Precise measurement of the longitudinal polarisation at HERA with a Fabry-Perot cavity polarimeter

Marie Jacquet

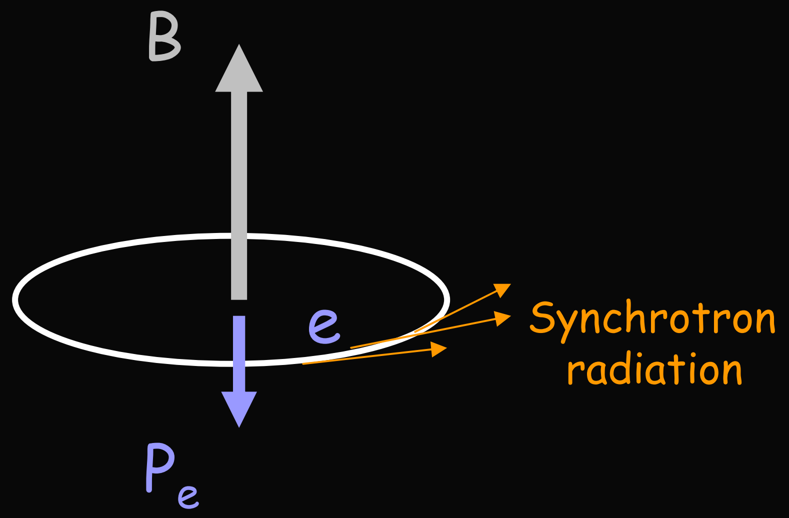
LAL, Orsay

(Work conducted by the H1/LAL Orsay group, in collaboration with DESY)

20/10/2010, IWLC2010, Cern

Electron beam polarisation in a circular collider

Sokolov Ternov effect



An electron turning in a magnetic field :

→ Photon radiation

→ with a Spin-flip probability :

$$P_{\uparrow\downarrow} \neq P_{\downarrow\uparrow}$$

Electrons are polarised naturally transversally

Principle of the polarisation measurement at HERA:

Compton diffusion :

S_γ : degree of circular polarisation of the laser beam

- Non destructive measurement
- Pol measurement can be done simultaneously with exp. data taking

$$\sigma(E_\gamma, \varphi_\gamma) \sim \sigma_0 - P_L S_\gamma \sigma_L - P_T S_\gamma \cos\varphi_\gamma \sigma_T$$

(σ_0, σ_L, σ_T : known QED)

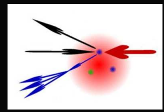
Mean position of the diffused photons for $S_\gamma = \pm 1$

→ P_T (transverse)

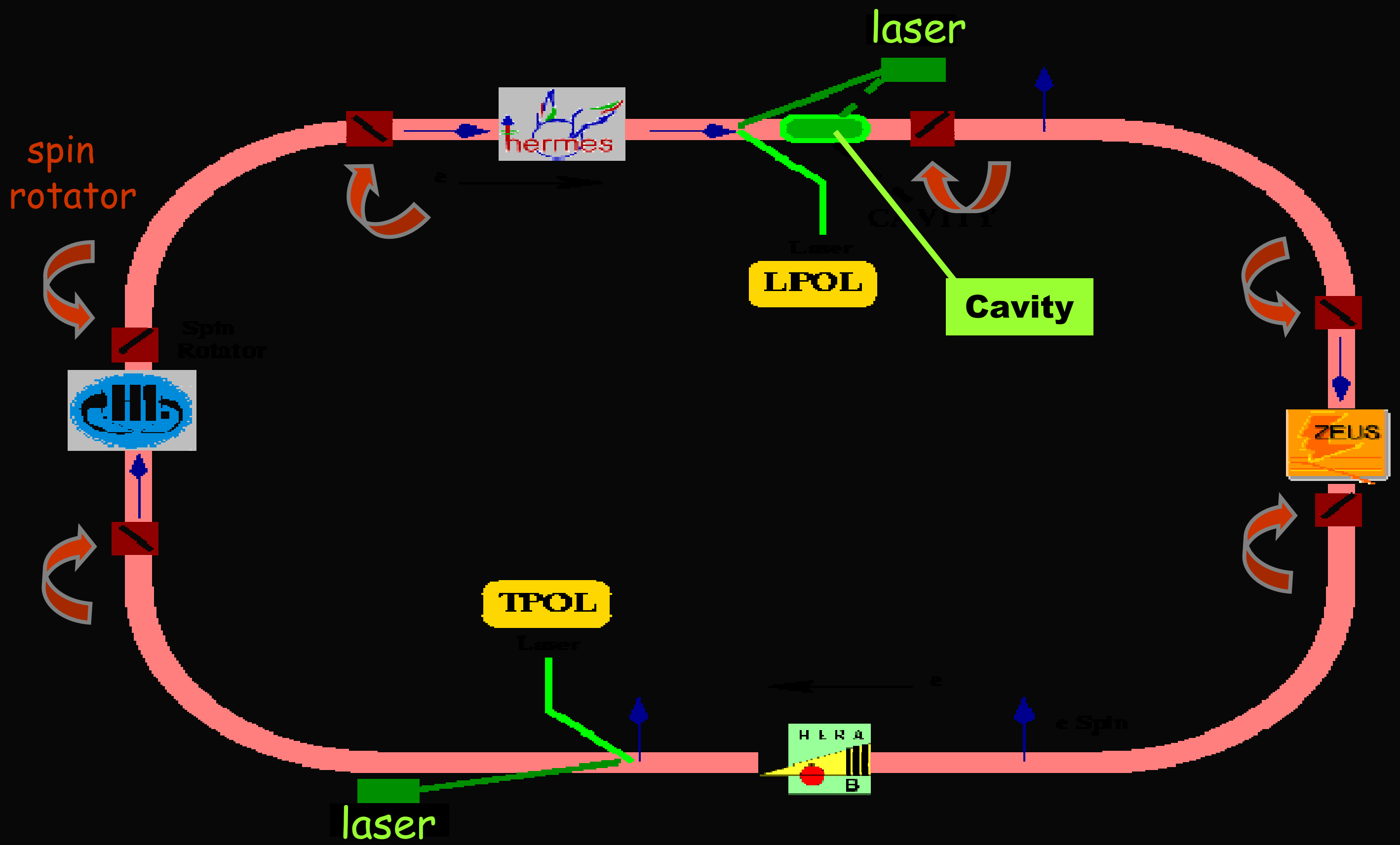
Energy spectrum of the diffused photons for $S_\gamma = \pm 1$

→ P_L (longitudinal)

HERA

- e± (27.6 GeV)  p (920 GeV)
- 220 bunches spaced by 96 ns

- e± longitudinally polarised around H1, ZEUS, HERMES



- Since 1995 : LPOL and TPOL

- 2003 : beginning of the Cavity project

	LPOL	TPOL
Laser	10 W pulsed (100 mJ/pulse, 100 Hz)	10 W CW laser
$e-\gamma$ crossing	100 Hz	10 MHz
n_γ	$\sim$1000 γ/pulse	$\sim$0.001 γ/bunch
ΔP_e(stat)	3%/bunch/20min	1%–4%/allbunches/min

- LPOL : multi-photon mode, 10 W pulsed laser 100 Hz
  (i.e. $n_\gamma \sim 1000$)
- TPOL : single photon mode, 10 W CW laser
  (i.e. $n_\gamma \ll 1$)

Low statistic per bunch

- At HERA, to have :

  $(dP/P)_{stat} < 1\%$ / bunch / min

  one need $n_{\gamma / bunch} \sim 1$

  → $P_{laser} \sim$ a few kW , CW

	LPOL	TPOL
Laser	10 W pulsed (100 mJ/pulse, 100 Hz)	10 W CW laser
$e-\gamma$ crossing	100 Hz	10 MHz
n_γ	$\sim$1000 γ/pulse	$\sim$0.001 γ/bunch
ΔP_e(stat)	3%/bunch/20min	1%–4%/allbunches/min

- LPOL : multi-photon mode, 10 W pulsed laser 100 Hz
  (i.e. $n_\gamma \sim 1000$)
- TPOL : single photon mode, 10 W CW laser
  (i.e. $n_\gamma \ll 1$)

→ Low statistic per bunch

- At HERA, to have :
  $(dP/P)_{stat} < 1\%$ / bunch / min
  one need $n_{\gamma/\text{bunch}} \sim 1$
  → $P_{laser} \sim$ a few kW , CW

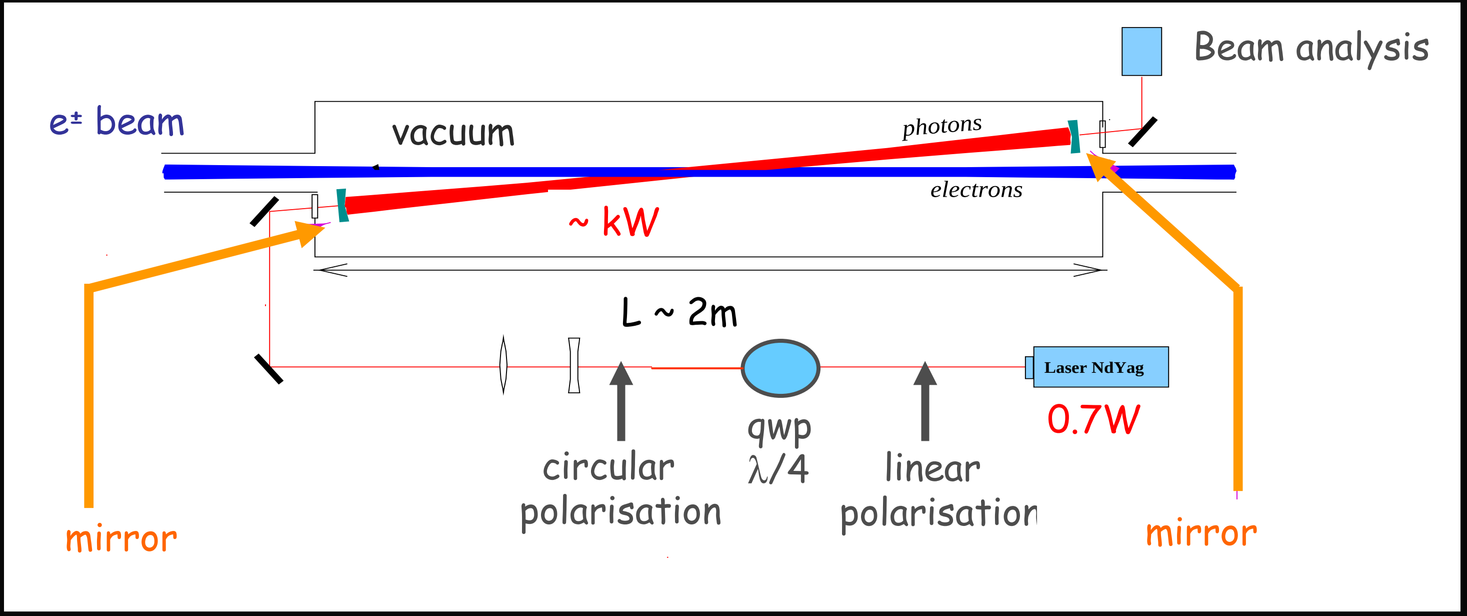
Technical solution to obtain $n_\gamma \sim 1$

→ Optical amplifier

→ Fabry-Perot Cavity

Marie Jacquet, 20/10/2010, IWLC2010,Cern

Fabry-Perot cavity : principle



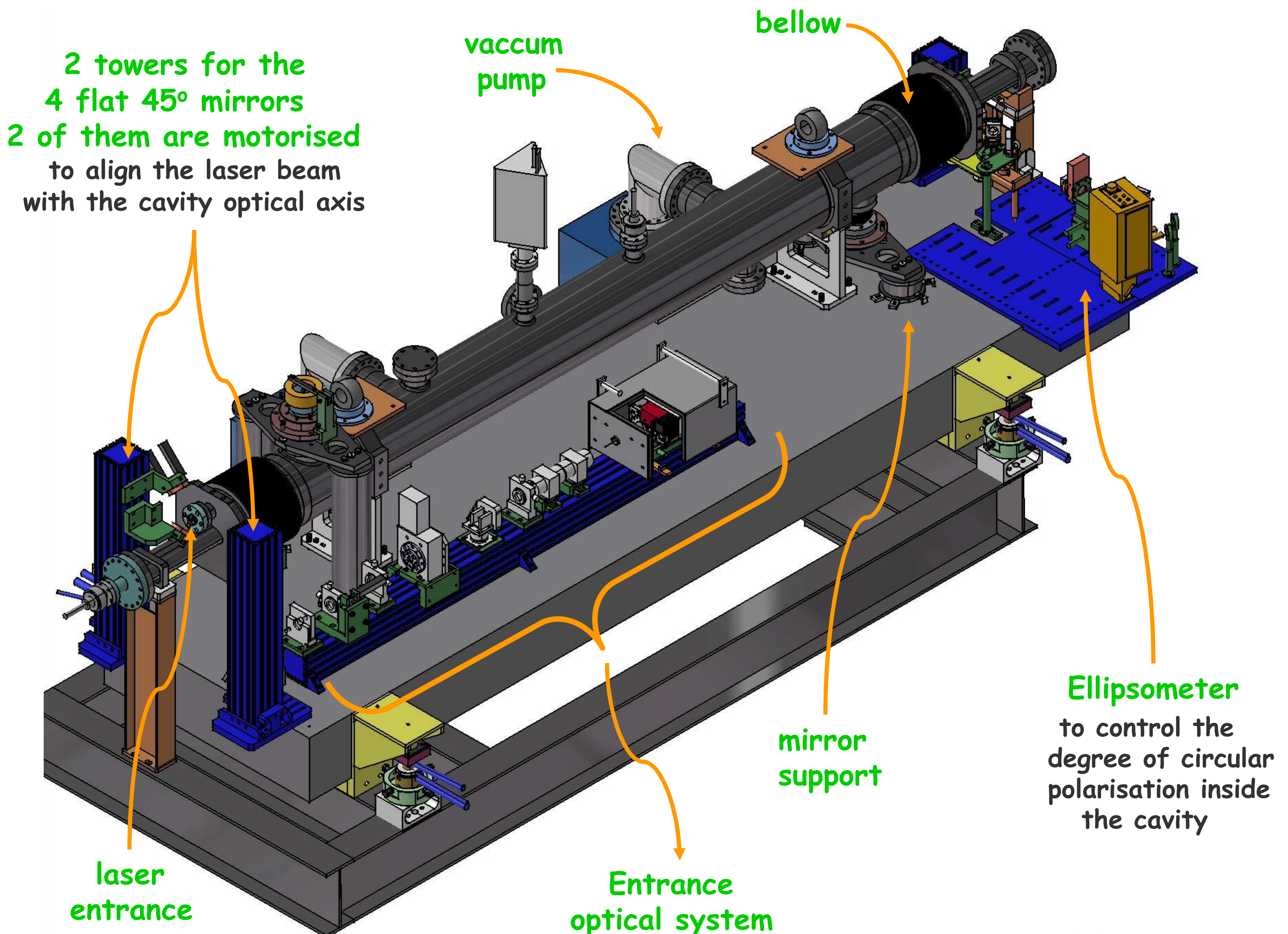
Fabry-Perot Cavity

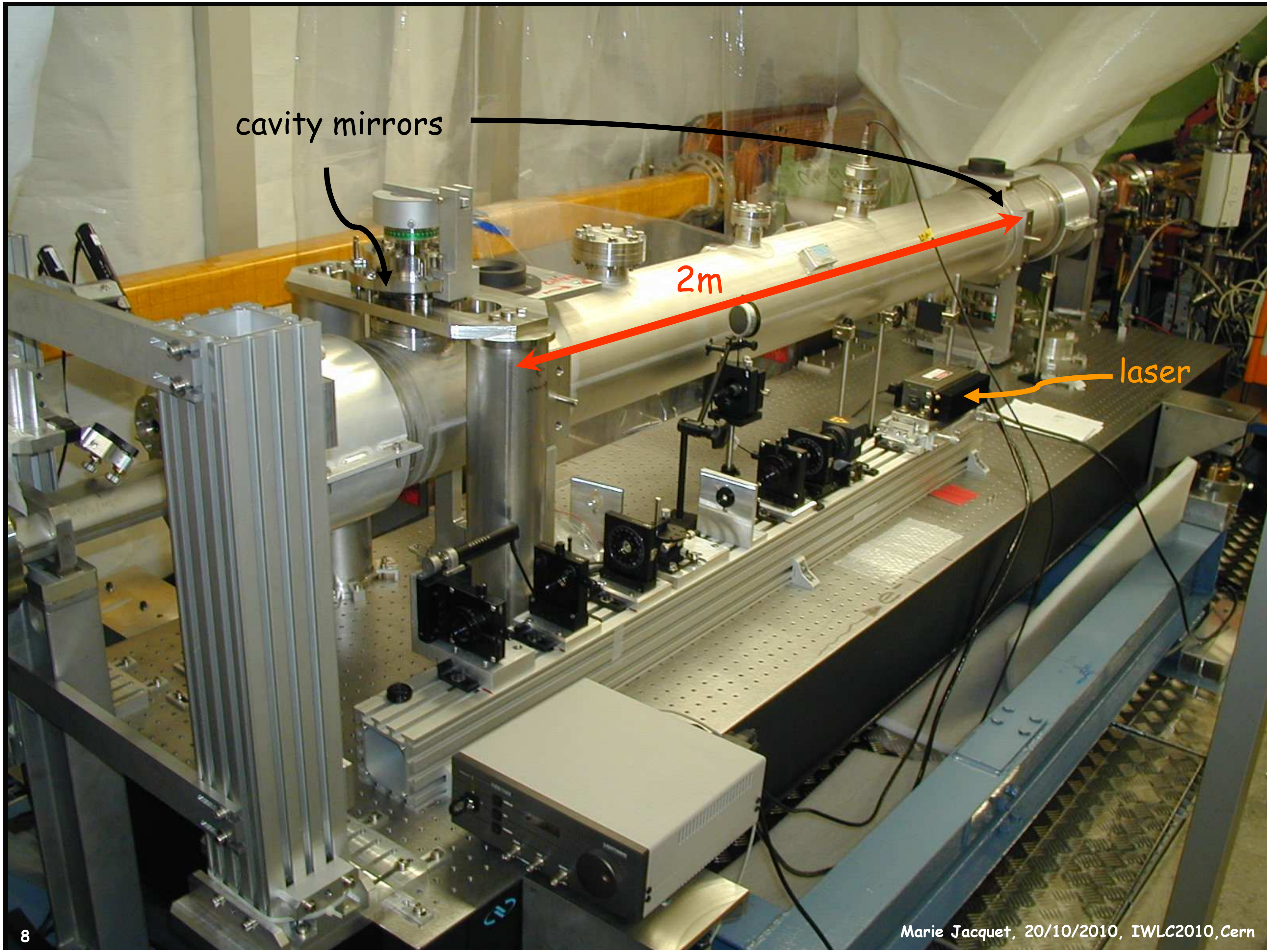
- cavity lenght L=2m
- 2 spherical mirrors fix
  one to respect to the other
- e-γ angle = 3.3°

Laser

- Infrared Nd:YAG (λ = 1064 nm)
- Frequency adjustable
- P = 0.7 W

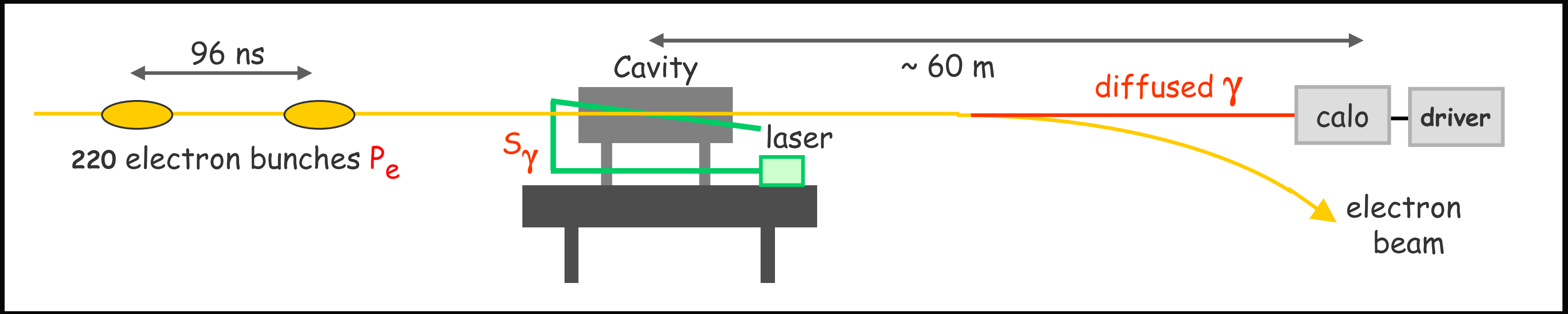
Feedback system to put and keep $\nu_{laser} = \nu_{cavity}$


2 towers for the
4 flat 45° mirrors
2 of them are motorised
to align the laser beam
with the cavity optical axis
vaccum
pump
bellow
laser
entrance
Entrance
optical system
mirror
support
Ellipsometer
to control the
degree of circular
polarisation inside
the cavity


cavity mirrors
2m
laser


Synchrotron isolation (3 mm lead)
Thermal isolation (aluminium)
ZEUS
HERMES
R 60 QL

System overview

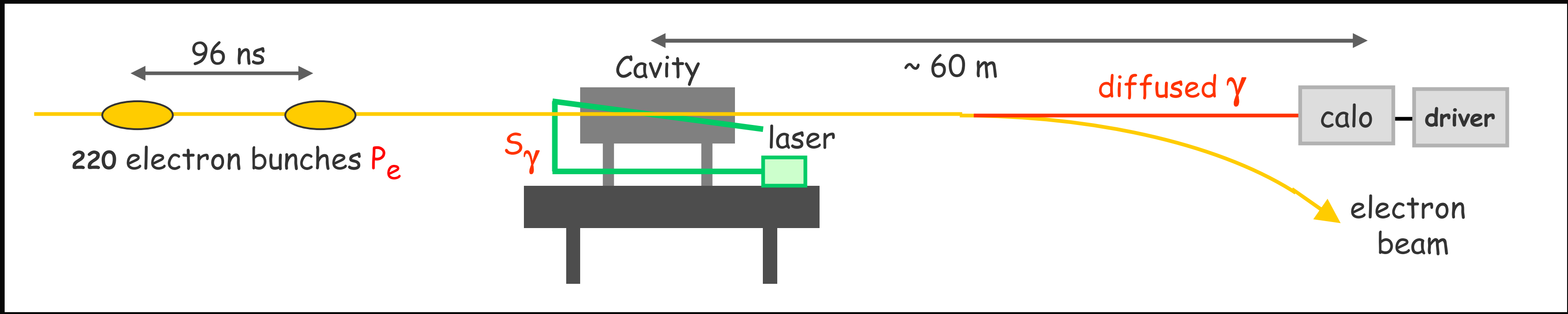


- ACQ : 400.000 acq / bunch

  ➘ 220 histograms every 10 sec

- Turn the laser ellipticity every 10 sec

System overview

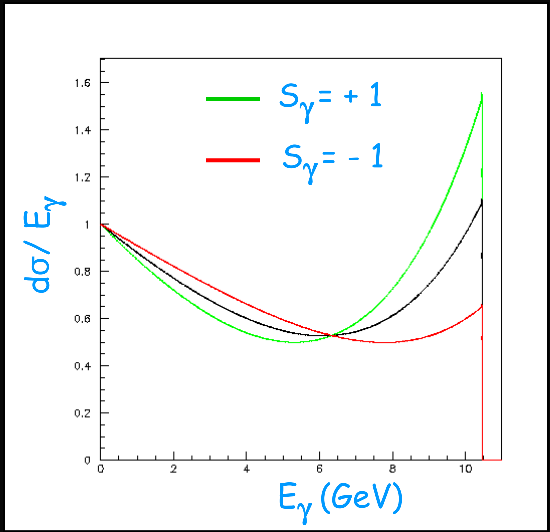


- ACQ : 400.000 acq / bunch
  ↘ 220 histograms every 10 sec
- Turn the laser ellipticity every 10 sec

laser docp

lepton beam polarisation

$$d\sigma/dE_\gamma \sim (d\sigma_0 / dE_\gamma) - (d\sigma_L / dE_\gamma)\, P_e\, S_\gamma$$



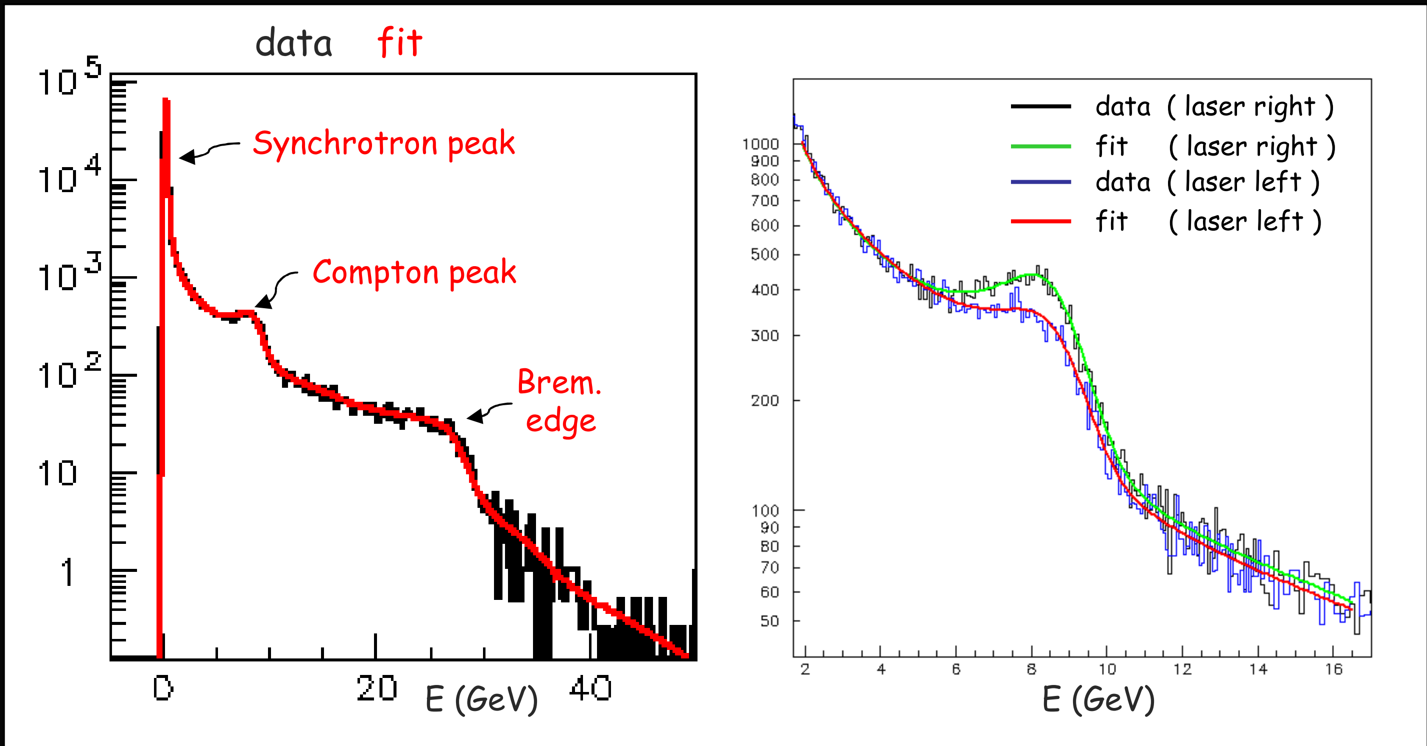
- Compton
- Bremsstrahlung (e- + residual gaz)
- Black body (beam pipe at 310 K)
- Synchrotron radiation

Electron polarisation extraction

Theoretical spectral distributions of Compton and backgrounds

Shape of the experimental spectra for $S_\gamma = \pm 1$

For each doublet of histos (laser $S_\gamma = \pm 1$), fit for each of the 220 bunches



Nb of Compton

Nb of bkgs

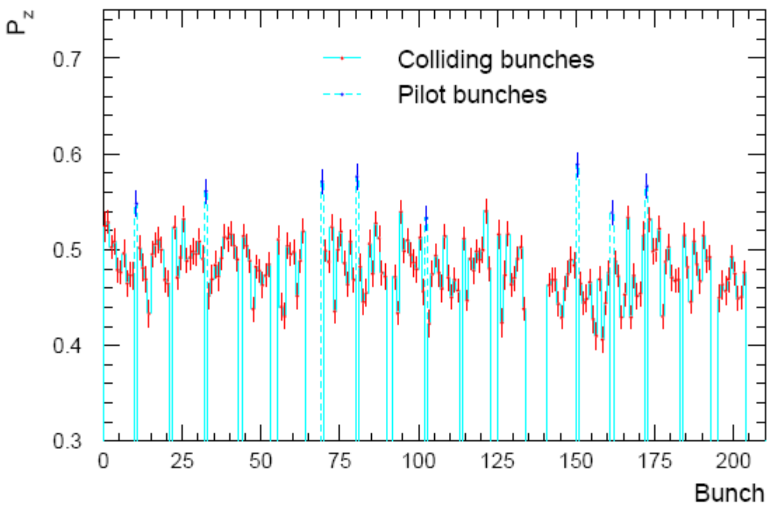
pola e^-

+ Regular determination of the calo characteristics (résolution + gain)

(e beam mvts)

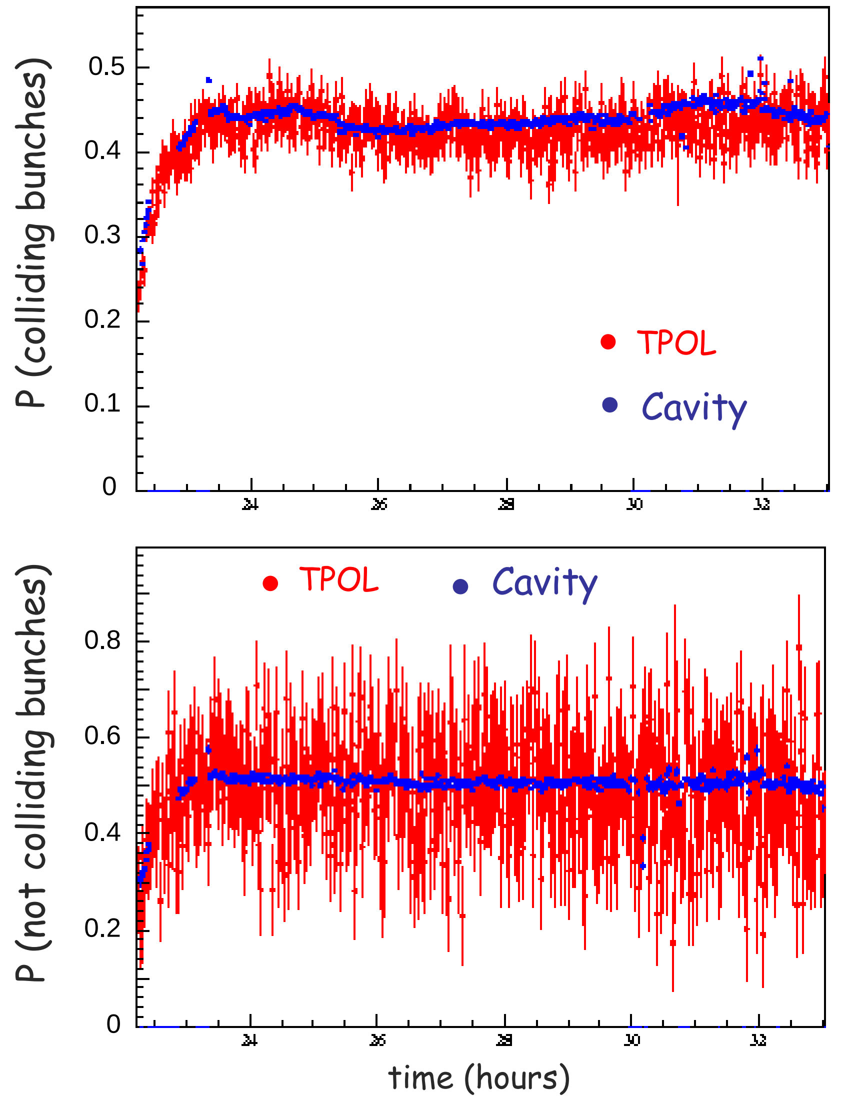
each point ⟷ 1 minute

(measurement every 20 sec + mean on 6 doublets)



2 % / min / bunch

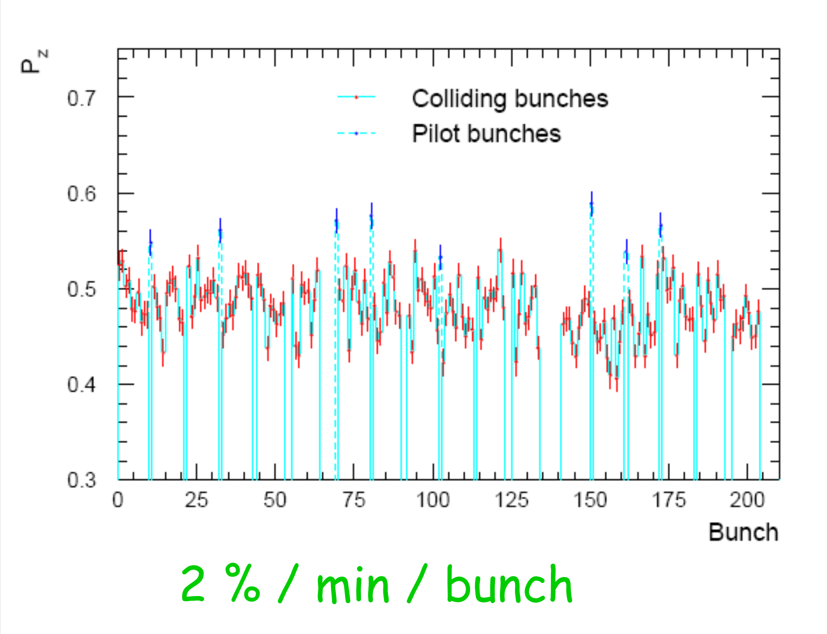
Statistical precision



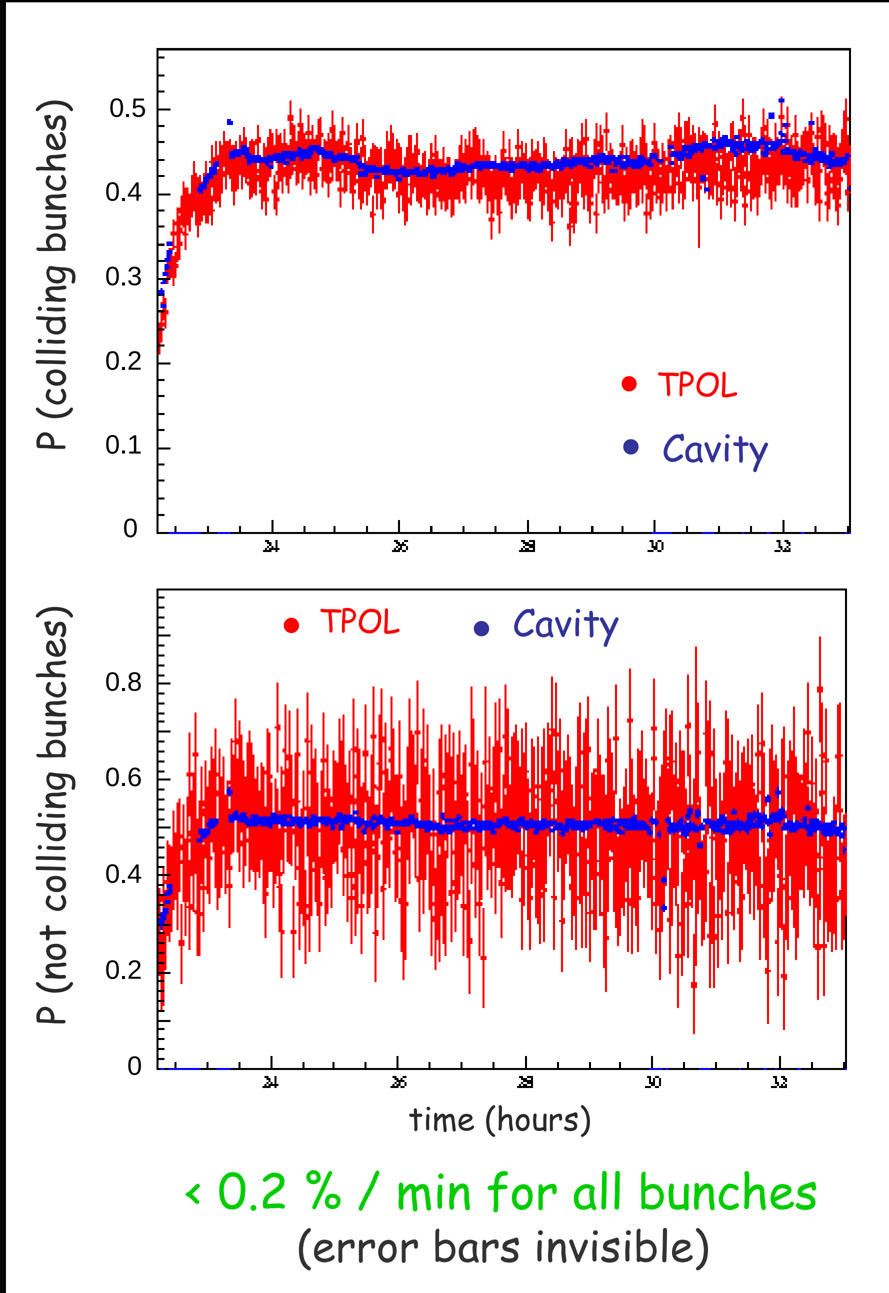
< 0.2 % / min for all bunches
(error bars invisible)

each point ⟷ 1 minute

(measurement every 20 sec + mean on 6 doublets)



Statistical precision



All cavity polarimeter data taking

~ 500 hours

(Oct. 2006 to June 2007)

Systematics

Systematics determined from the full cavity data set + Dedicated data taking periods with non standard setups

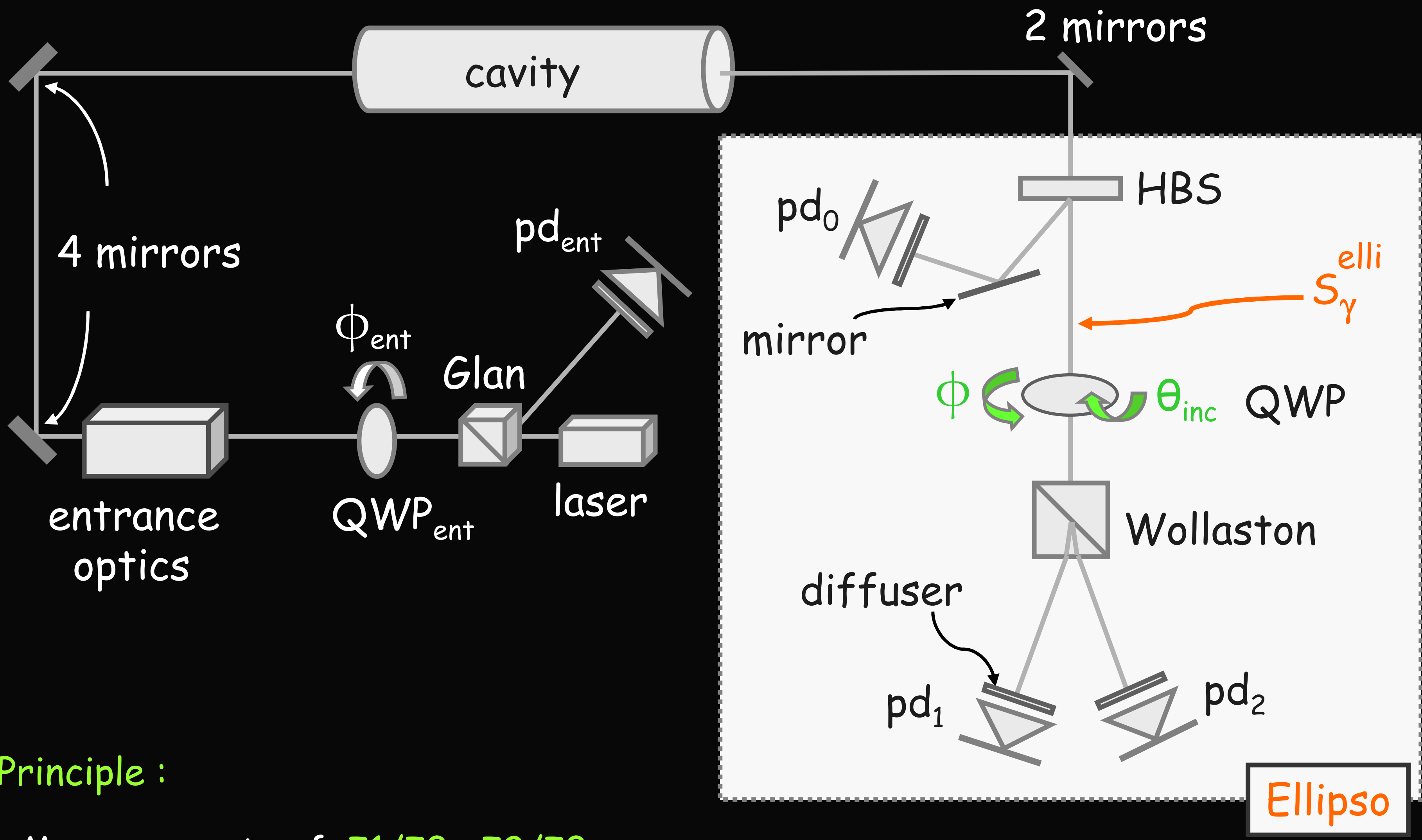
- Calorimeter resolution and ADC to energy conversion
- Black body temperature
- Calorimeter position
- Synchrotron peak position → ~ 1 %
- Electronic sampling substraction
- …

Knowledge of S_γ (directly involved in σ Compton) $\sigma = \sigma_0 - P_e S_\gamma \sigma_L$

→ ΔS_γ transmitted unchanged to P_e

Not determinable from data themselves

Determination of S_γ



Principle :

Measurements of I1/I0 , I2/I0
for different ϕ , θ_{inc} → S_γ^{elli} à qq ‰

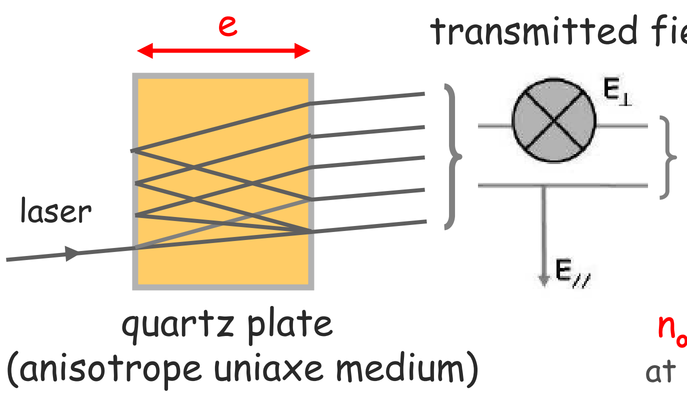
Need a precise control of the ellipsometer optical elements

Need a precise control of the ellipsometer optical elements

- Performance Wollaston (extinction around 10^{-5})
- Diode response (σ /mean < 1 ‰)

Need a precise control of the ellipsometer optical elements

- Performance Wollaston (extinction around 10^{-5})
- Diode response (σ /mean < 1 ‰)
- QWP



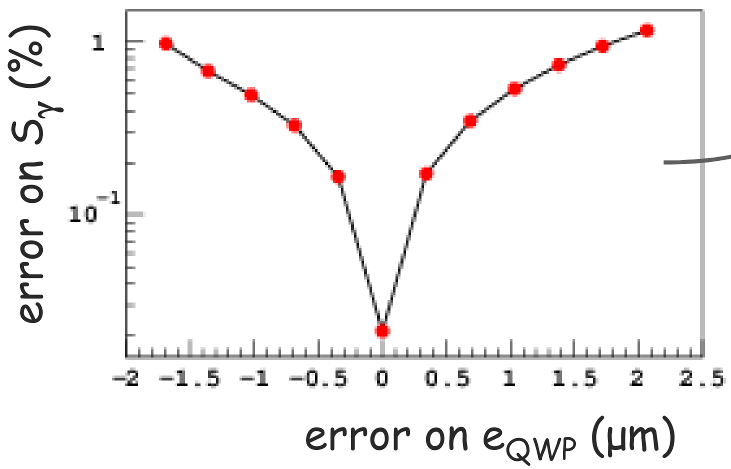
$\Delta\varphi = \Delta n \frac{2\pi}{\lambda} e$

n_o et n_e known at 10^{-5} precision

manufacturer value

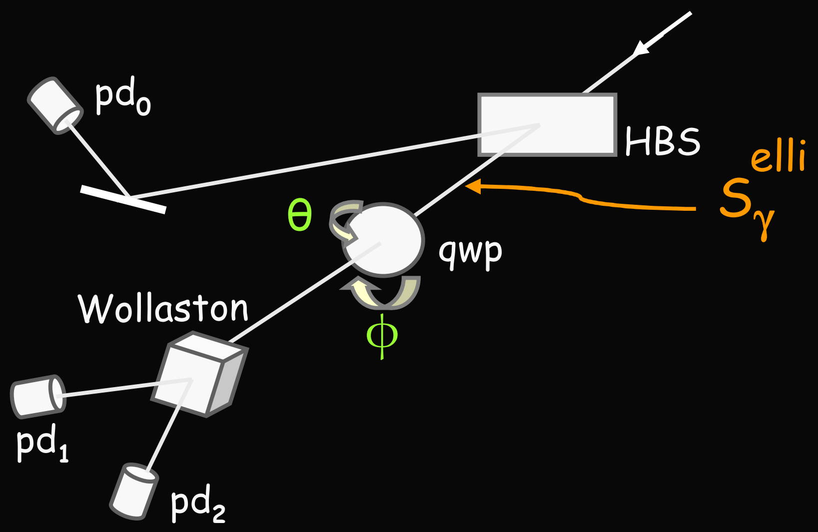
91 µm ± few µm

Induces a few per mill error on S_γ



Necessity to determine the thickness e at the per mill level

Ellipsometer calibration, how ?



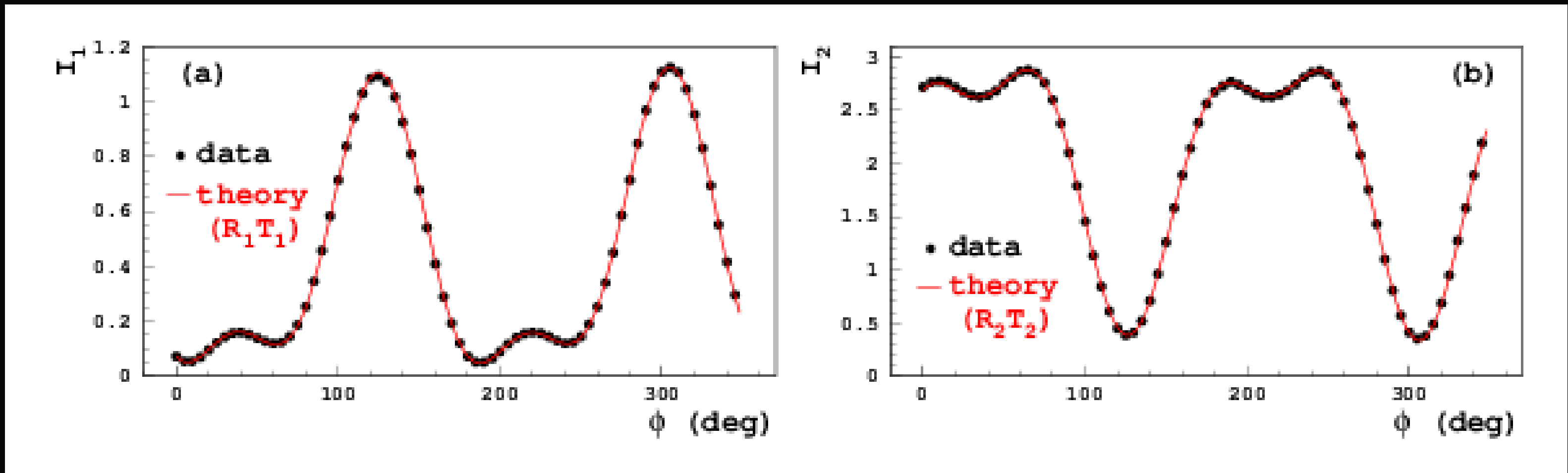
measurements of I1/I0 , I2/I0
for different ϕ , θ_{inc} , incident pola

Fit with a model :

- multiple internal reflexions
- all possible misalignement parameters

e
Δn
S_γ^{elli}
misal

Fit example : I1/I0 and I2/I0 vs ϕ

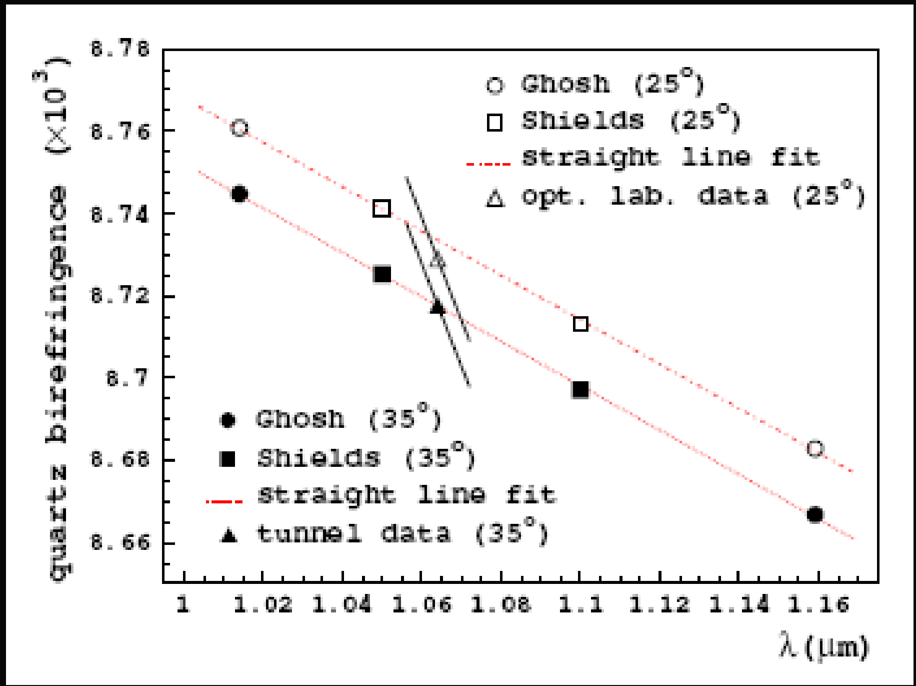


Two independant calibrations :

- at Orsay in laboratory (25°)
- at HERA in the tunnel (35°)

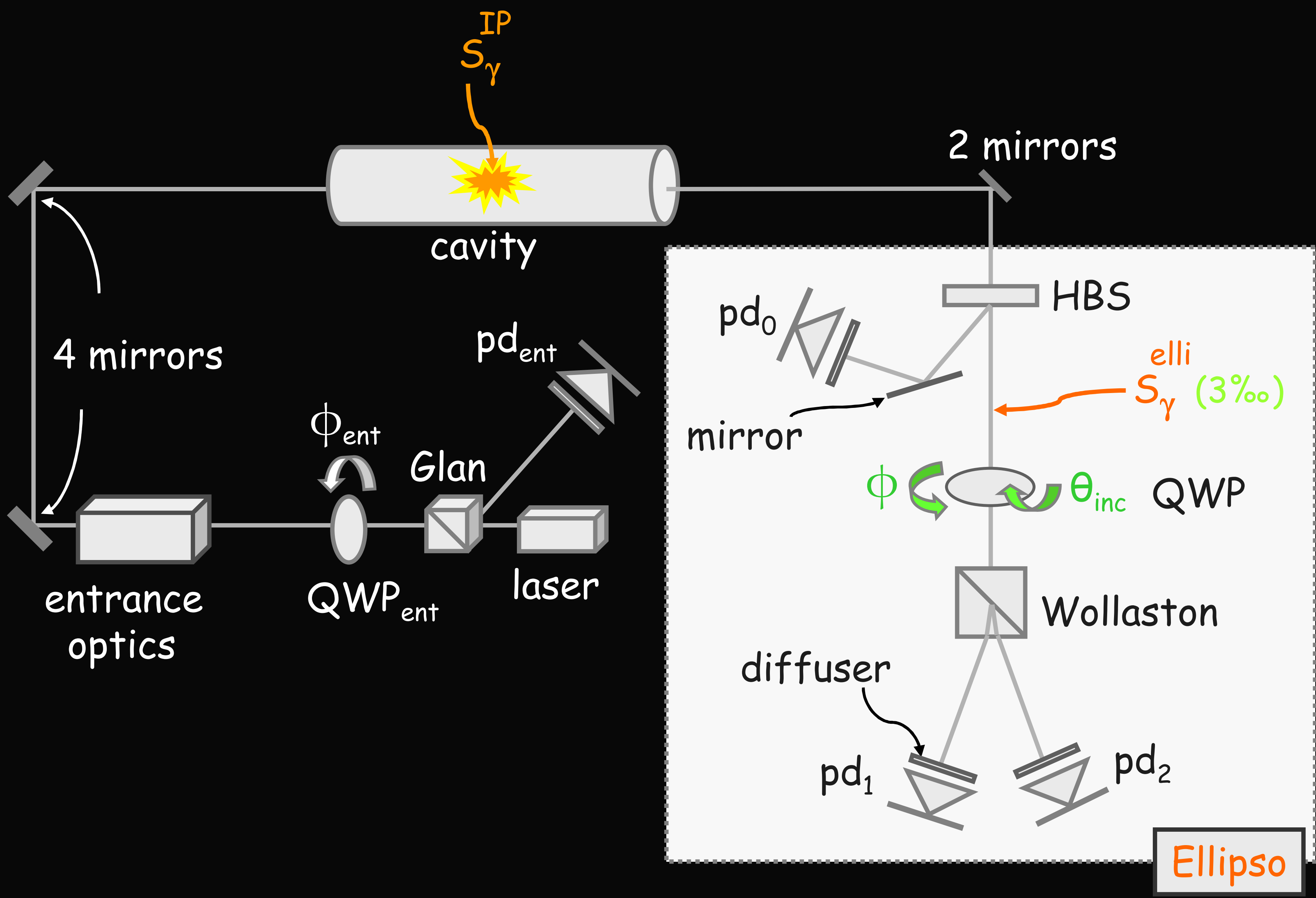
ΔS_γ^{elli} < 3‰ at the ellipsometer entrance

Cross check

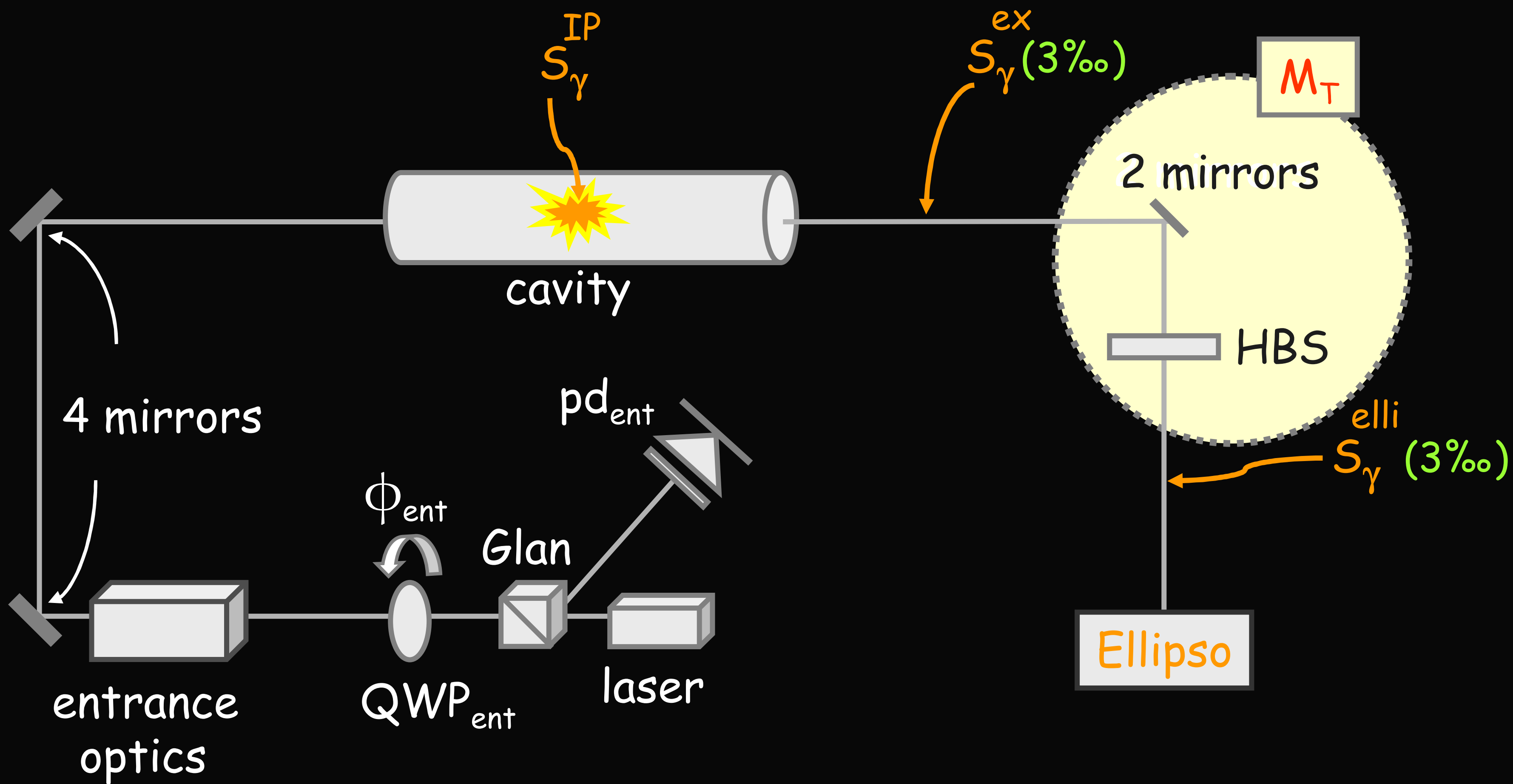


Quartz birefringence, compared with values published previously (1956 et 1999)

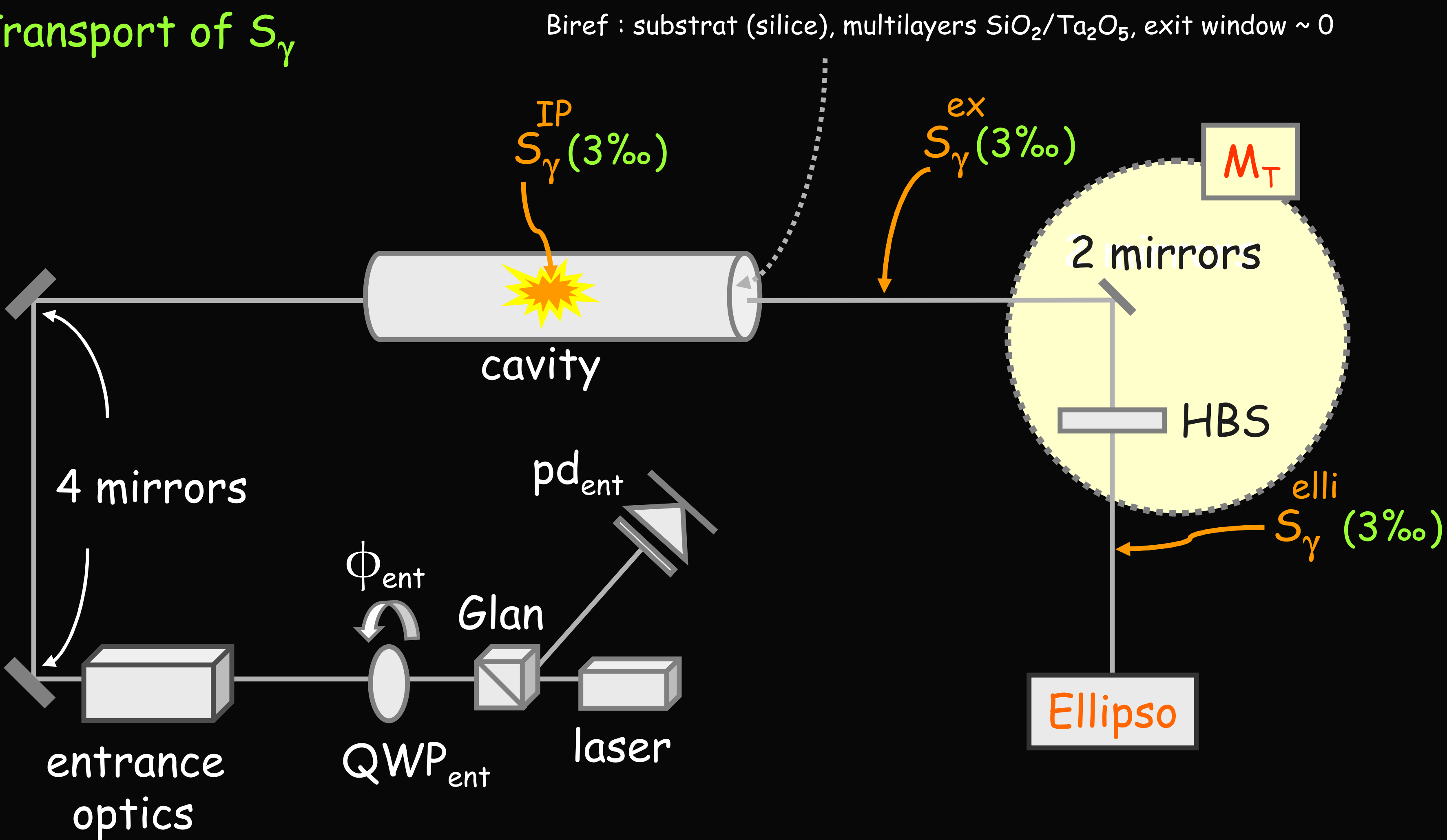
Transport of S_γ



Transport of S_γ

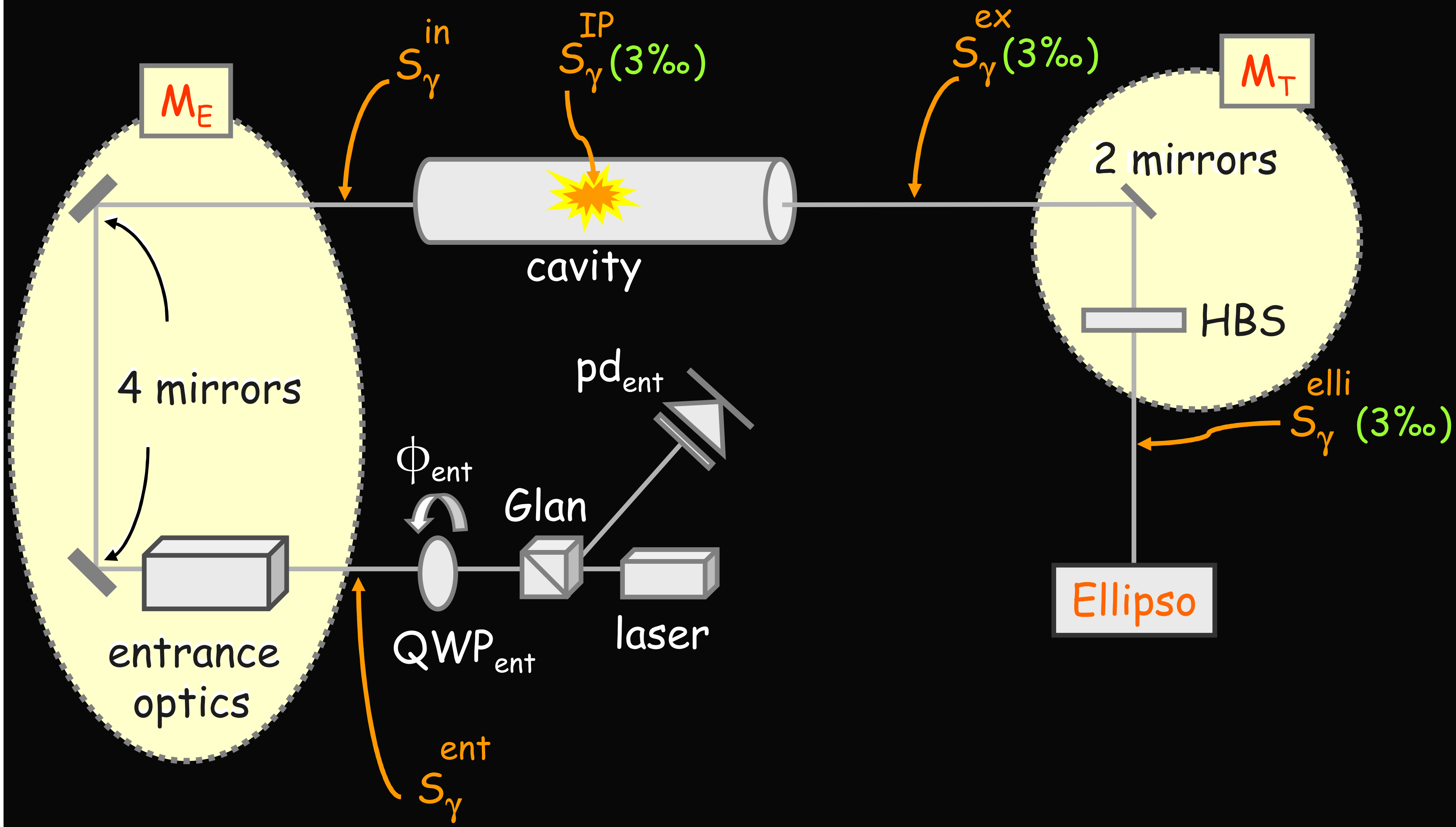


Transport of S_γ



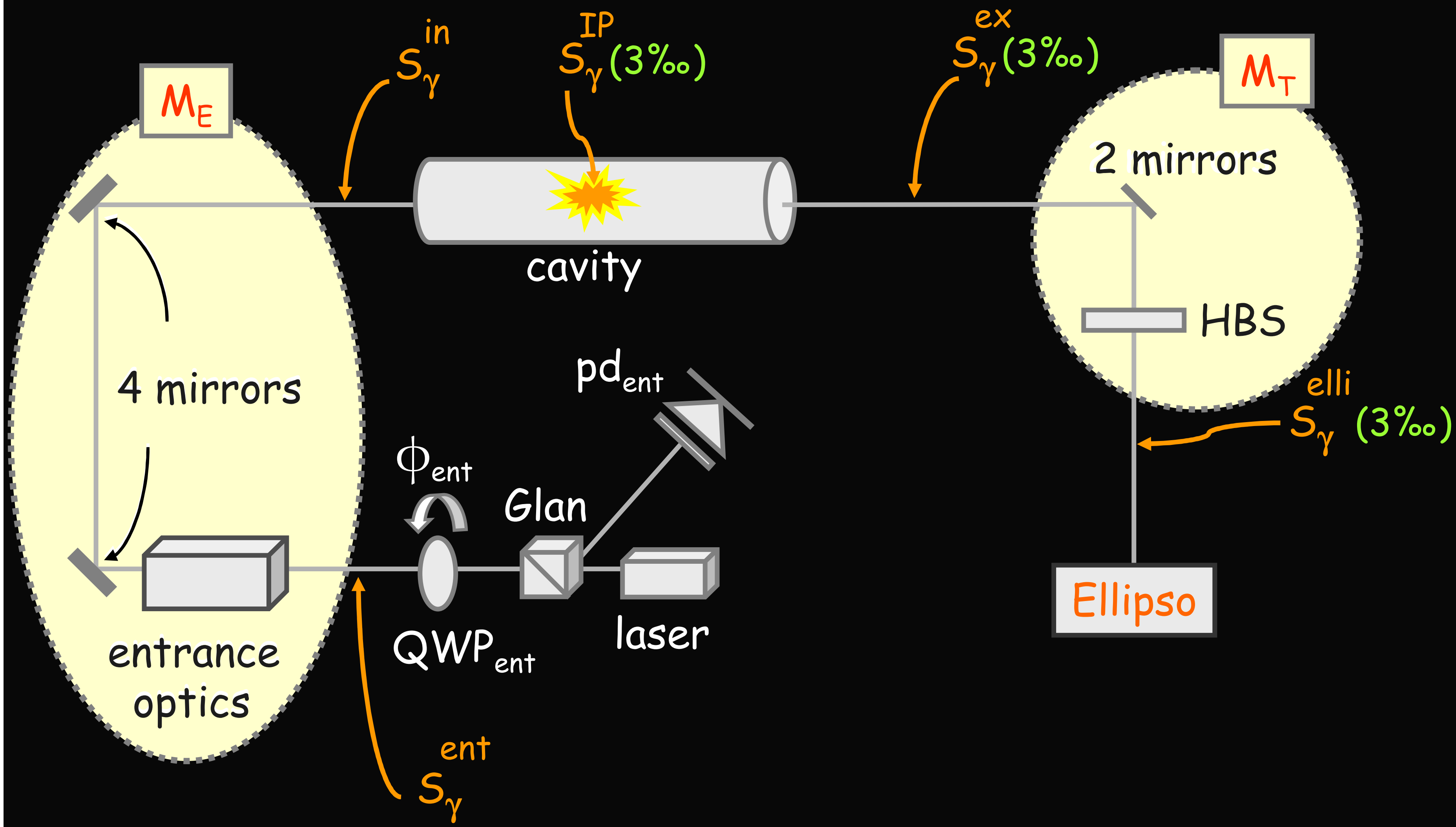
- S_γ at the center of the cavity determined at 3‰

Transport of S_γ



- S_γ at the center of the cavity determined at 3‰

Transport of S_γ



- S_γ at the center of the cavity determined at 3‰
- coherence in all the optical system : ΔS_γ ~ 5 ‰

Conclusions & Outlook

Fabry-Perot Cavity polarimeter :

... higher STATISTICAL precision

- By increasing the power of the continuous wave laser at a few kW
- By increasing the frequency of the e⁻/laser interaction at 10MHz (every electron bunch)

→ $n_{\gamma} \sim 1$ per bunch crossing

Statistical precision : 2% per bunch per min

Improvment over the other two HERA polarimeters limited by

- either lower laser intensity (TPOL)
- or smaller e/photon interaction rate (LPOL)

... and smaller SYSTEMATIC error

Syst. uncertainty : ~ 1%

(a factor 2-3 smaller than the precision quoted currently by other polarimeter at HERA)

Reach such a small systematic uncertainty was possible

1. Thanks to the few photon mode → The photon energy spectra can be described by convoluting signal and background QED processes with detector effects

(impossible for LPOL with n_γ >> 1)

2. Thanks to the a complete model description of the ellipsometer optical system and of the transport of S_γ between the ellipso and the IP → S_γ controlled at 3‰ at the e/γ IP

These precise polarisation measurements → Good prospect for applications in a future linear collider

At ILC : ΔP_e syst. ~ 2 ‰ necessary for physics program achievment

These precise polarisation measurements → Good prospect for applications in a future linear collider

At ILC : ΔP_e syst. ~ 2 ‰ necessary for physic program achievment

... tracks for decreasing the systematic error

- a larger ADC resolution (LPOL cavity 0.4%)
- a better calorimeter uniformity (LPOL cavity 0.6%)
- reduce the choice for calorimeter description (LPOL cavity 0.4%)
- still improve the control of S_γ (LPOL cavity 0.3%)

References

LAL 09-210 (2009)

JINST 5 P06005 (2010)

JINST 5 P06006 (2010)

... thank you