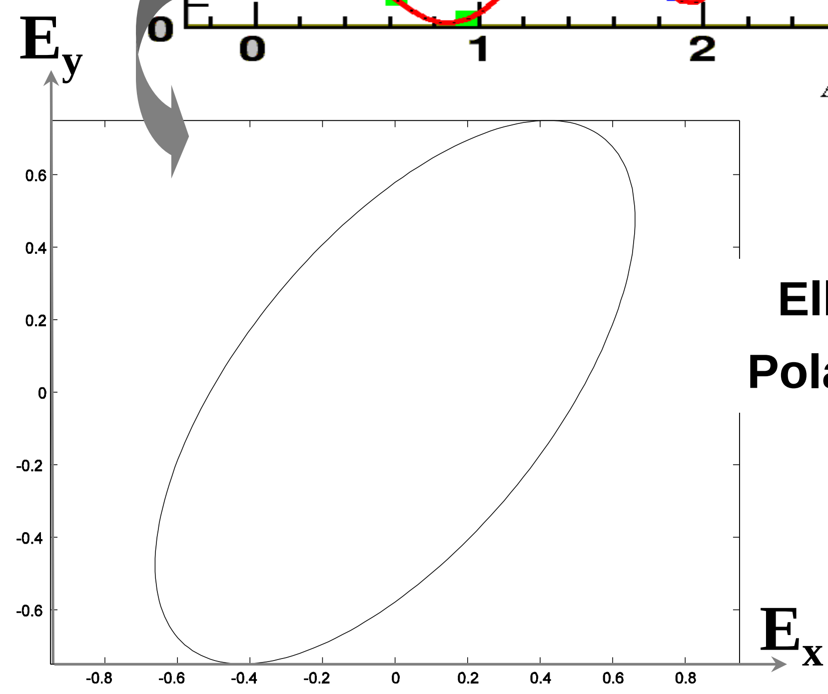

Mesurements
I2/I0
I1/I0
Example of ellipsometer polarisation measurement
Fit
VOLTS
Angle QWP (radians)
0
1
2
3
4
5
6
0.5
1
1.5
2
2.5
3


E_y
quasi-circulaire
polarisation
E_x


light beam to be analysed
HBS
I0
qwp
wollaston
I2
I1





Elliptical Polarisation

Advantages of QWP+polarizer ellipsometer:

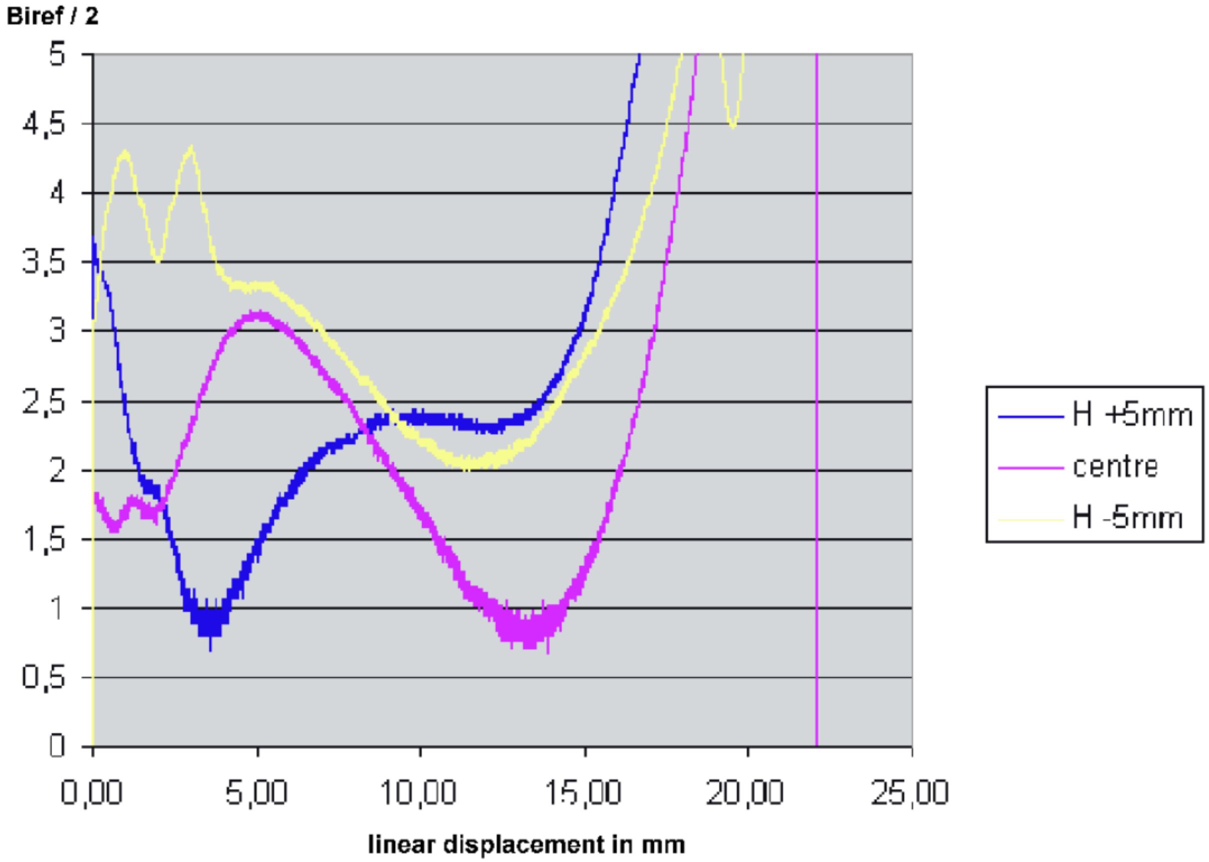
- Simple and robust method
- With some model extention e.g. :
  - For ‘high’ laser power :Thermoelastic induced birefringence
  - quartz optical activity or circular birefringence
    (induced by magnetic dipolar & quadrupolar electric responses of the crystal) ~7. 10^{-5} effect
    (though sapphire Xtal could be used)
- ➔ at least 10^{-4}-10^{-5} precision should be achievable
  - Above 10^{-5}, crystal homogeneity, roughness, polarizer extinction for ex. may limit the model completeness (to be studied)

Disadvantages

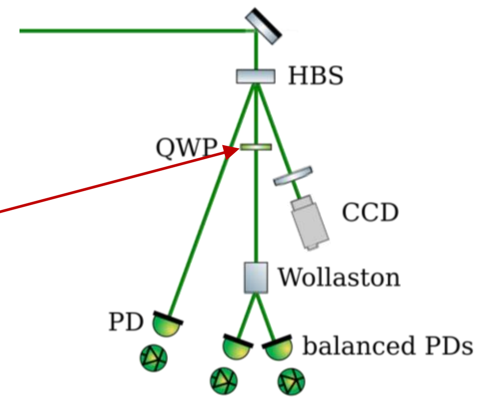
- Tedious alignments
- Long time calibration
- Long time measurements

Another limit comes from the vacuum windows

Measured birefringence (in mrad) of Lpolcav vacuum window (glass-metal welding), pollution of degree of circular polarization is in biref^2/2 ➔ 10^{-5} effect

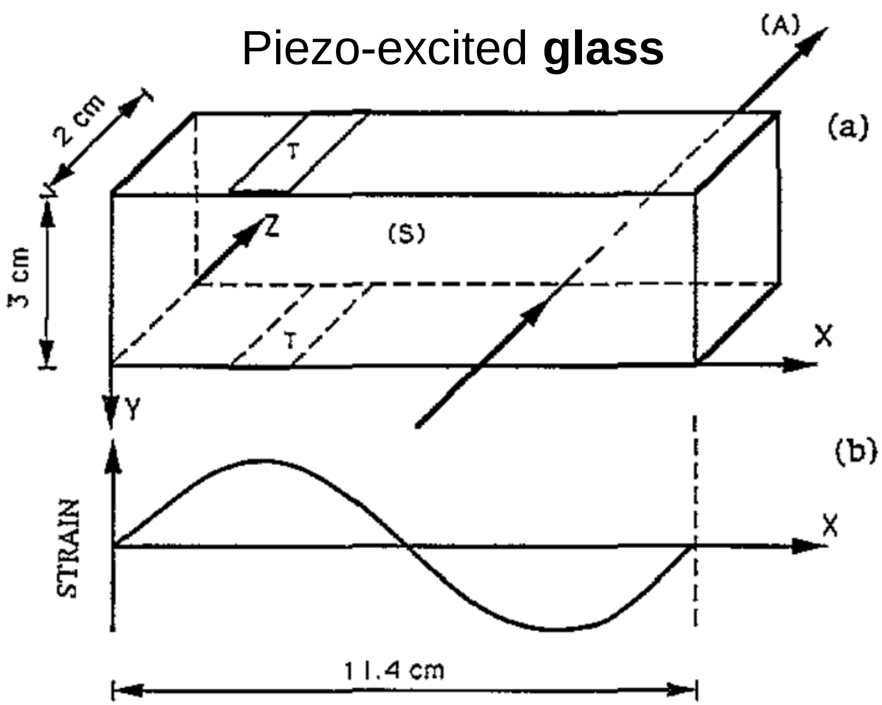


Improvement : Photo-elastic modulator



Replace motorized QWP by PEM

Piezo-excited **glass**



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

Birefringence induced by stress

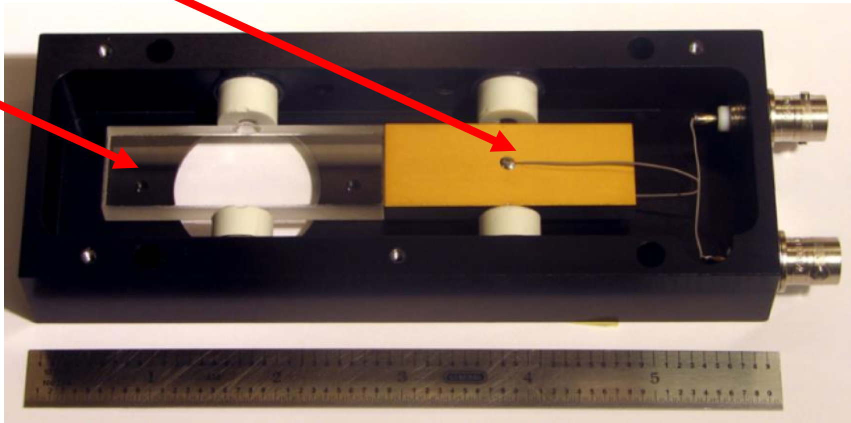
$$n_x \# n_0\left[1-\frac{n_0^2}{2}(p_{11}\,U_{xx}+p_{12}(U_{yy}+U_{zz}))\right]$$

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

Modulated difference of refraction indices

Modulation of phase of waveplate

- Modulation frequency : 50 kHz
  - FFT➔ amplitudes at various signal harmonics
    - Gives the degree of circular polarization
  - Fast and compact measurement based on ‘simple’ component: glass plate & piezo



- Parasitic effects well studied/documented:
  - Thermal effects ➔ feedback technics on the piezo controller
  - Anharmonicity effect➔ accounted in signal analysis

- Internal multiple reflexions

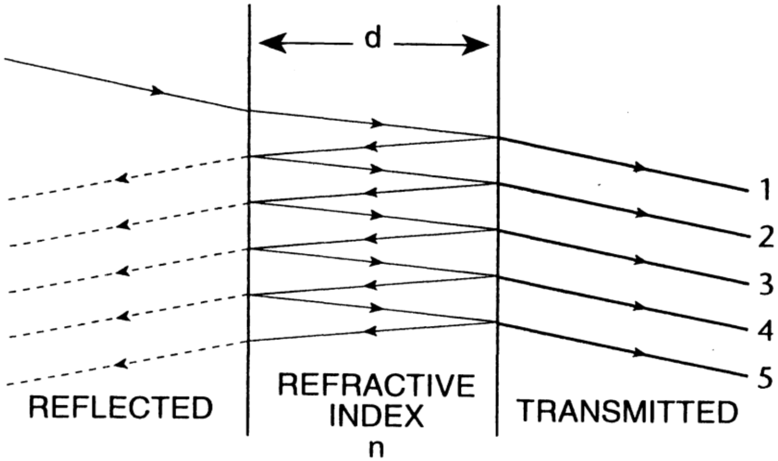
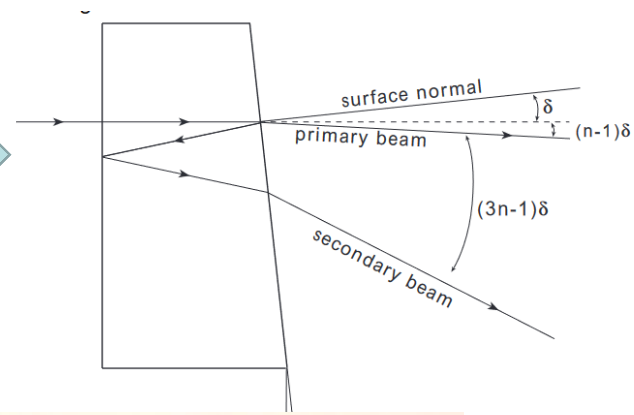
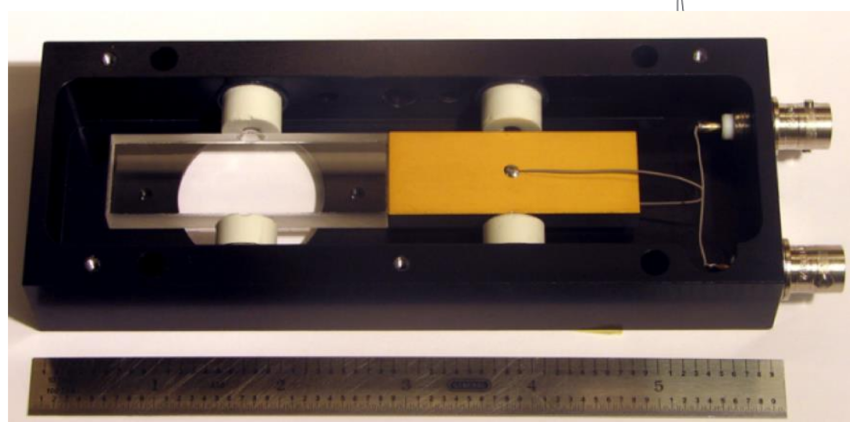


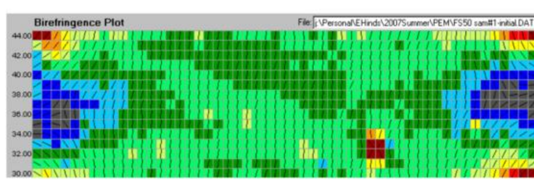
Figure 2: Interference in a PEM Optical Element

PEM wedge shape (Hinds Instr)





- Static birefringence
  - Extracted from signal analysis



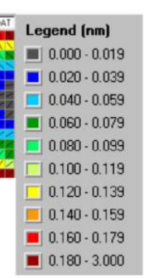


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Fig.2. The birefringence map of a bare optical element made of fused silica, showing residual linear birefringence typically below 0.1 nm.

Summary

- QWP+polarizer, robust ellipsometer
  - From SLD/Jlab/HERA experiences ~10^{-3} precision on laser beam polarization ‘easily’ attainable
  - Pushing to 10^{-5} may require further ‘R&D’
  - Tedious alignment & calibration procedures (hard to automate)
- Use of PEM instead of the QWP
  - A priori:
    - Automate calibration should be possible
    - R&D needed to set precision limits
      - Already started at Orsay (A. Martens)