The Compton backscattering Polarimeter of the A4 Experiment

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Polarimeter Group: J. Diefenbach, Y. Imai, J. Lee, M. Sikora, S. Taylor

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Satellite Workshop of SPIN2004
Institut für Kernphysik, Universität Mainz

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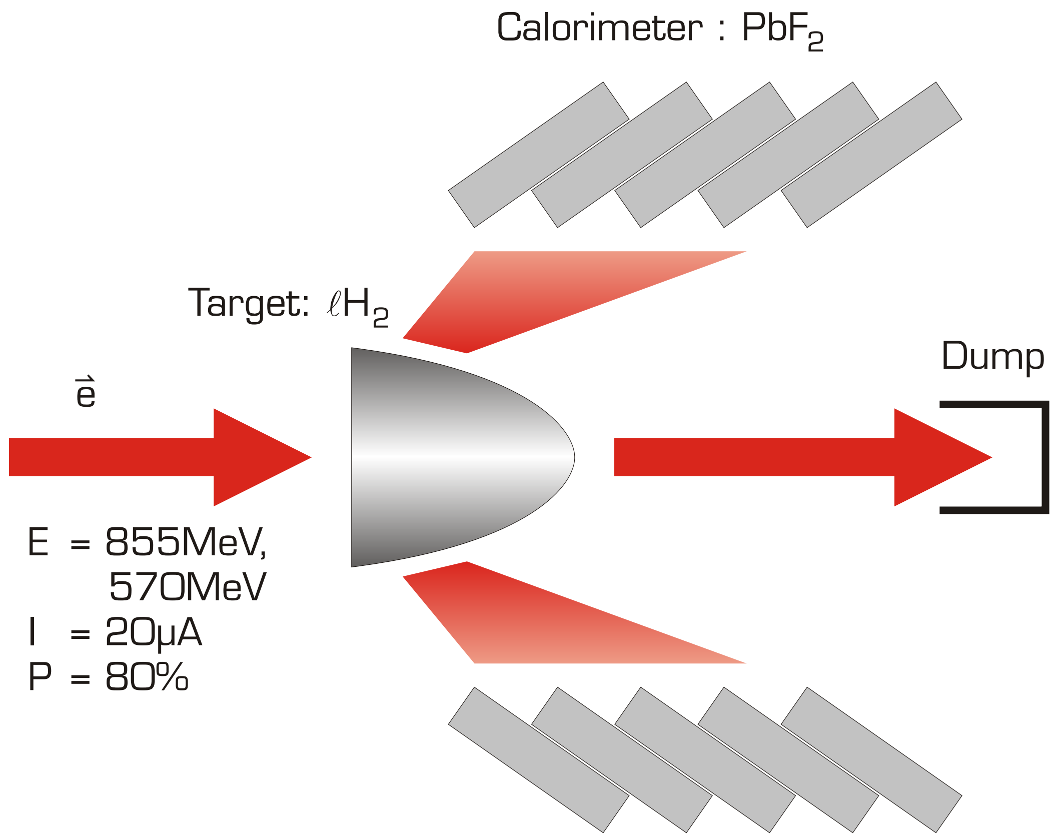
1. Introduction
2. Compton Polarimetry
3. The A4 Compton Polarimeter
4. Status and Results
5. Summary and Outlook

1. The A4 Experiment

Objective:
Determine the strange quark contribution to the nucleon properties.

Method:
Measure the parity-violating cross-section asymmetry in the elastic electron-nucleon-scattering with polarized beams
(cf. talk by F. Maas)



Measured quantity:

$$A_{exp} = P_e A_{phys}$$

exp. asymmetry — physics asymmetry

beam polarization

→ **absolute polarization measurement needed**

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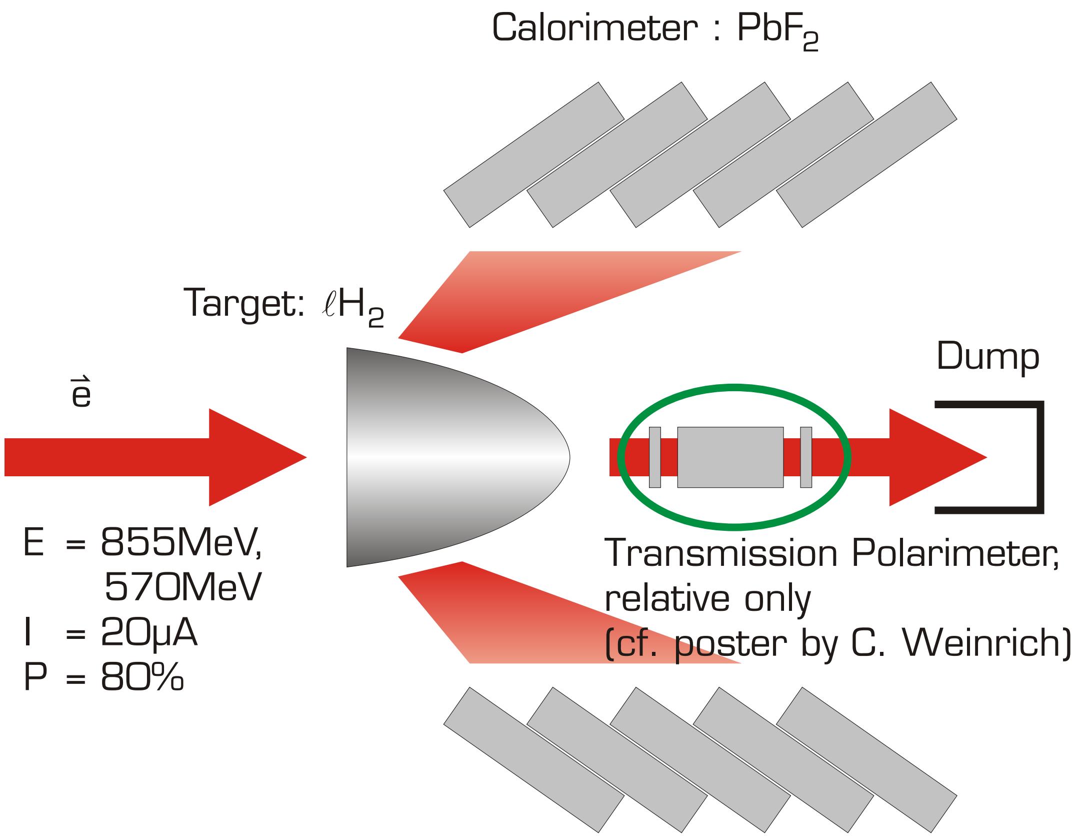
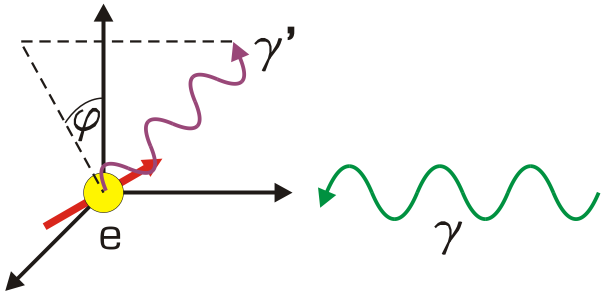
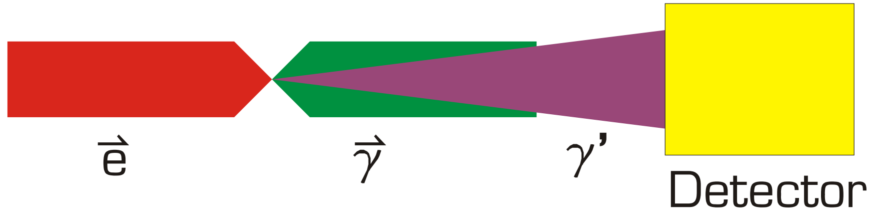


→ **absolute polarization measurement needed**
Method: Compton backscattering polarimetry

2. Compton Polarimetry

Scattering of Photons on Leptons





Lipps, Tolhoek Physica XX(1954)

Compton cross-section:

$$\frac{d}{d} \quad \frac{d_{\ \ 0}}{d} \quad Q\frac{d_{\ \ 1}}{d} \quad V P^{e}_{long}\frac{d_{\ \ long}}{d} \quad V P^{e}_{trans}\cos\ \frac{d_{\ \ trans}}{d}$$

Q,V : Stokes parameters

Q linear polarization

V circular polarization

→ cross-section asymmetry for circular light (Q=0, V=+/-1)

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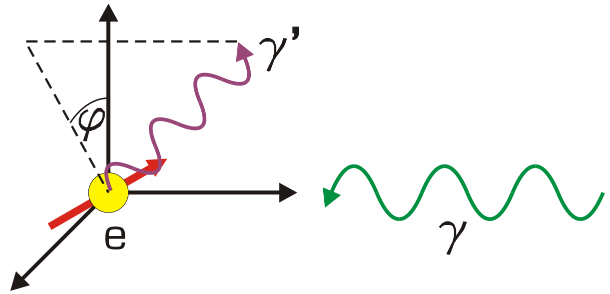

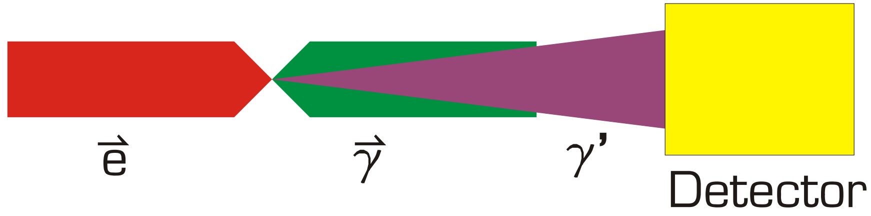

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→ cross-section asymmetry for circular light (Q=0, V=+/-1)

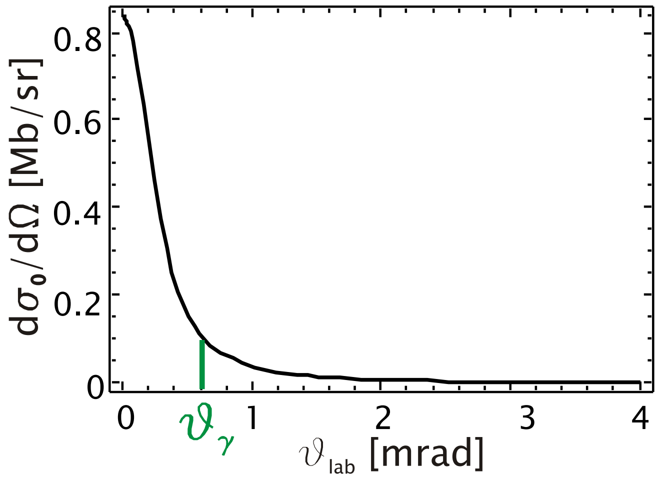
Asymmetry for φ-averaging detector (longitudinal polarization):

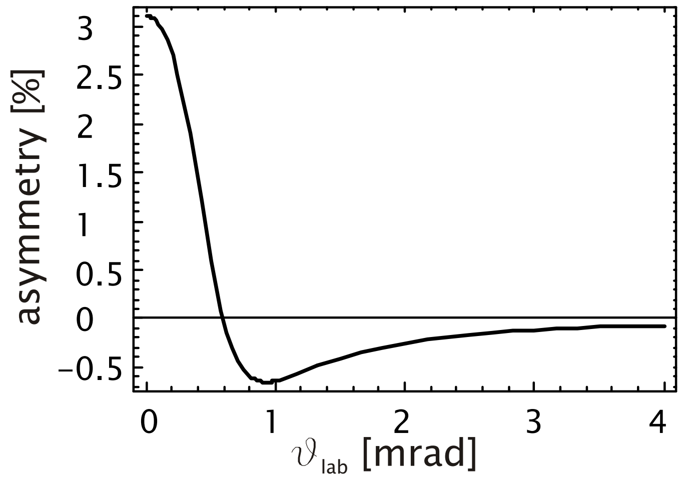
$$A \quad \frac{\frac{d}{d}_{right} \quad \frac{d}{d}_{left}}{\frac{d}{d}_{right} \quad \frac{d}{d}_{left}} \quad |V| P^{e}_{long}\frac{d_{long}/d}{d_{0}/d}$$

→ Asymmetry proportional to beam polarization

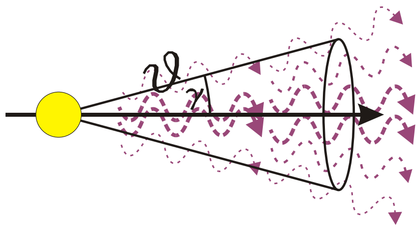
Measuring time

Angular dependence of cross-section and asymmetry:





➡ **backscattered photons concentrated to small cone**



$E = 854.3$ MeV

$\gamma = 1671.8$

$k_{in} = 2.41$ eV

$\vartheta_\gamma = 0.6$ mrad

$k_{fmax} = 26.2$ MeV

➡ **calorimetric detectors will be φ-averaging**

Measuring time

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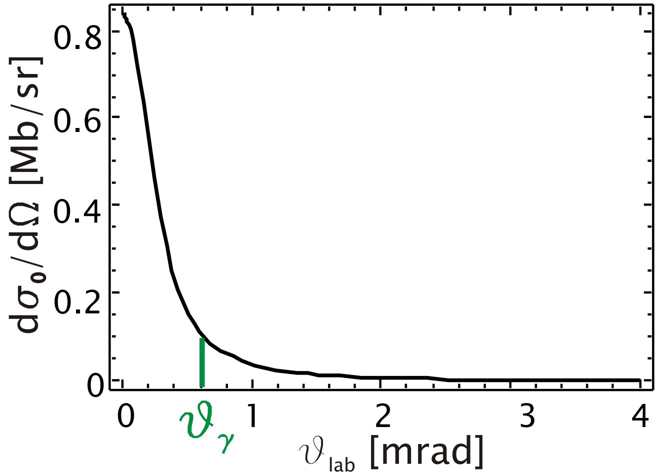

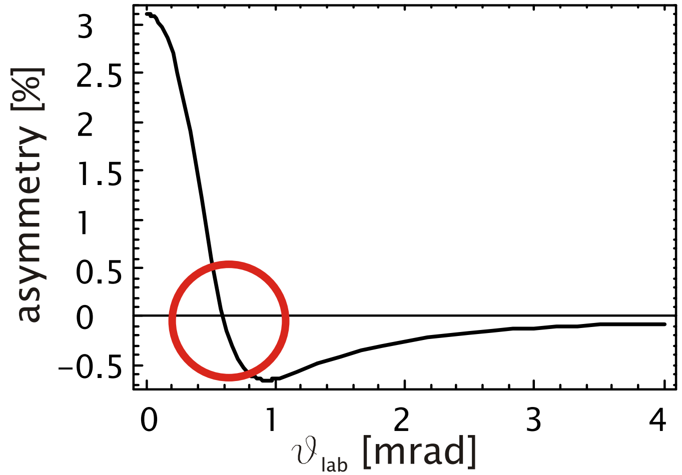

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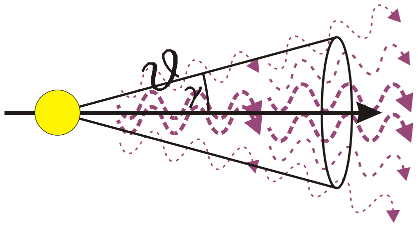

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Measuring time:

counting rate asymmetry

$$t \quad \frac{1}{L\,\langle A\rangle^2}$$

energy spectrum asymmetry

$$t \quad \frac{1}{L\,\langle A^2\rangle}$$

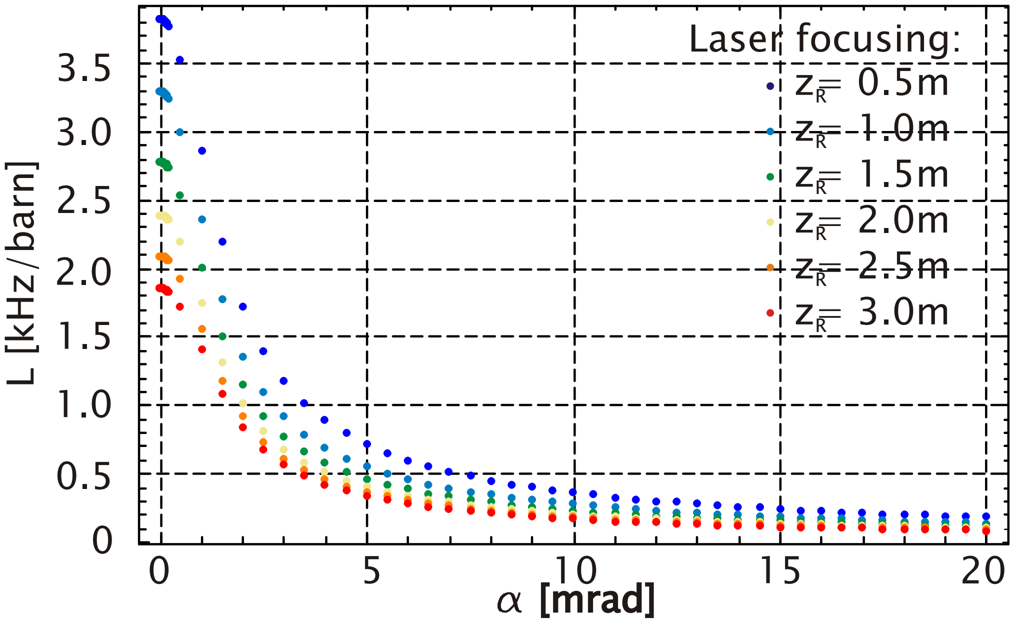
Chen, Bardin, Cavata et al.
"Conceptual Design Report..."

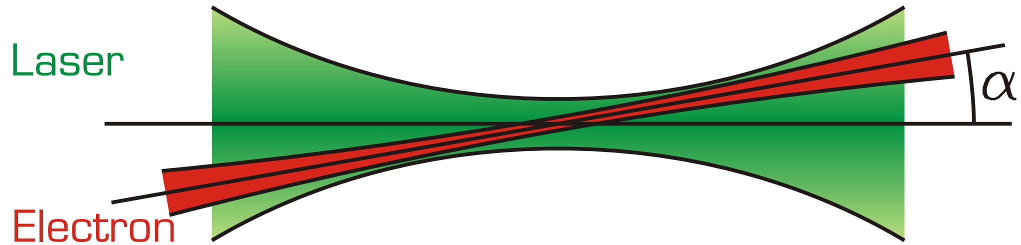
Luminosity

Luminosity requirements (assumption: green light, 514.5 nm, 80% electron polarization)

ΔP/P [%]	t [min]	L [kHz/b]: 855 MeV	570 MeV
10	15	1.15	2.51
5	15	4.59	10.05
3	15	12.76	27.91
1	15	114.86	251.16

Numerical calculation of achievable luminosity





assumptions: laser light, 514.5 nm
laser power 10 W
gaussian beams

$E_{laser} = 26\pi$ μm mrad

$E_e^{hor} = 7.8\pi$ μm mrad

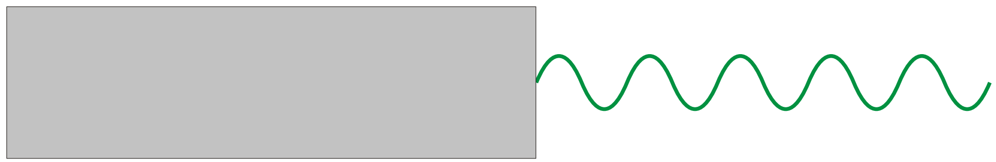
$E_e^{vert} = 1.0\pi$ μm mrad

➡ **antiparallel geometry desireable**
more laser power needed

3. Layout of the A4 Polarimeter

Methods of increasing the laser power

1. Fabry-Pérot external cavity (e.g. JLab Hall A)



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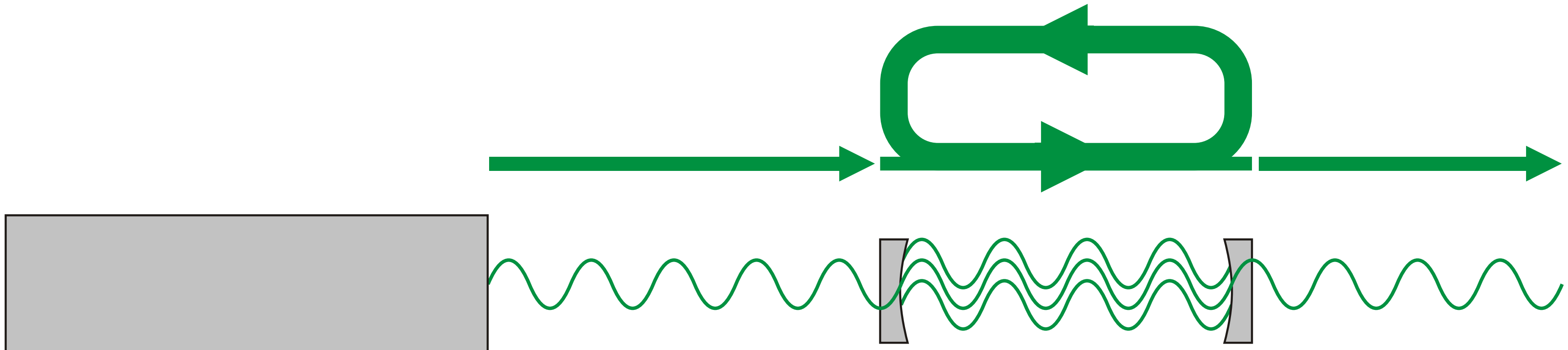

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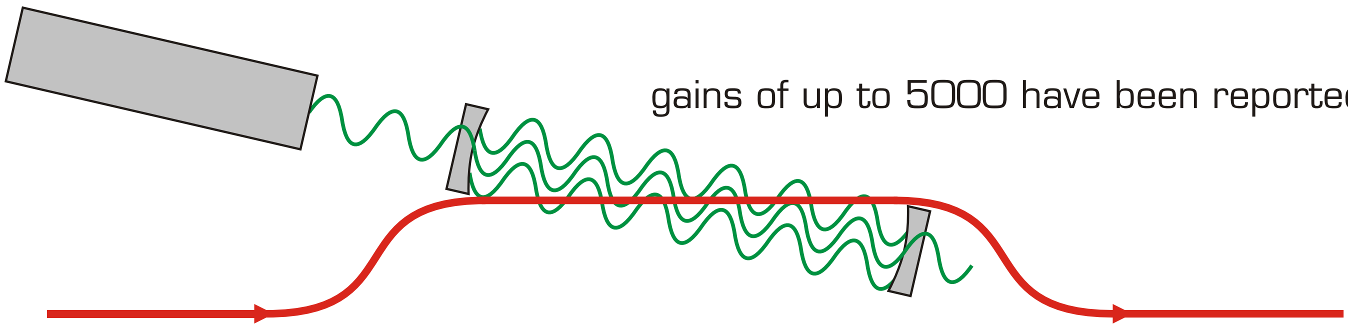

gains of up to 5000 have been reported

Drawback: gain-bandwidth-product

$g \qquad const$

→ **frequency stabilization necessary**

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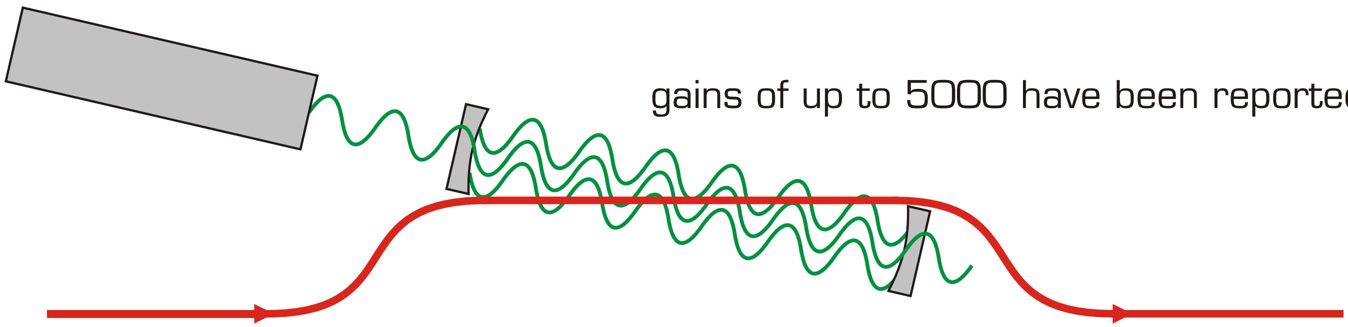

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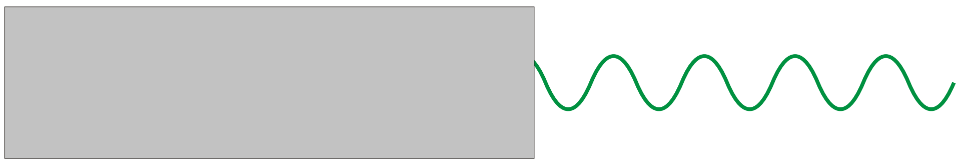
2. Internal cavity (A4 polarimeter)



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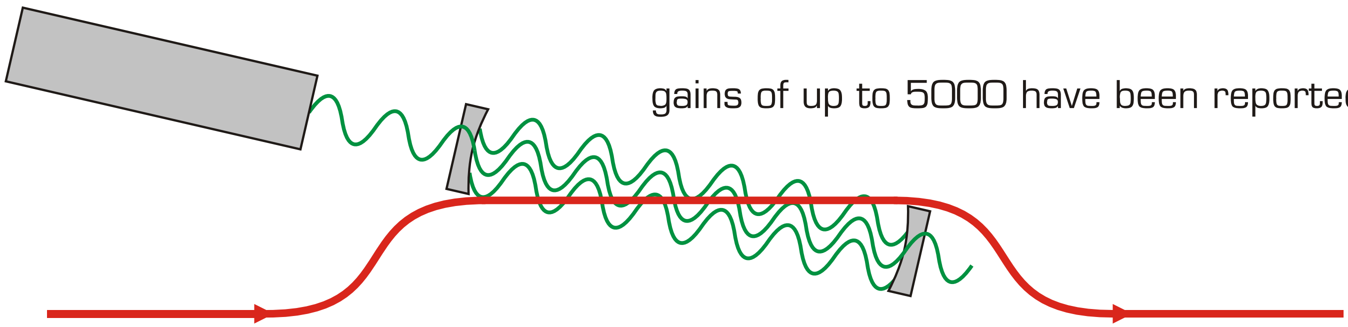

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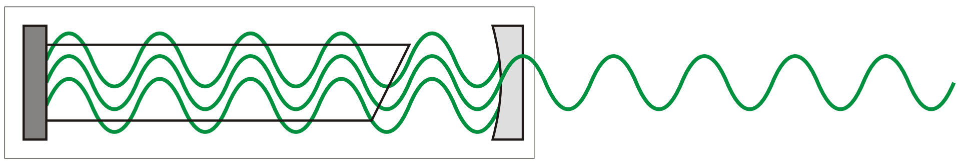
2. Internal cavity (A4 polarimeter)

Laser is already Fabry-Pérot-cavity



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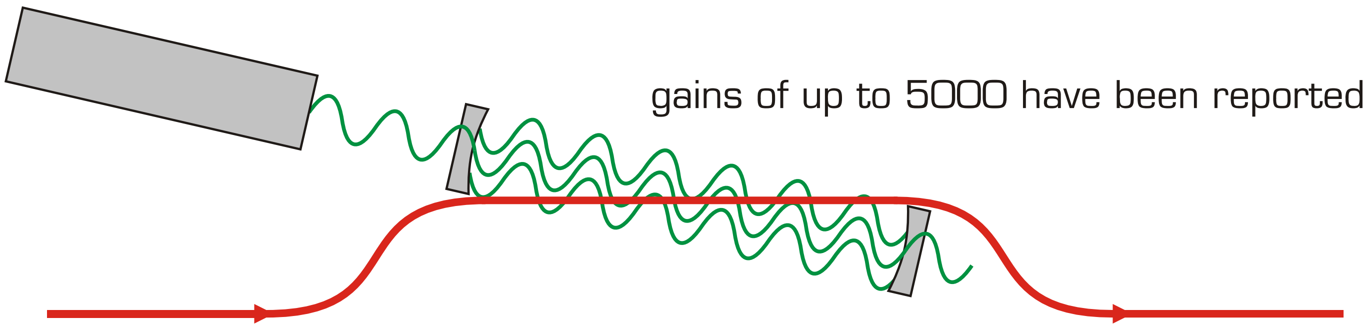

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→ frequency stabilization necessary

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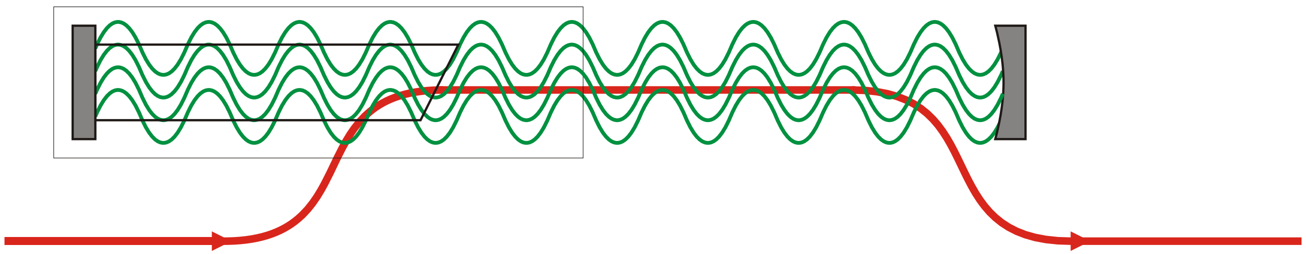
2. Internal cavity (A4 polarimeter)

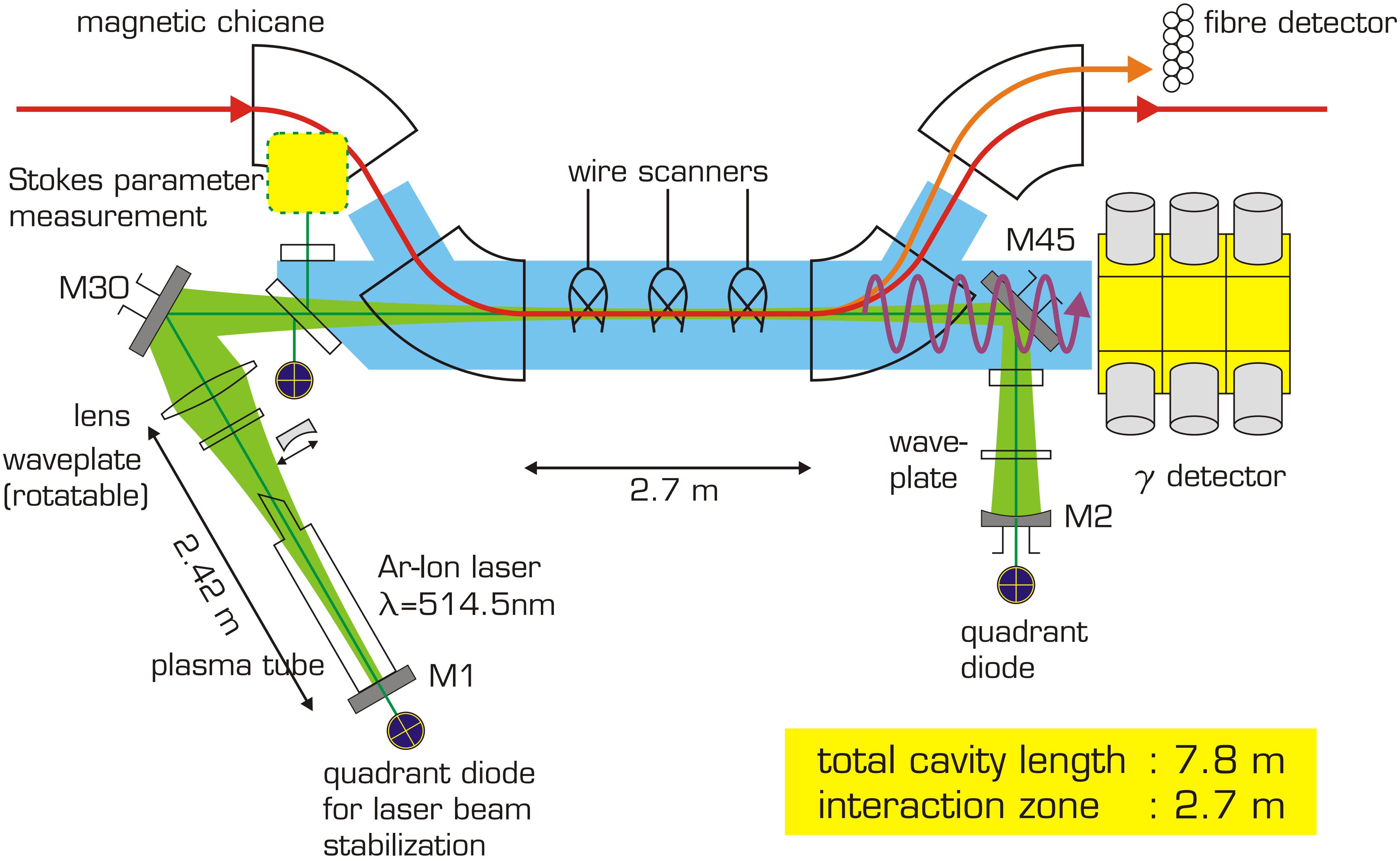
Laser is already Fabry-Pérot-cavity → extend cavity, make all mirrors high-reflective



→ no frequency stabilization necessary

but: maximum power smaller than with external cavity

Schematic View of the Polarimeter



total cavity length : 7.8 m
interaction zone : 2.7 m

Optical System

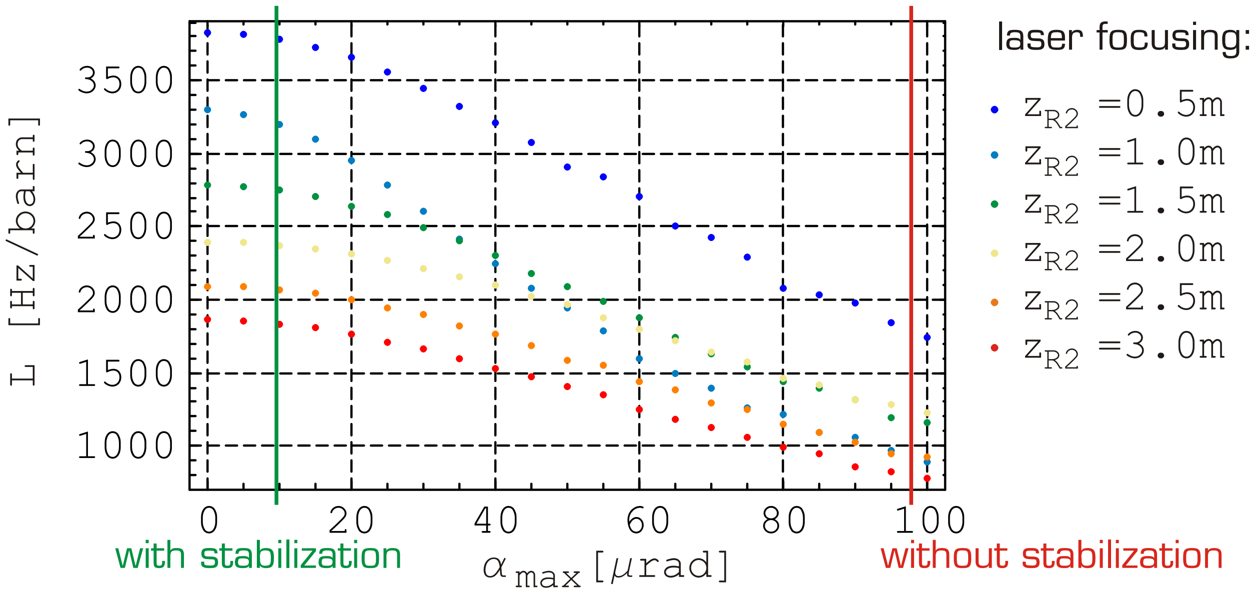
- optical system designed around commercial laser system (Coherent Innova 400)
- subject to boundary conditions:
    1. maintain beam profile in laser medium
    2. keep optics accessible
    3. fit system into chicane
    4. optimize beam profile in interaction region for high luminosity

- challenges:

    sensitivity of beam axis to vibrations in the optical elements depends on optics spacing
    sensitivity of luminosity to beam axis fluctuations depends on focusing

→ perform MC-simulations for optimization

Mean luminosity as function of vibration amplitude



compromise:

z_{R2} = 2.5 m
L_{max} = 2.1 kHz/barn per 10W power

Polarization

Polarization of the laser light enters directly into the asymmetry:

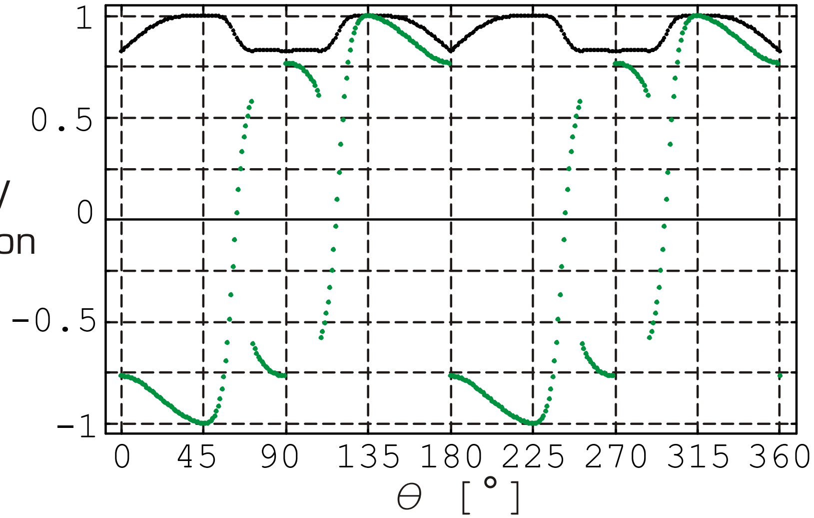
$$A \qquad |V|$$

→ **maximize circular polarization**
measure polarization state

1. Analysis of polarization state inside laser resonators

- calculate polarization using Jones/Stokes-formalism
- result: need two waveplates
- one waveplate rotatable to select light helicity

● Stokes parameter V
● round-trip attenuation



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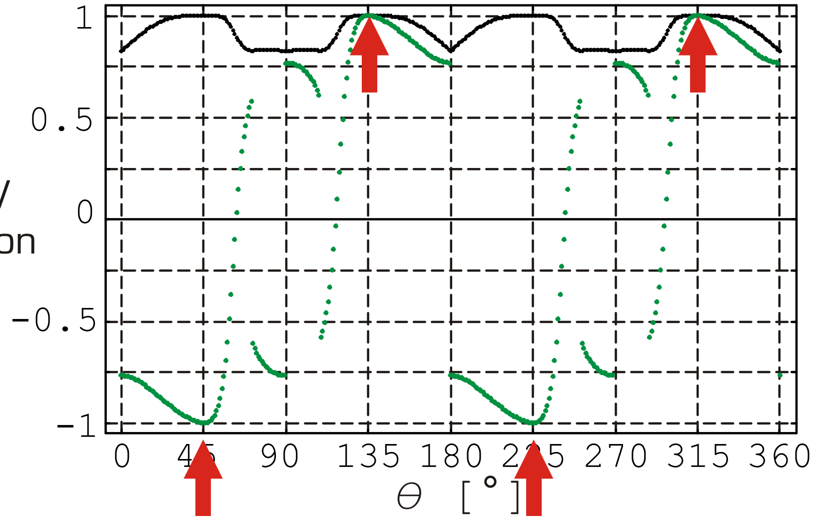

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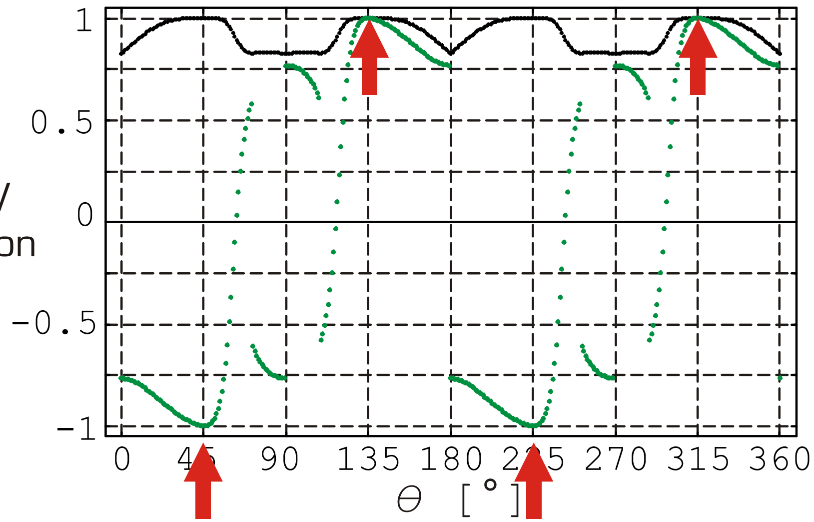


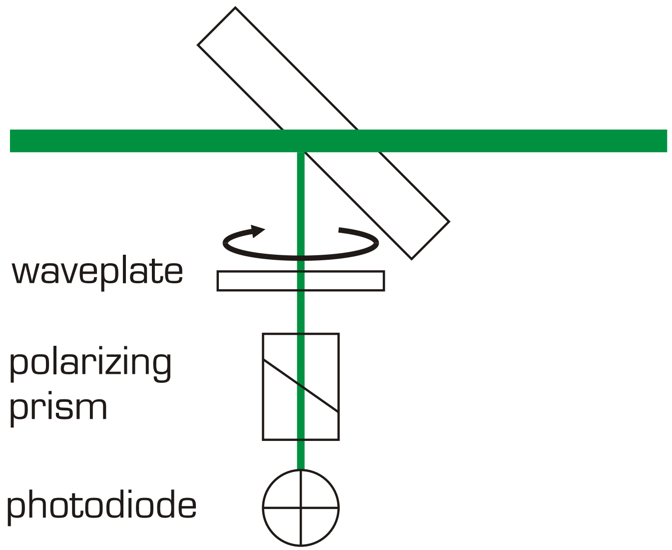
➡ **V = +/-1 possible**

2. Stokes parameter measurement

- use vacuum window as beamsplitter (0.6% reflectivity)
- method: rotating quarter waveplate and linear polarizer
- result: transmitted intensity modulated

$$I(\ ) \ \frac{1}{4}(2I \quad Q) \quad 2V\sin 2 \quad U\sin 4 \quad Q\cos 4$$

linear ✣ — circular — linear ✕ — linear ✣



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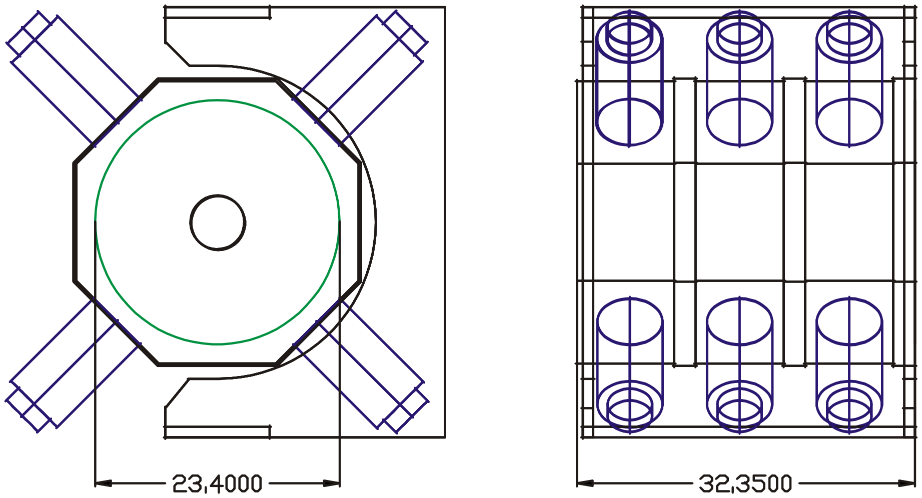
Photon arm:

NaI calorimeter, 3 crystals, 4 PMT each

- length: 12 X_0
- diam.: 5.2 r_M

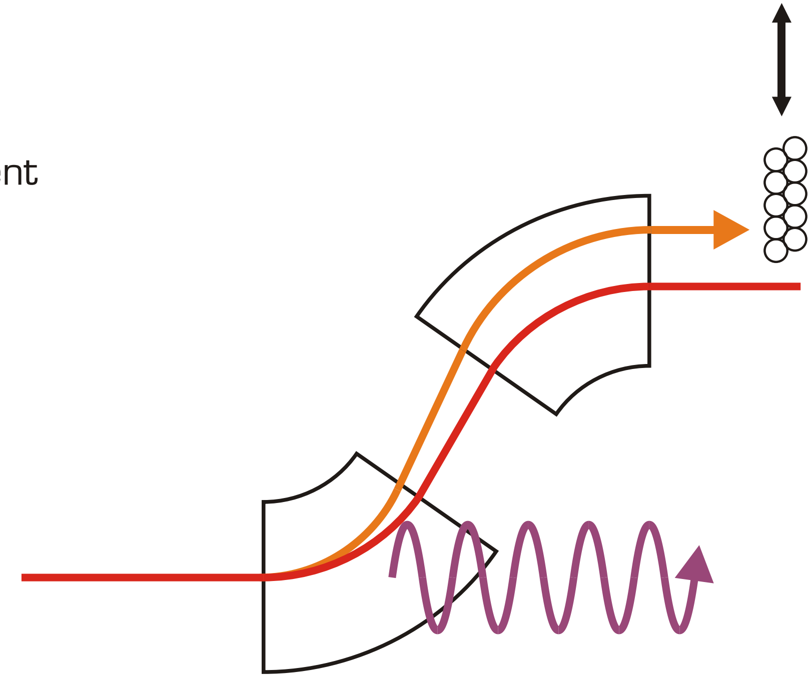


Electron arm:

- electron involved in scattering loses energy
- dispersion in last half of chicane leads to displacement with respect to main beam

→ **install SciFi-array behind chicane to detect recoil electron**

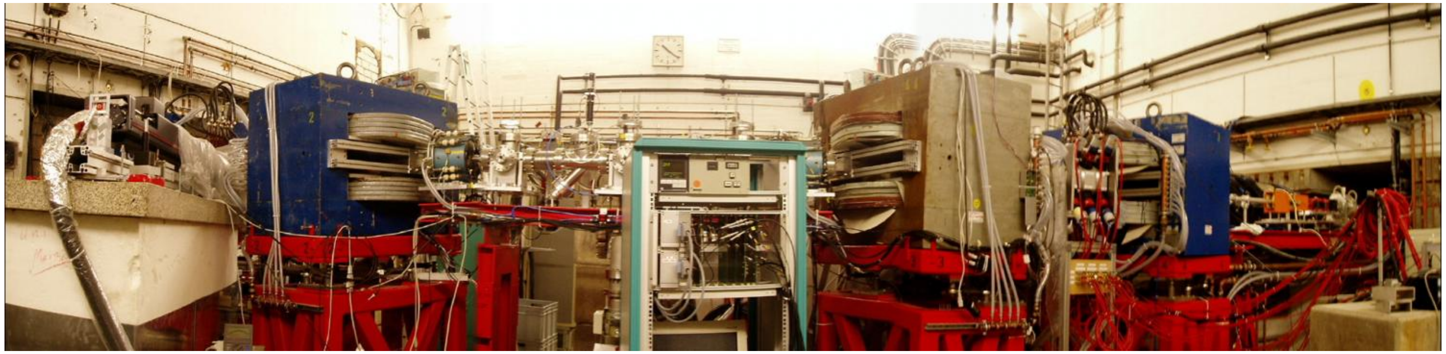
measure photons in coincidence with electrons to improve data quality



4. Status and Results

1. Magnetic chicane

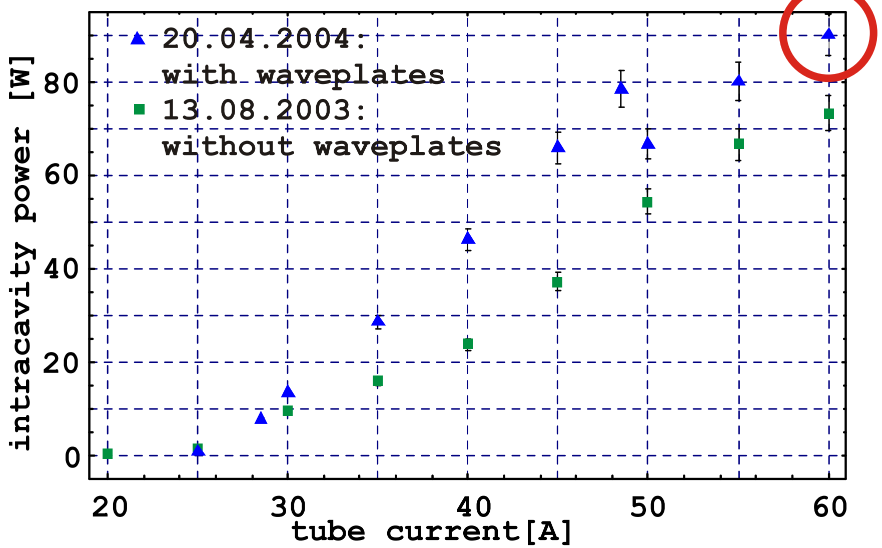
- installed the magnetic chicane for the polarimeter in MAMI experimental Hall 3 (Dec 2002)
- no degradation of the beam quality on A4 target



this way beam →

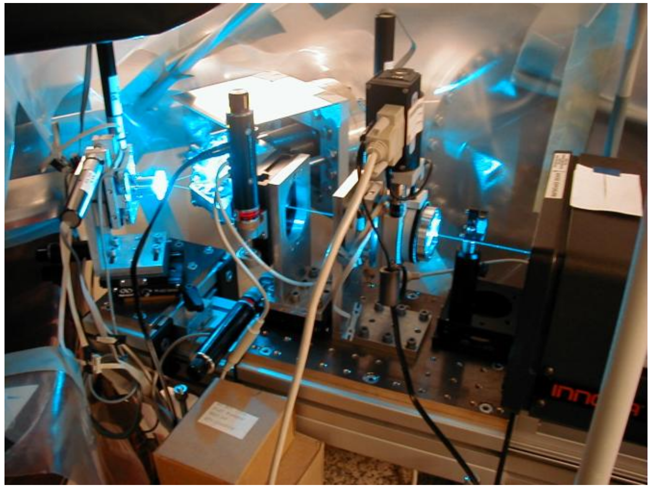
2. Optical system

- installed the optical system in two steps: first, the laser resonator, then the polarization components
- system works reproducibly



maximum power measured:

P = 90W

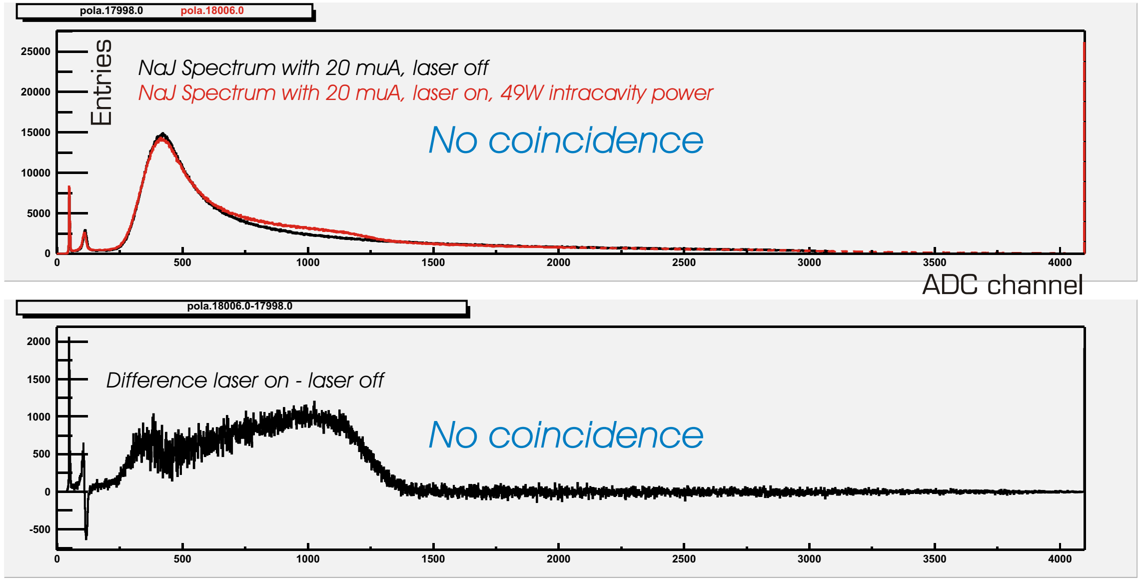


3. Photon calorimeter

- first successful overlap test in Aug 2003

- measured backscattered photon spectra with NaI

Compton rate	**: 2.6 kHz**
Background rate	**: 18.6 kHz**
SNR	**: 1:7.1**



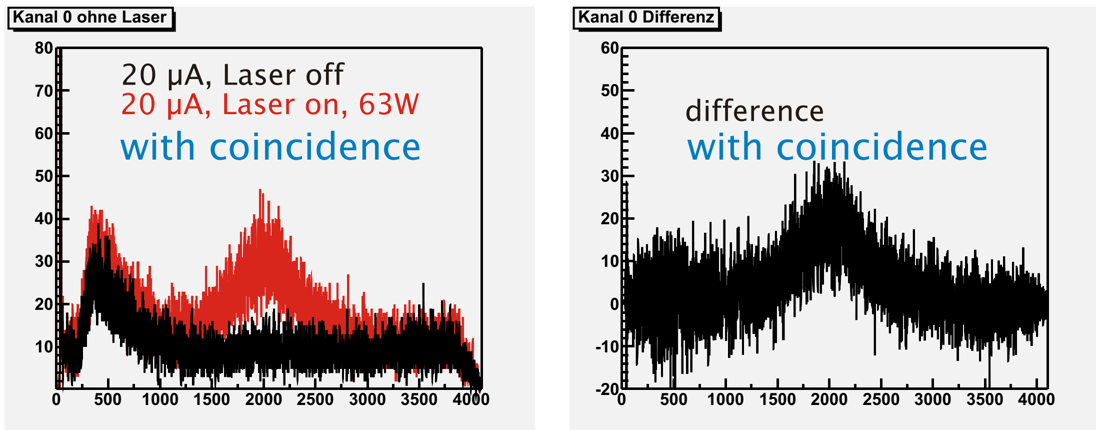
4. Photon-electron coincidence

- installed the SciFi-array behind the chicane in May 2004

- data quality improved by coincidence condition

Compton rate	**: 60.5 Hz**
Background rate	**: 125 Hz**
SNR	**: 1:2.1**

- despite non-optimal beam conditions (overlap, fibre position ...)



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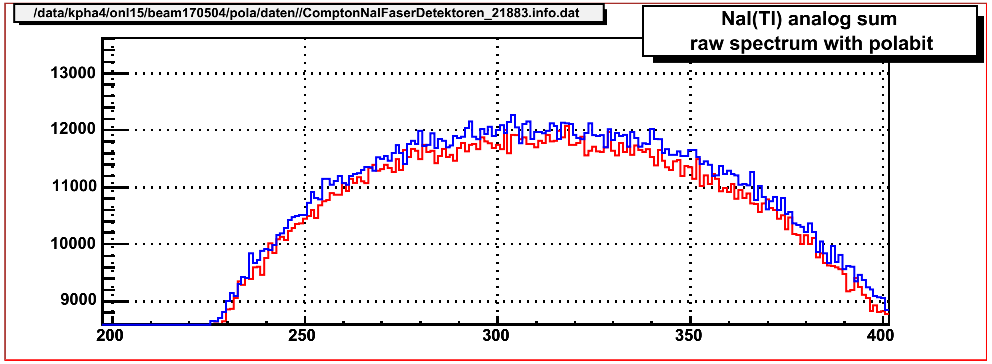
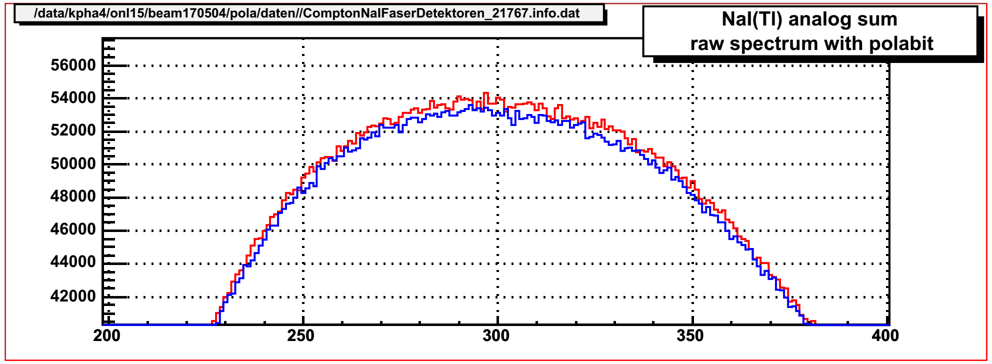
First Asymmetries

- measured first Compton asymmetries with polarized light (July 2004)
  asymmetries due to switching of electron helicity
- asymmetry clearly changes sign when inserting GHS at source

cumulative spectra

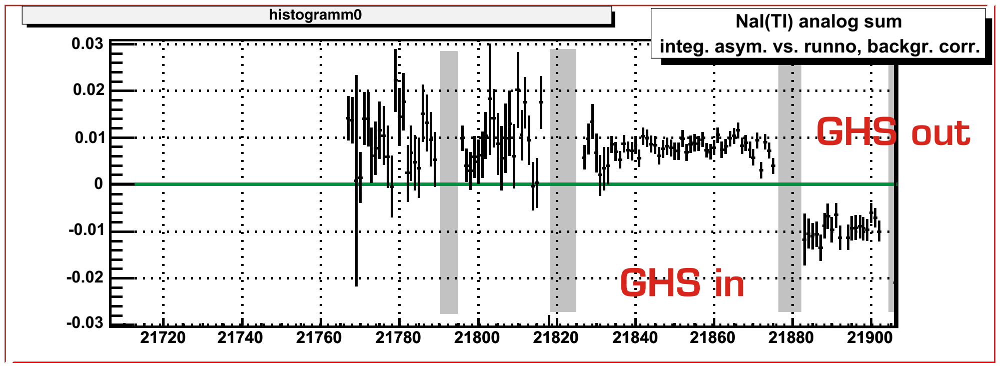


GHS out



GHS in

runwise asymmetry



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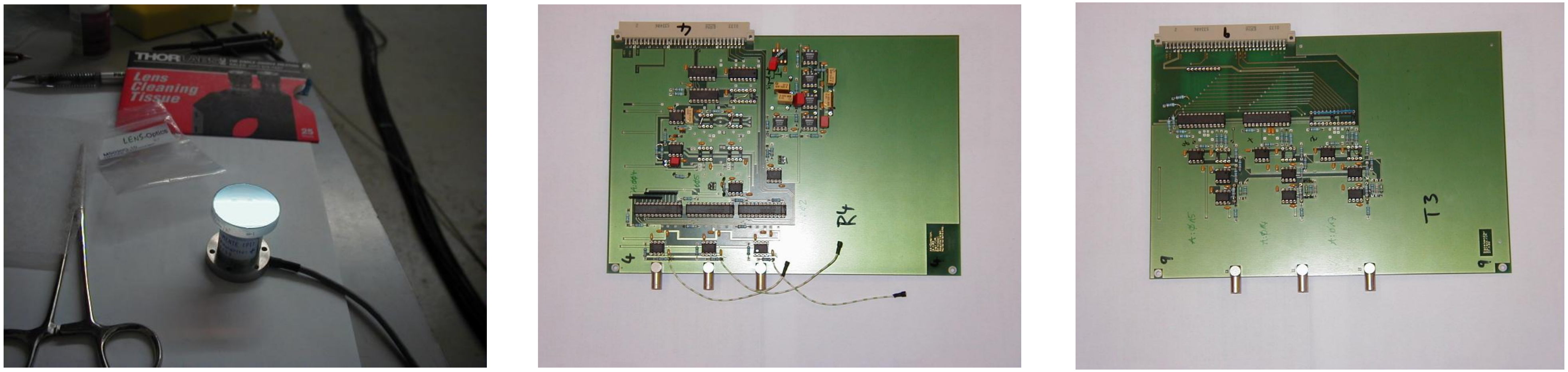
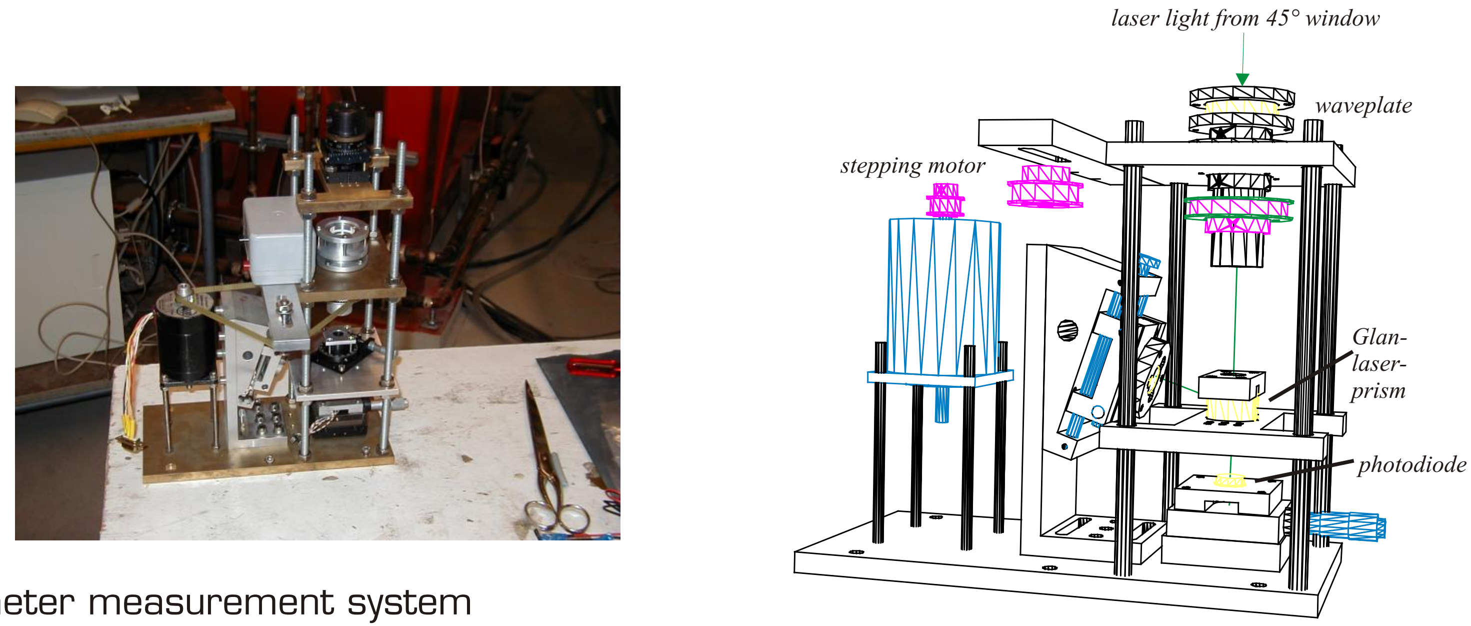
Photographs



Piezo system and electronics for laser beam position stabilization



Stokes parameter measurement system

5. Summary and Outlook

Achieved:

- planned and installed a magnetic chicane for a Compton backscattering polarimeter

- planned and installed an optical system for the polarimeter, for the first time using the internal cavity concept
  maximum polarized laser power: 90 W

- comissioned a NaI calorimeter and measured backscattered photon spectra

- comissioned an electron detector and improved data quality by using the coincidence technique

- planned and installed a stabilization system for the laser beam position

- measured first Compton asymmetries with polarized light NEW!

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Next steps:

- refine the Stokes parameter measurement to extract quantitative data on electron polarization
- improve vacuum to reduce background

→ **ready for longitudinal physics programme**

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- upgrade to <u>transverse spin measurement</u>:
  use position-sensitive detector to measure spatial Compton asymmetry

→ **ready for entire physics programme**