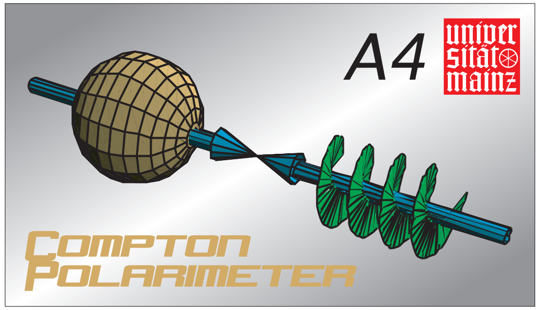

The A4 Compton Backscattering Polarimeter

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International School of Nucler Physics 26th Course
Ettore Majorana Center for Scientific Culture, Erice

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1. Introduction
2. Compton Polarimetry
3. Layout of the Polarimeter
4. Status and Results
5. Outlook and Summary

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1. Introduction

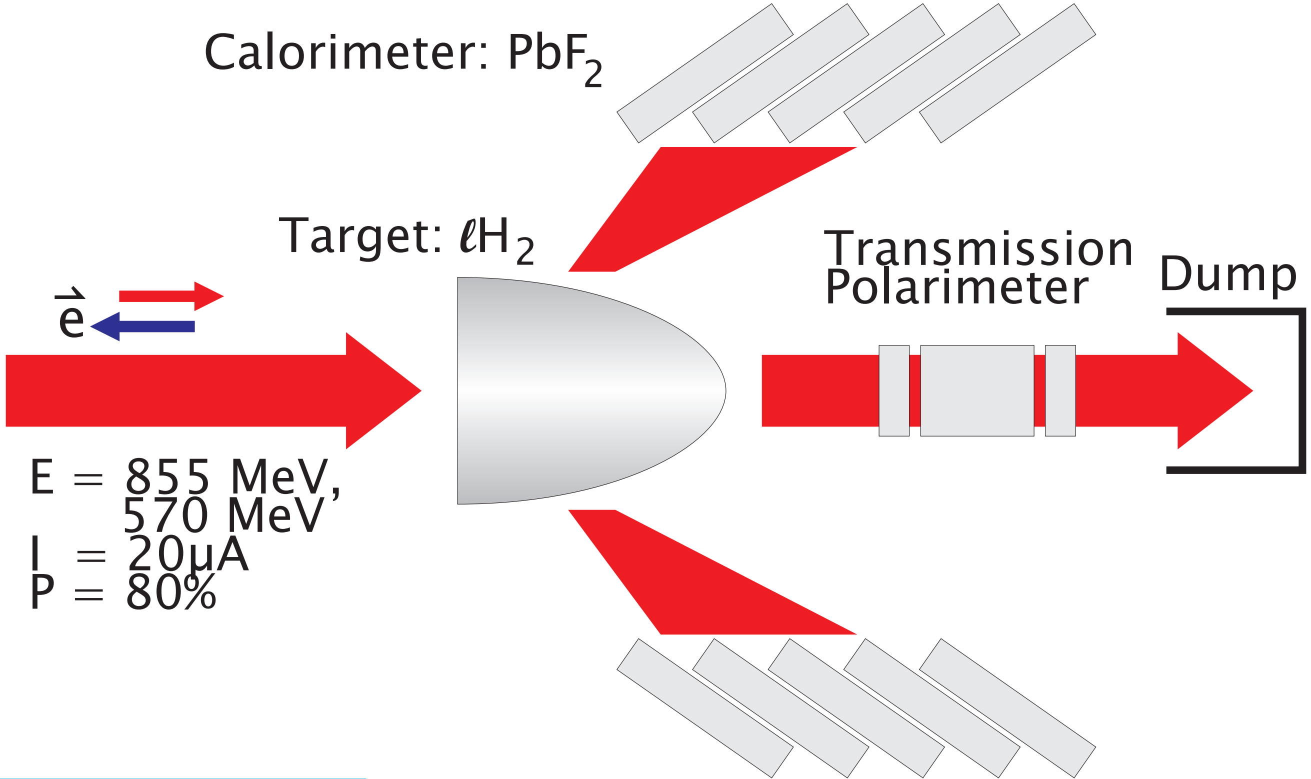
The A4 experiment

physics goal :

determine strange quark contributions to the nucleon properties

method :

measure the parity violating cross-section asymmetry in elastic eN-scattering with polarized beams



measured quantity:

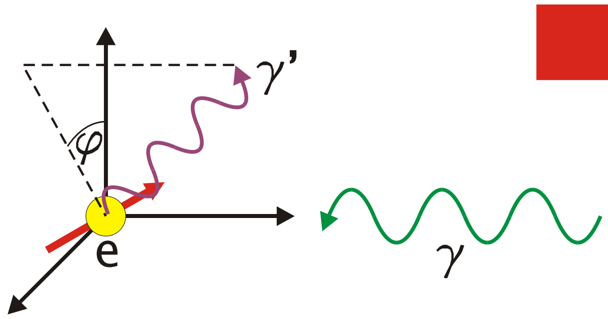
$$A_{exp} = P_e A_{phys}$$

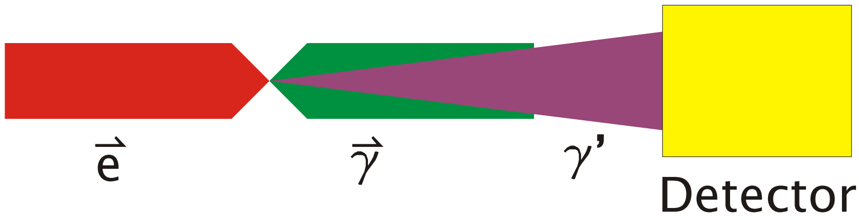
exp. asymmetry — beam polarization — physics asymmetry

→ Need to measure the absolute beam polarization
Method: Compton backscattering polarimetry

2. Compton Polarimetry

Scattering of photons on leptons





Compton cross-section:

Lipps, Tolhoek Physica XX(1954)

$$\frac{d}{d} \quad \frac{d\ \ _0}{d} \quad Q\frac{d\ \ _1}{d} \quad V P^e_{long} \frac{d\ \ _{long}}{d} \quad V P^e_{trans} \cos \quad \frac{d\ \ _{trans}}{d}$$

Q,V : “Stokes Parameters” (initial photon polarization)
Q : linear contribution
V : circular contribution (+1 : right circular, −1 : left circular)

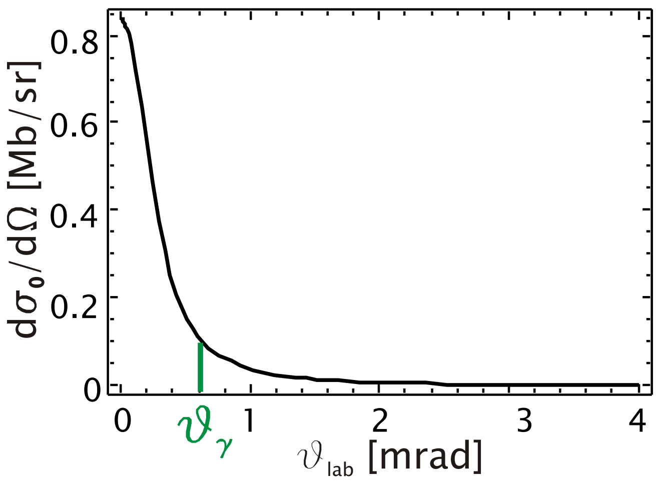
With circular light: asymmetry between scattering of right- and left-handed photons

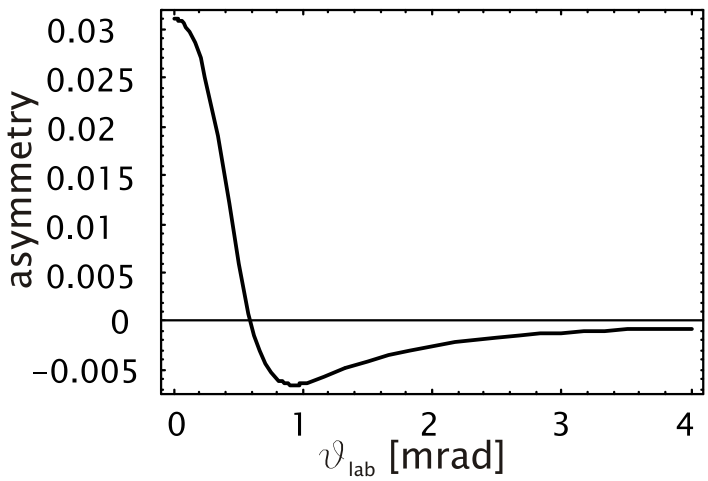
average over φ (longitudinal polarization)

$$A \quad \frac{\frac{d}{d}\ _{right} \quad \frac{d}{d}\ _{left}}{\frac{d}{d}\ _{right} \quad \frac{d}{d}\ _{left}} \quad |V| P^e_{long} \frac{d\ \ _{long}/d}{d\ \ _0/d}$$

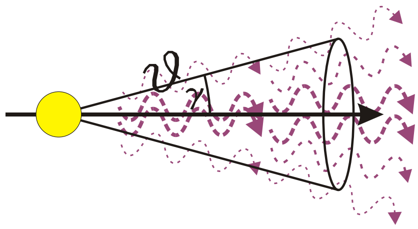
→ Asymmetry proportional to beam polarization

Angular distribution 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

➡ most calorimetric detectors will average over φ

Measuring time

counting rate asymmetry

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

energy spectrum asymmetry

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

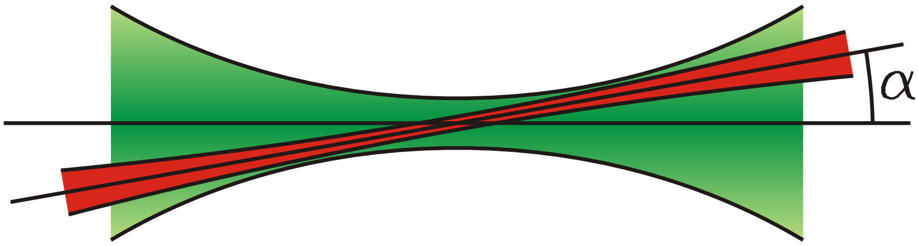
Chen, Bardin, Cavata et al.
"Conceptual Design Report..."

Luminosity requirements

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

green light (514.5nm), 80% electron polarization

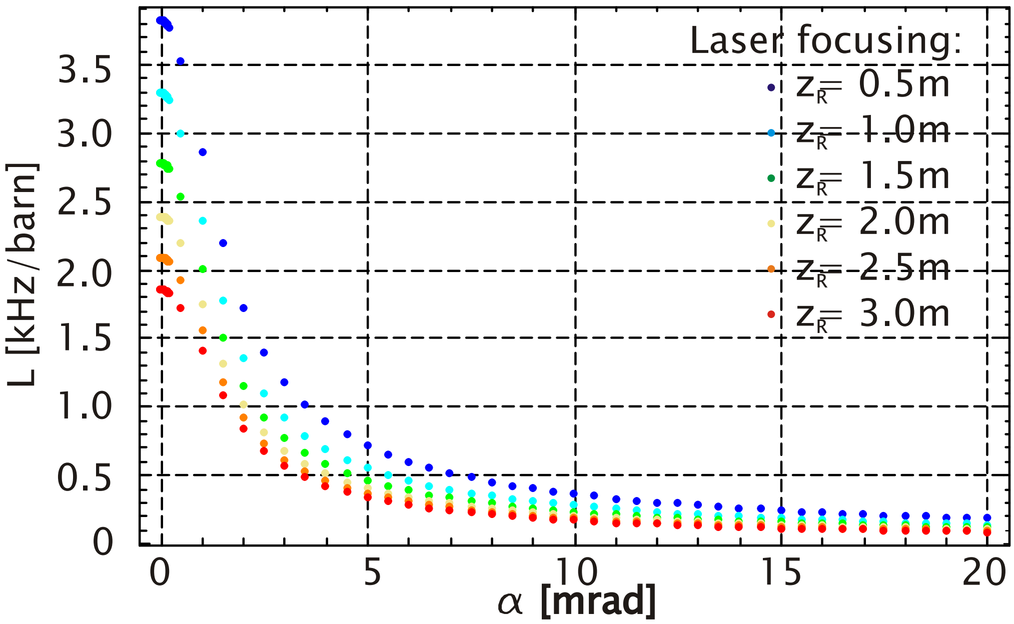
Luminosity for colliding beams



$$L \quad v_{rel} \quad {}_1(\vec{x}) \quad {}_2(\vec{x}) d^3x$$

depends on:
- beam focusing
- crossing angle

numerical results:



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

$E_L = 26\pi$ µm mrad
$E_e^{hor} = 7.8\pi$ µm mrad
$E_e^{vert} = 1.0\pi$ µm mrad

➞ antiparallel geometry is desirable

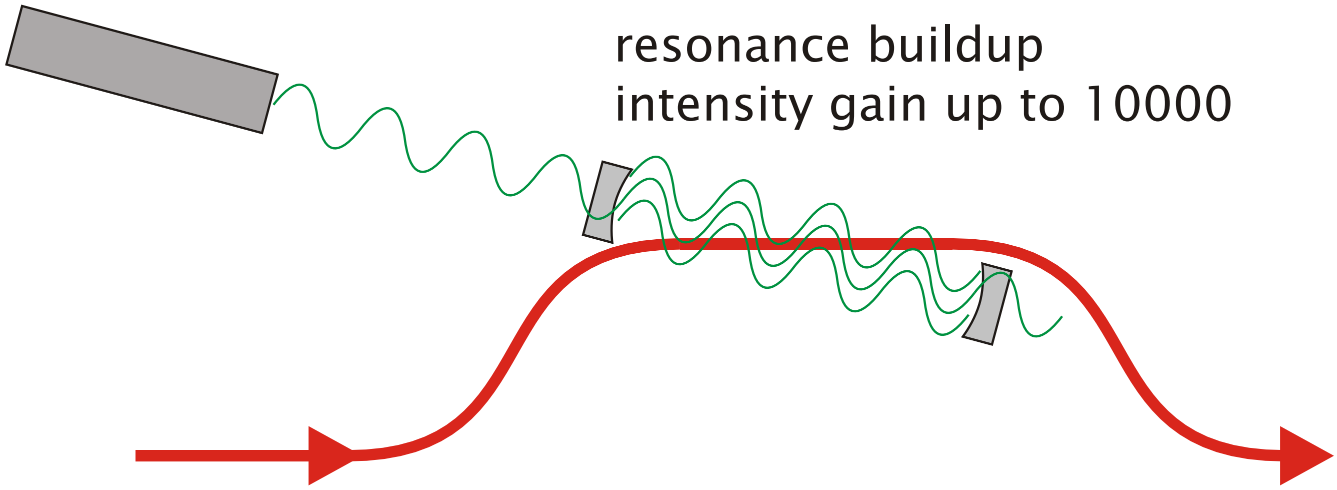
➞ more laser power needed

3. Layout of the A4 Polarimeter

Methods of increasing the laser power

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

resonance buildup
intensity gain up to 10000



drawback: gain–bandwidth–product

$$g \qquad const$$

➞ frequency stabilization necessary

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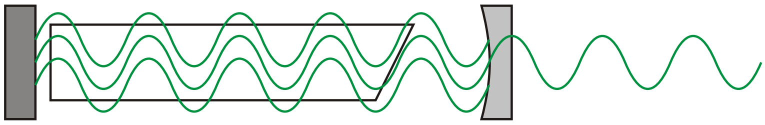
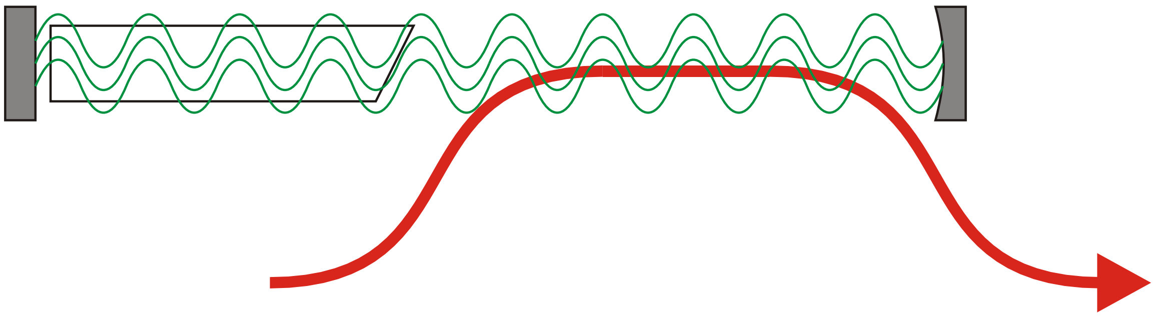
2. Internal cavity (A4 Polarimeter)



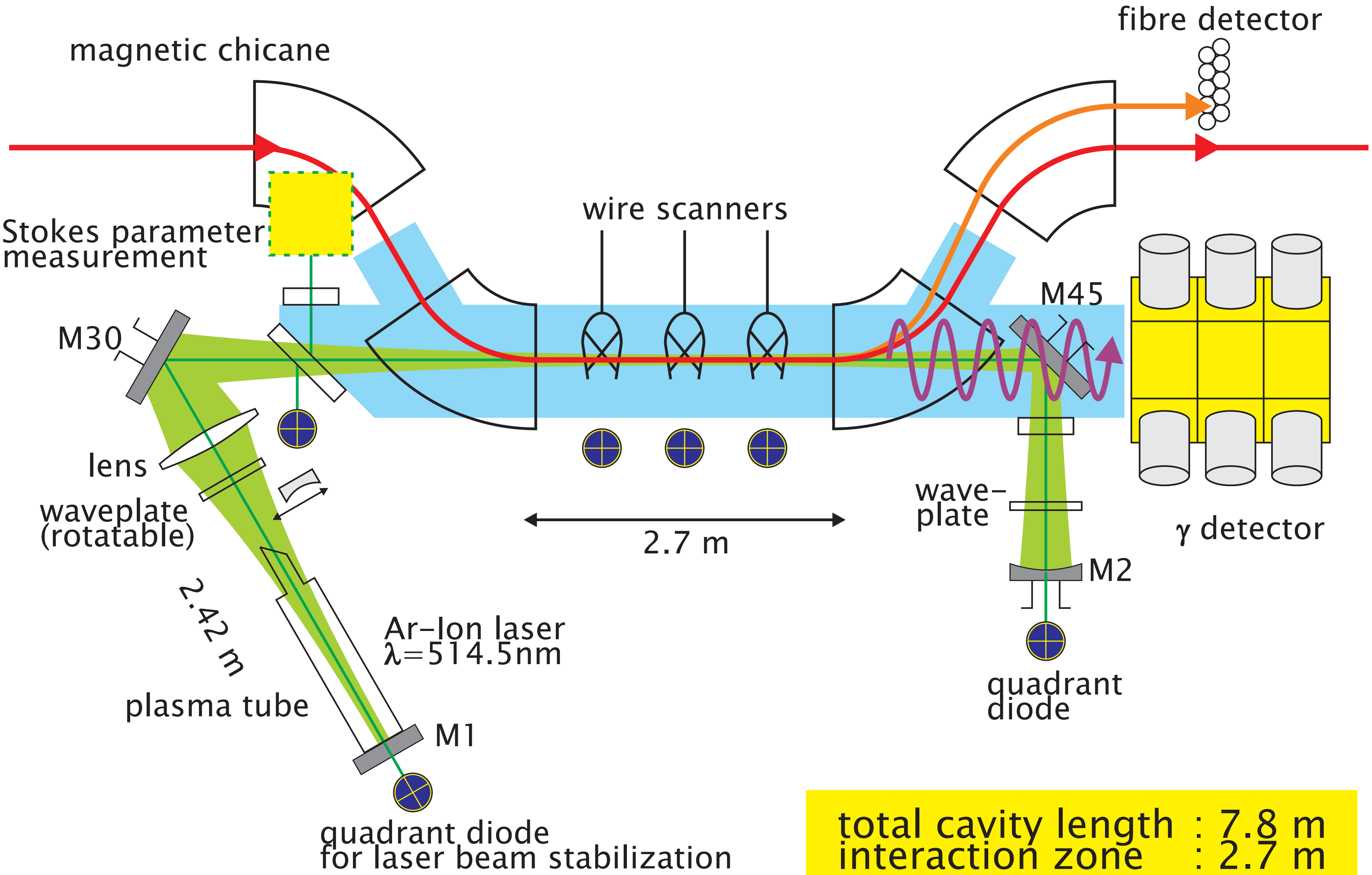
extend cavity
make all mirrors high reflective



➞ no frequency stabilization necessary

but: maximum intensity lower than with external cavity

Schematic View of the Polarimeter



total cavity length : 7.8 m
interaction zone : 2.7 m

Optical System

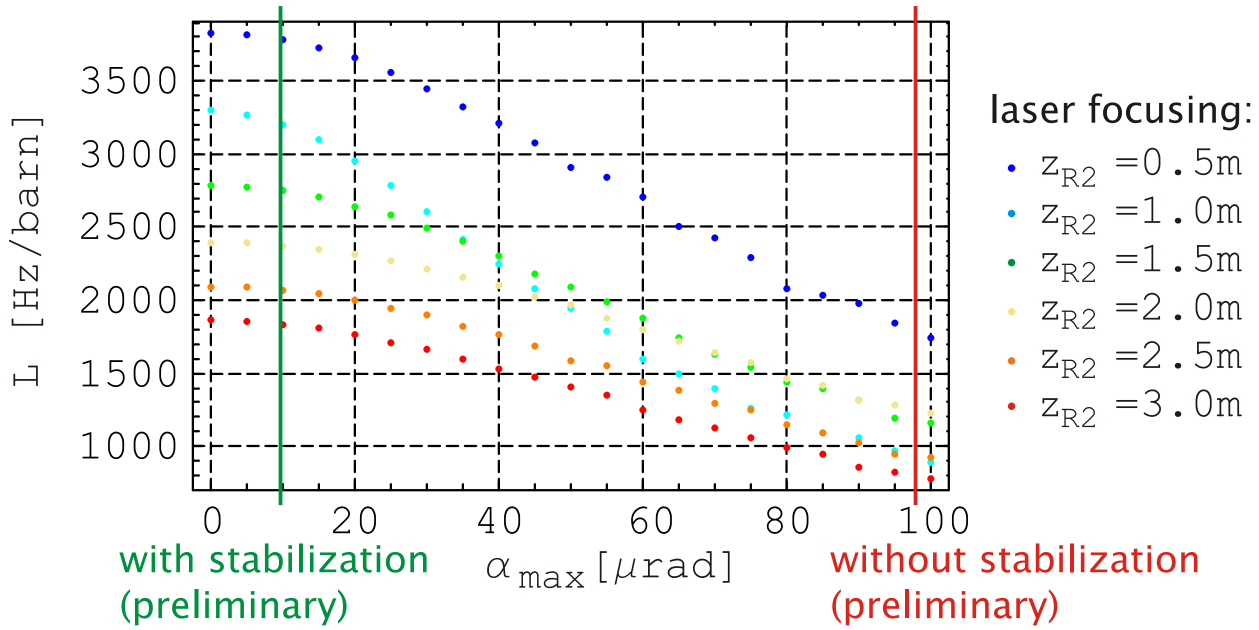
- design based on commercial laser crate
- subject to boundary conditions:
  1. beam profile in laser medium unchanged
  2. optics accessible for maintenance
  3. system to fit into chicane
  4. profile matching for high luminosity despite vibrations in the optical system

Problem:

- Sensitivity of beam axis to optics vibration depends on optics spacing.
- Sensitivity of luminosity to beam axis fluctuations depends on beam focusing

➡ perform MC-simulations to find compromise

Mean luminosity as function of tilt noise amplitude:



compromise: $z_{R2} = 2.5\text{m}$

$L_{max} = 2.1$ kHz/barn per 10W

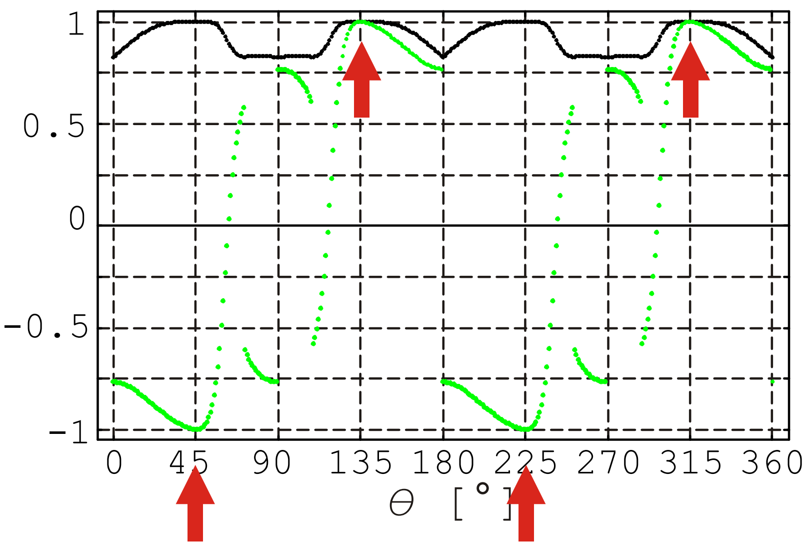
– Polarization of the laser light enters into asymmetry

$$A \qquad |V|$$

➡ maximize V (=circular polarization)

➡ measure polarization state

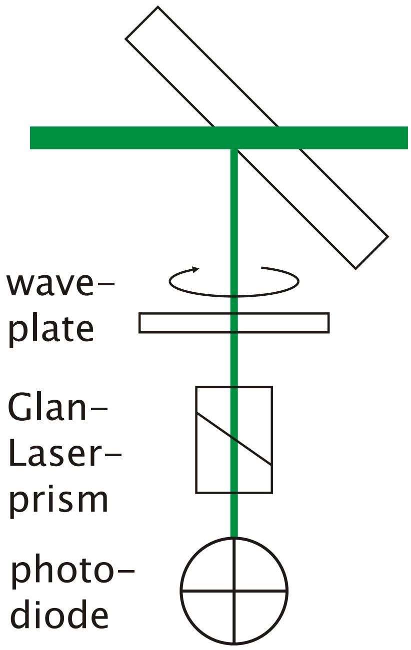
1. Resonator analysis with Jones/Stokes–formalism
   - need two waveplates (because within resonator)
   - analyze resulting polarization when rotating one waveplate



- round–trip attenuation
- Stokes parameter V

➡ V=+/–1 possible

2. Stokes parameter measurement
   - use vacuum window as beamsplitter
   - method: rotating waveplate and linear polarizer
   - result: intensity modulation, amplitudes proportional to Stokes parameters

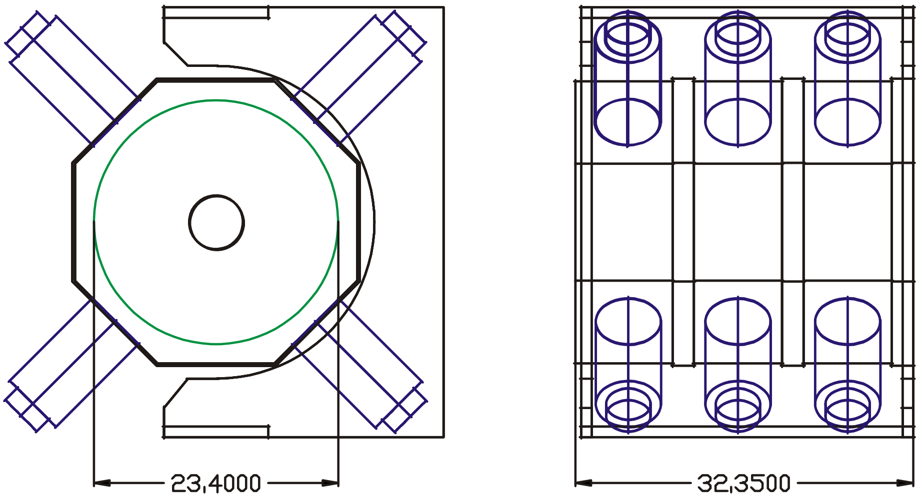


$$I(\ ) \quad \frac{1}{4}(2I \quad Q) \quad 2V\sin 2 \quad U\sin 4 \quad Q\cos 4$$

linear ✣ circular linear ✕ linear ✣

Photon arm

NaI calorimeter, 3 crystals, 4PM each
- length: 12 X_0
- radius : $2.2r_M$

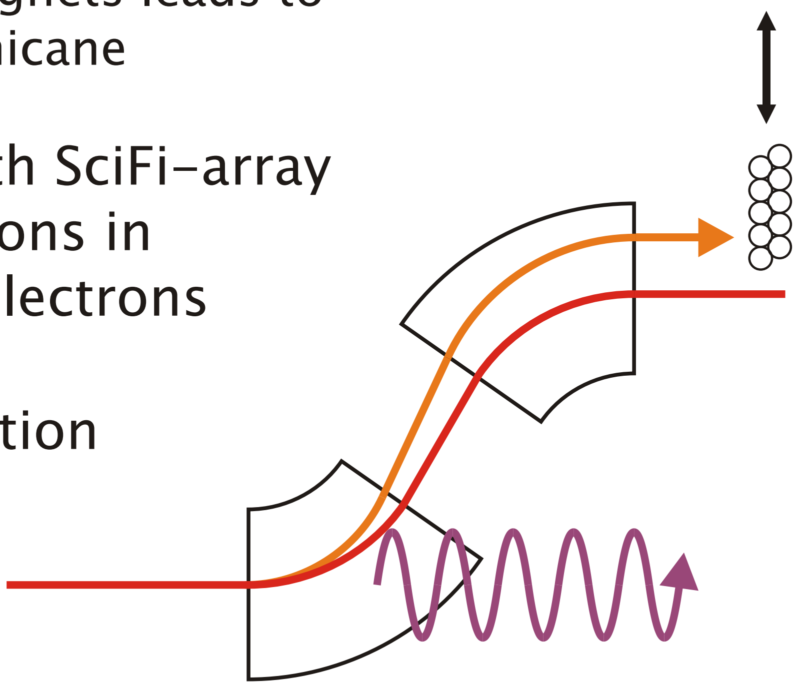


Electron arm

- involved electron loses energy
- dispersion in dipole magnets leads to displacement behind chicane

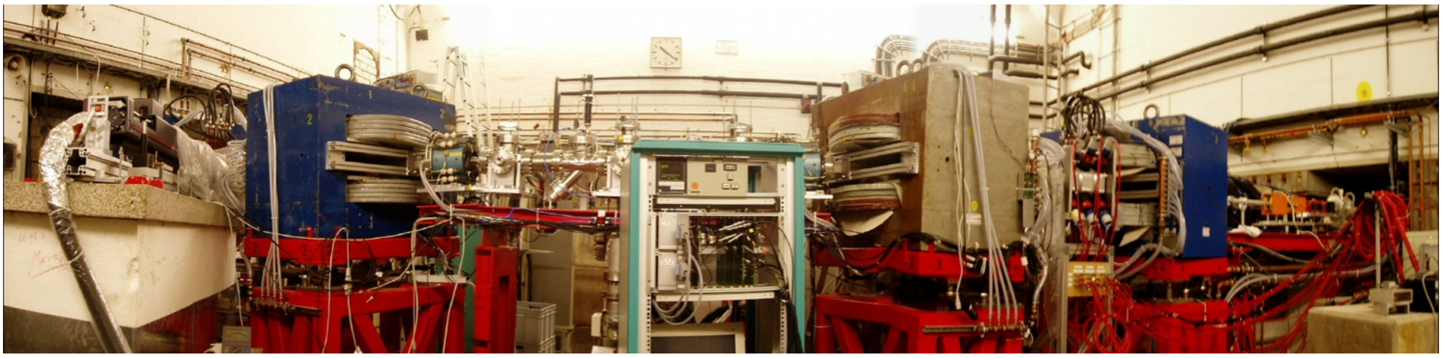
➡ detect electron with SciFi–array and measure photons in coincidence with electrons

➡ background reduction

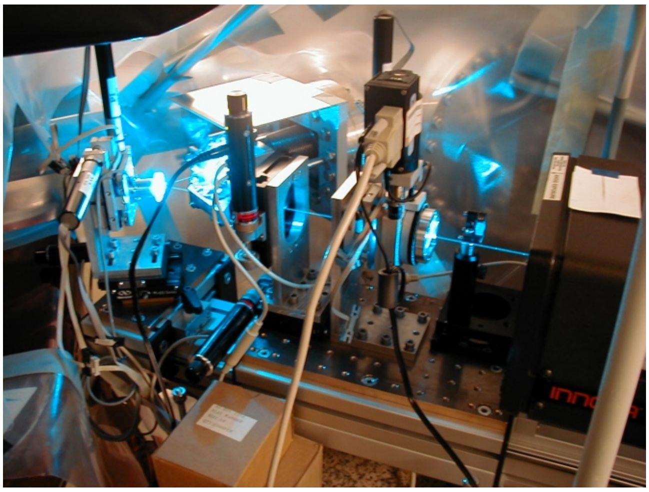


4. Status and Results

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



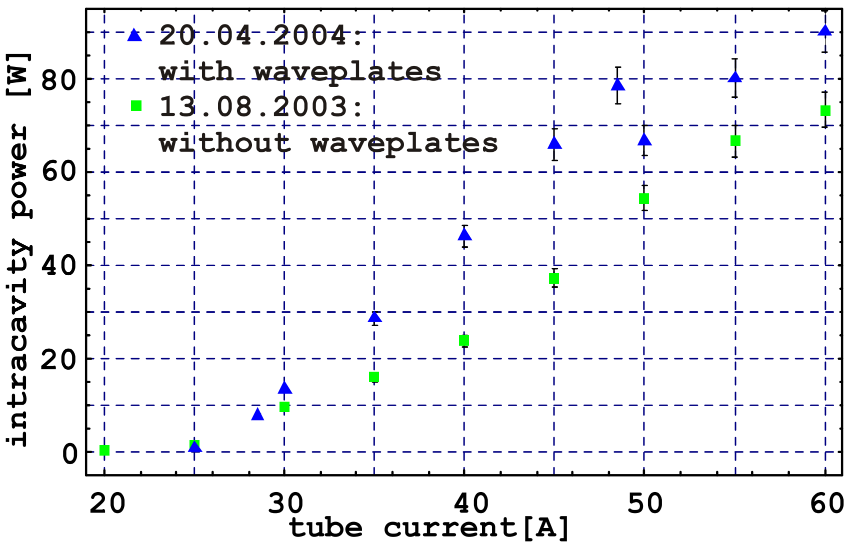
- successfully installed laser and optical system
- at first, operated without waveplates (Dec 2002)



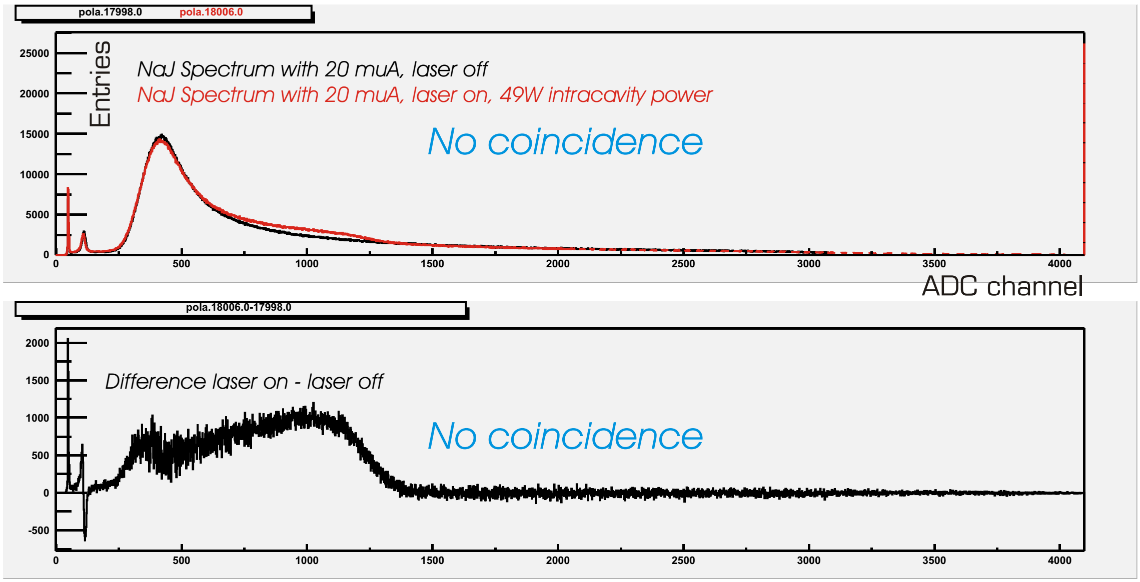
P = 70 W (max)

- resolved problems with stress birefringence in the vacuum windows (Mar 2004)
- installed the waveplates (Mar 2004)

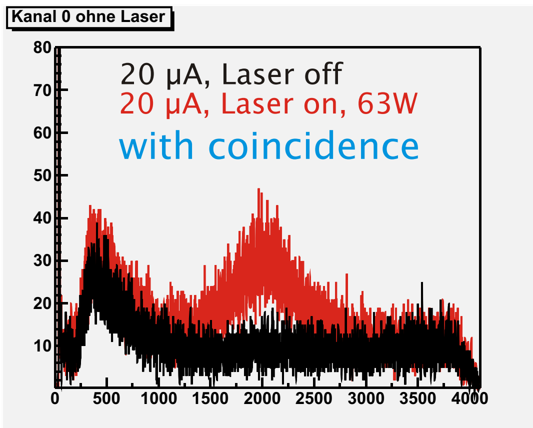
P = 90 W (max)

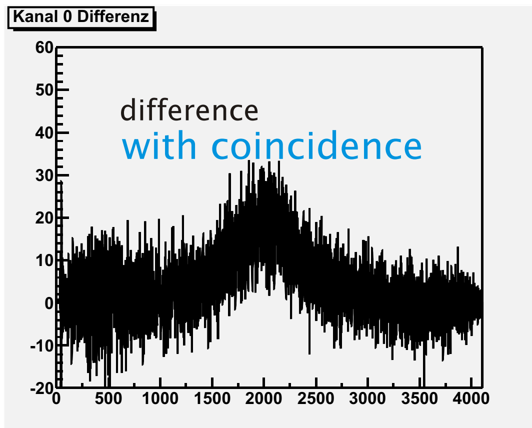


- performed first successful overlap tests and measured backscattered photons with the NaI (Aug 2003)



- installed a SciFi array behind the chicane
  array is operational and has been used for
  background reduction in a test beamtime (May 2004)





without fibre detector

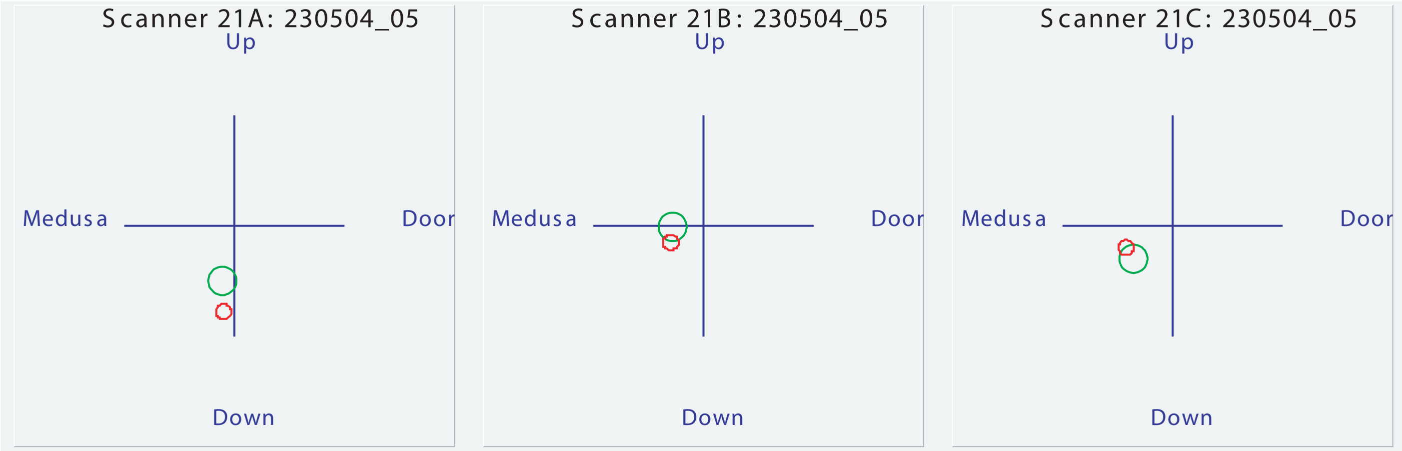
Compton rate:	2.6 kHz
background rate:	18.6 kHz
SNR:	1:7.11

with fibre detector

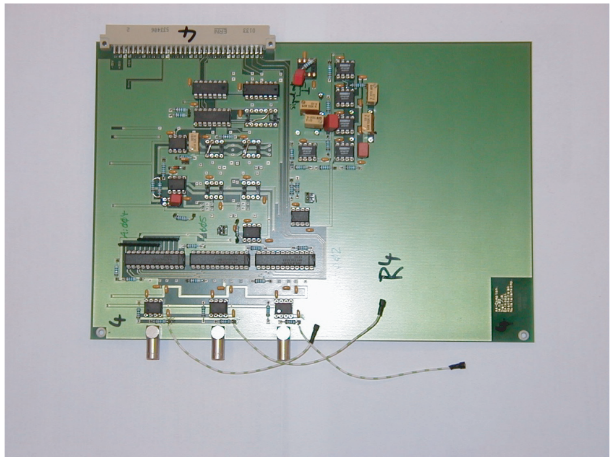
Compton rate:	60.5 Hz
background rate:	125 Hz
SNR:	1:2.07

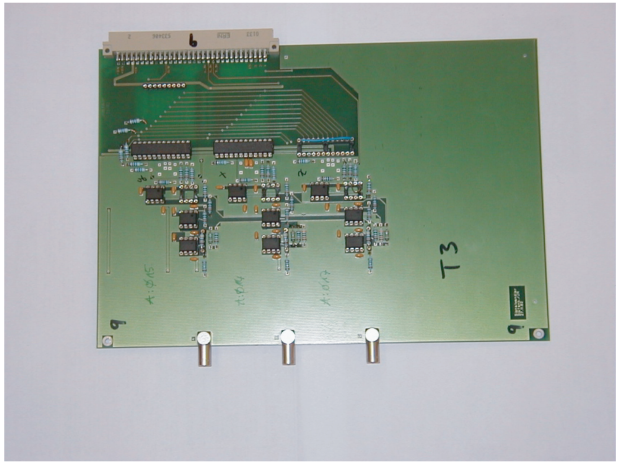
despite non-optimal experimental conditions:
- imperfect overlap
- no laser stabilization

– example for beam overlap

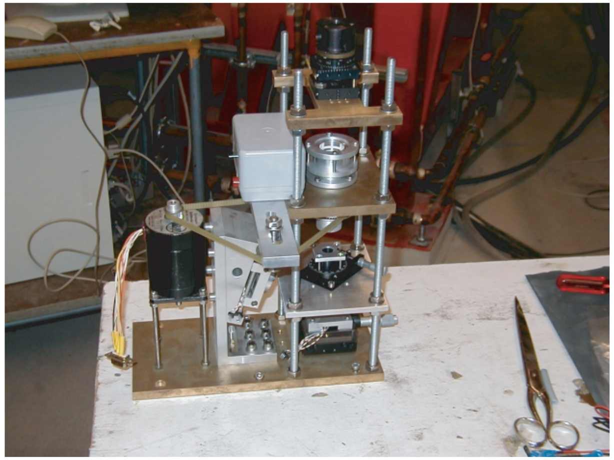


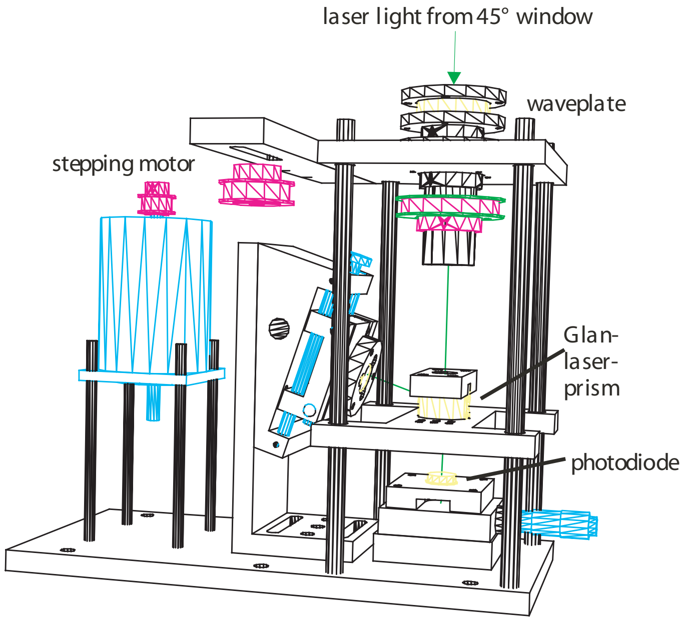
– installed a beam stabilization system (Nov 2003)
system has been tested and is being prepared for routine operation within the polarimeter system



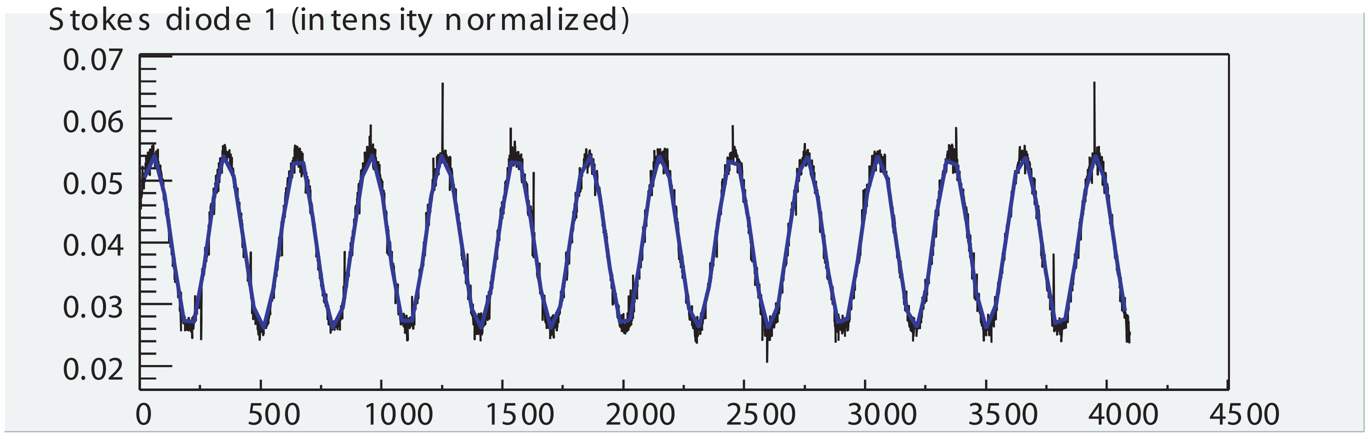


– installed a Stokes parameter measurement system (Aug 2003)



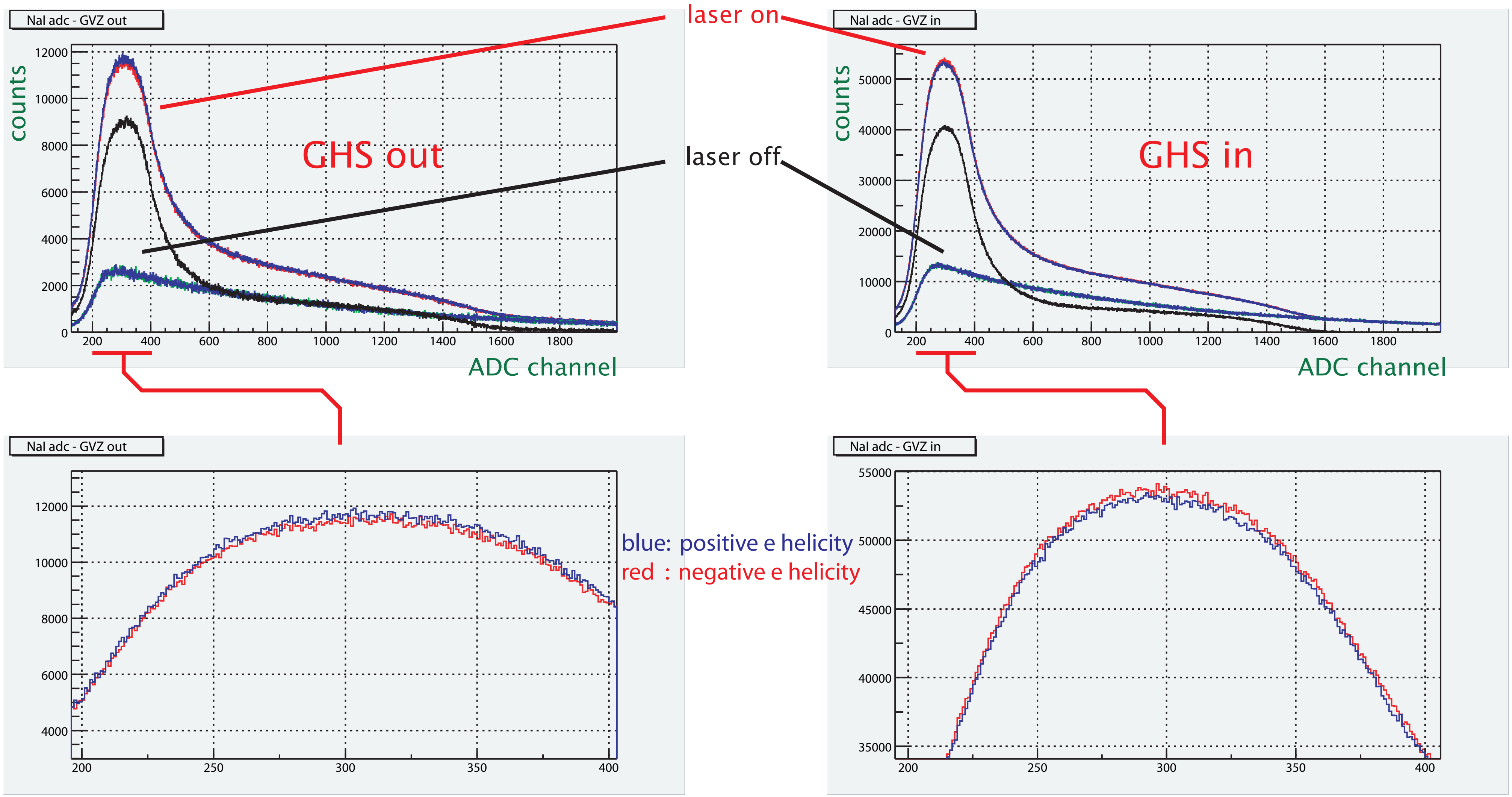


– system has been tested and is being prepared for routine operation within the polarimeter



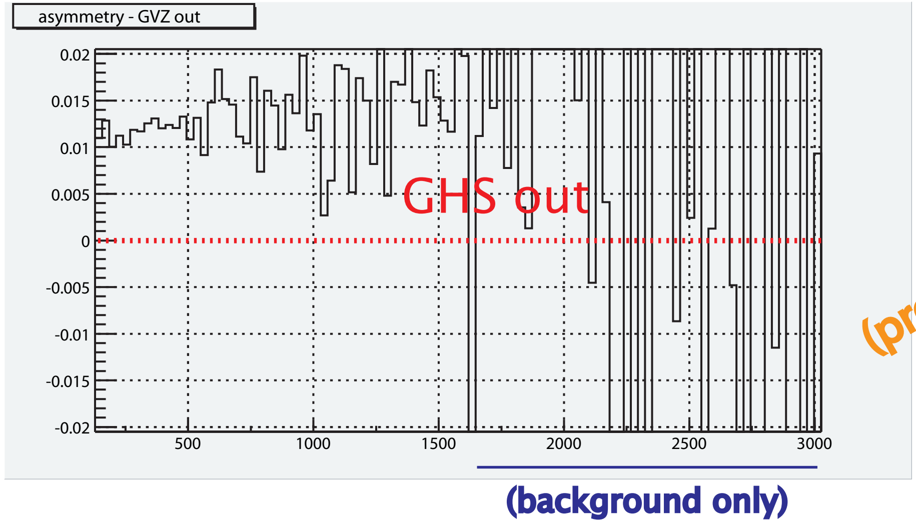
– measured first Compton asymmetry (Aug 2004)

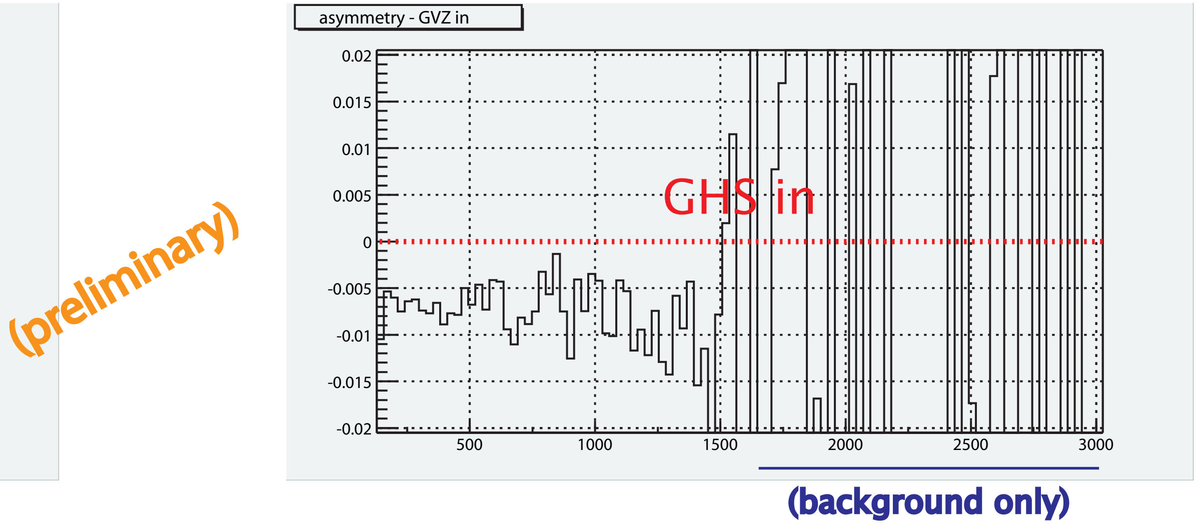
Energy spectra for both electron helicities:



– measured first Compton asymmetry (Aug 2004)

Energy spectrum asymmetries:





- quantitative analysis running
- check for possible systematics

5. Summary and Outlook

- planned and successfully installed a magnetic chicane for a Compton backscattering polarimeter
- planned and successfully installed an optical system, laser intensities up to 90W @ 514.5 nm
- commissioned a detector and measured first backscattered photons
- planned and successfully installed a stabilization system for the laser optics
- commissioned an electron detector and improved SNR from 1:7 to 1:2
- measured first Compton asymmetries NEW!!

Next steps:

- refine laser polarization measurement and detector calibration to extract quantitative polarization results
- upgrade the vacuum system

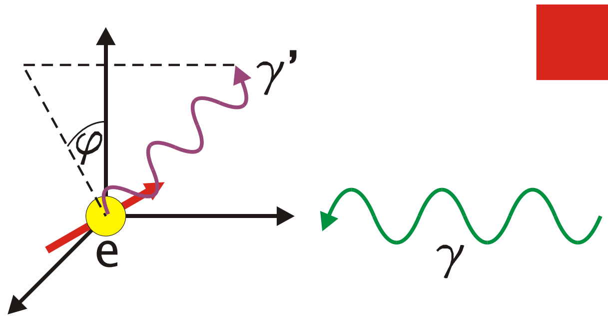
→ ready for longitudinal asymmetry program

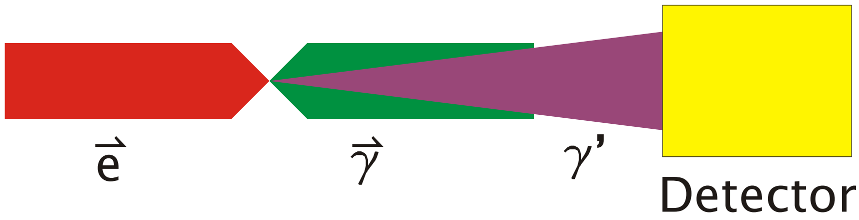
- upgrade to transverse spin measurement: use position-sensitive detector to measure spatial Compton asymmetry

→ ready for entire physics program

2. Compton Polarimetry

Scattering of photons on leptons





Compton cross-section:

Lipps, Tolhoek Physica XX(1954)

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

Q,V : "Stokes Parameters" (initial photon polarization)
Q : linear contribution
V : circular contribution (+1 : right circular, −1 : left circular)

With circular light: asymmetry between scattering of right- and left-handed photons

average over φ (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**