Das A4-Comptonrückstreupolarimeter

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A4-Kollaboration

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Universität Mainz

Das A4-Comptonrückstreupolarimeter

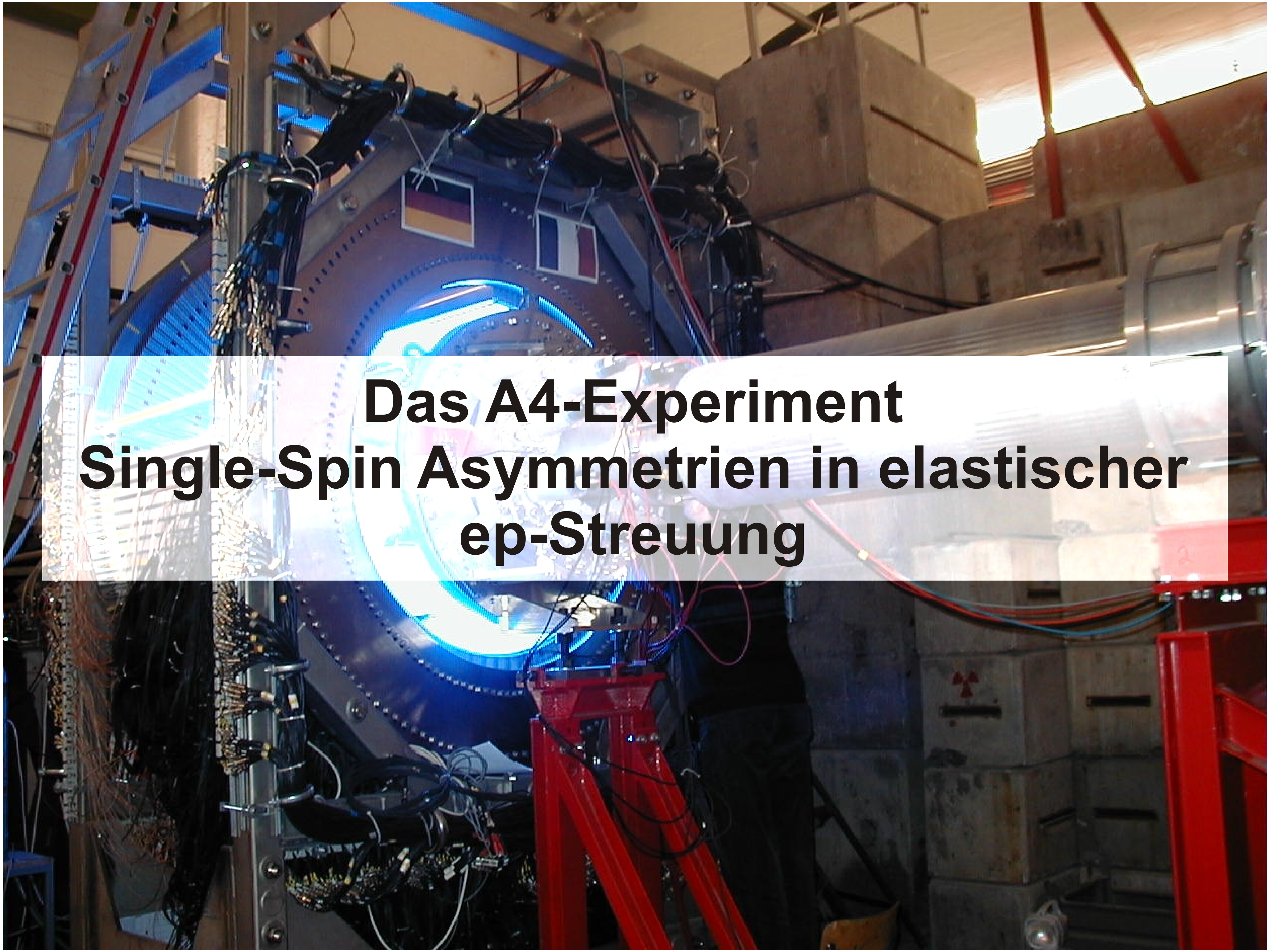
Das A4-Experiment

Compton-Polarimetrie

Konzept und Aufbau des A4-intra-cavity-Comptonrückstreupolarimeters

Erste Ergebnisse

Zusammenfassung und Ausblick



Das A4-Experiment
Single-Spin Asymmetrien in elastischer ep-Streuung

Single-Spin Asymmetrien in elastischer ep-Streuung

Paritätsverletzung

Bestimmung der seltsamen Formfaktoren des Nukleons

↓

Verteilung der s- und $\bar{s}$-Quarks im Nukleon

PV in der (1232)-Resonanz

Struktur des Nukleons

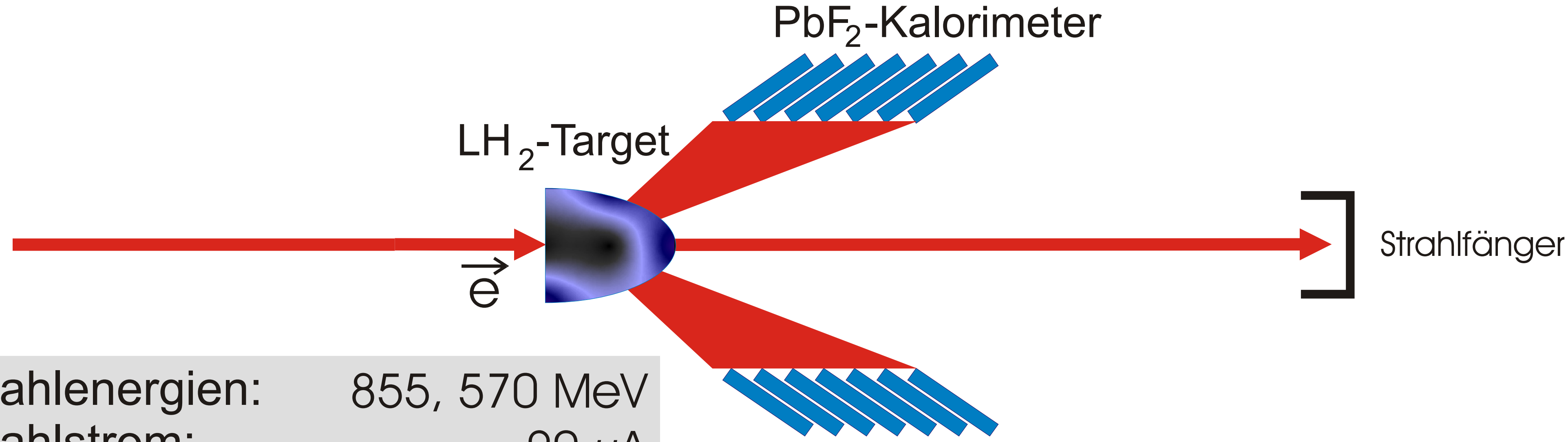
Doppelt virtuelle Comptonstreuung

Zwei-Photon Austausch

hadronischer “Strukturgehalt” des Nukleons

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

Aufbau des A4-Experiments

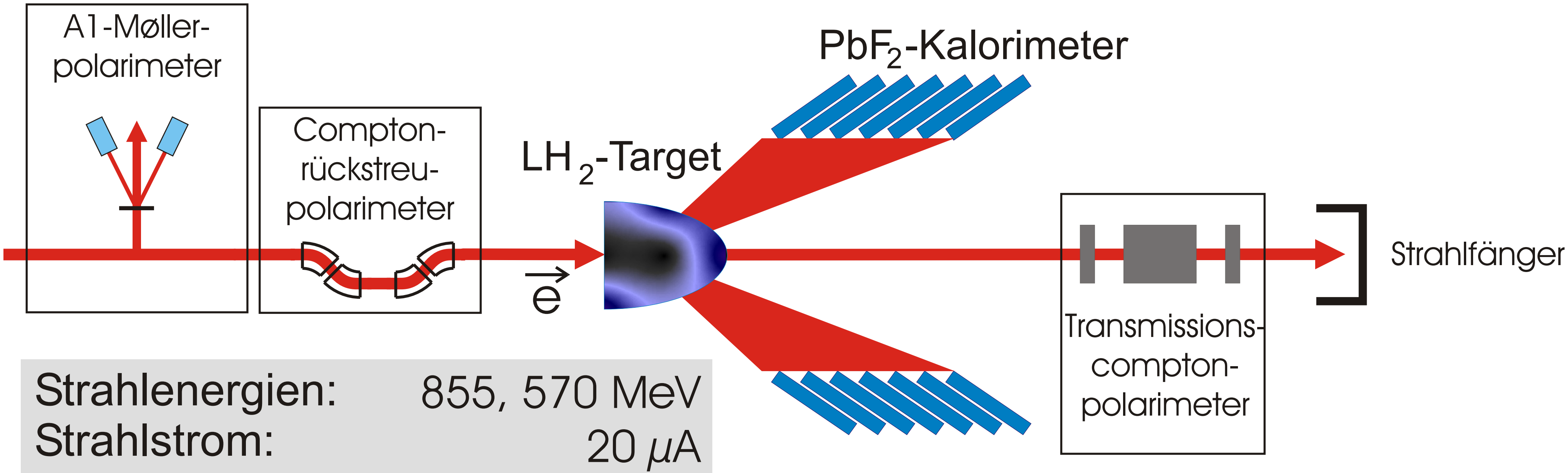

PbF_2-Kalorimeter
LH_2-Target
$\vec{e}$
Strahlfänger

Strahlenergien:	855, 570 MeV
Strahlstrom:	20 μA
Polarisationsgrad (P_e):	≈80%

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

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

Notwendigkeit der Polarisationsmessung

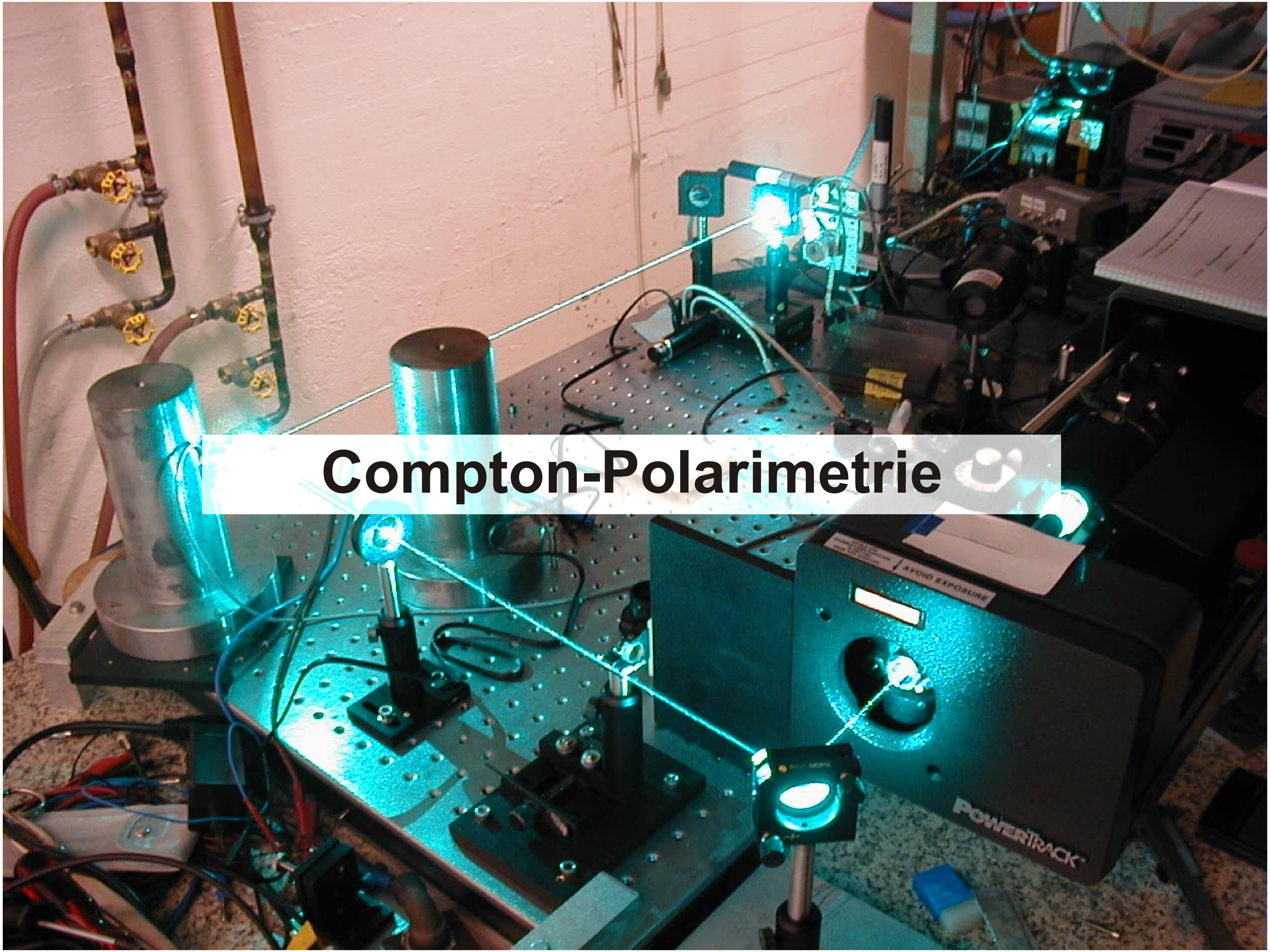

A1-Møller-
polarimeter
Compton-
rückstreu-
polarimeter
$\vec{e}$
LH $_2$-Target
PbF$_2$-Kalorimeter
Transmissions-
compton-
polarimeter
Strahlfänger

Strahlenergien: 855, 570 MeV
Strahlstrom: 20 μA
Polarisationsgrad (P_e): ≈80%

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

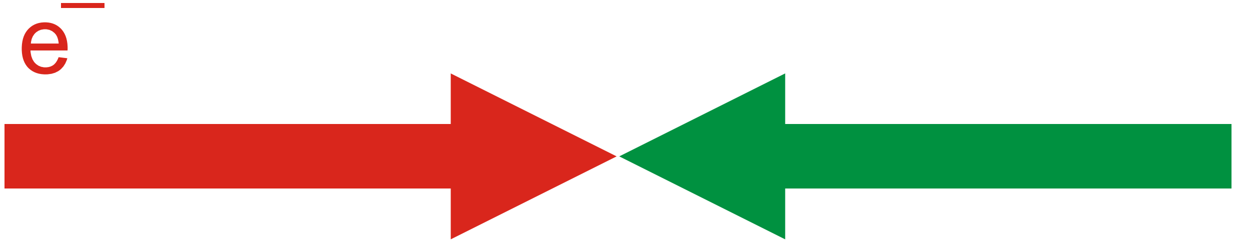
A1-Møller Polarimeter
Transmission-Comptonpolarimeter
Comptonrückstreupolarimeter

Compton-Polarimetrie

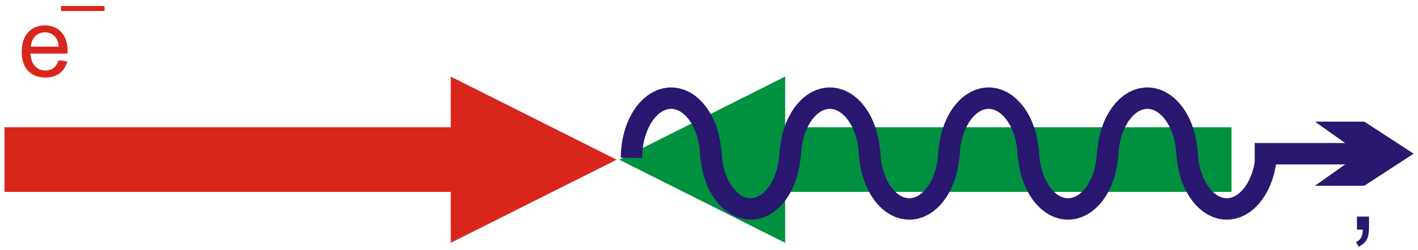

AVOID EXPOSURE
POWERTRACK

Comptonstreuung

Comptonstreuung



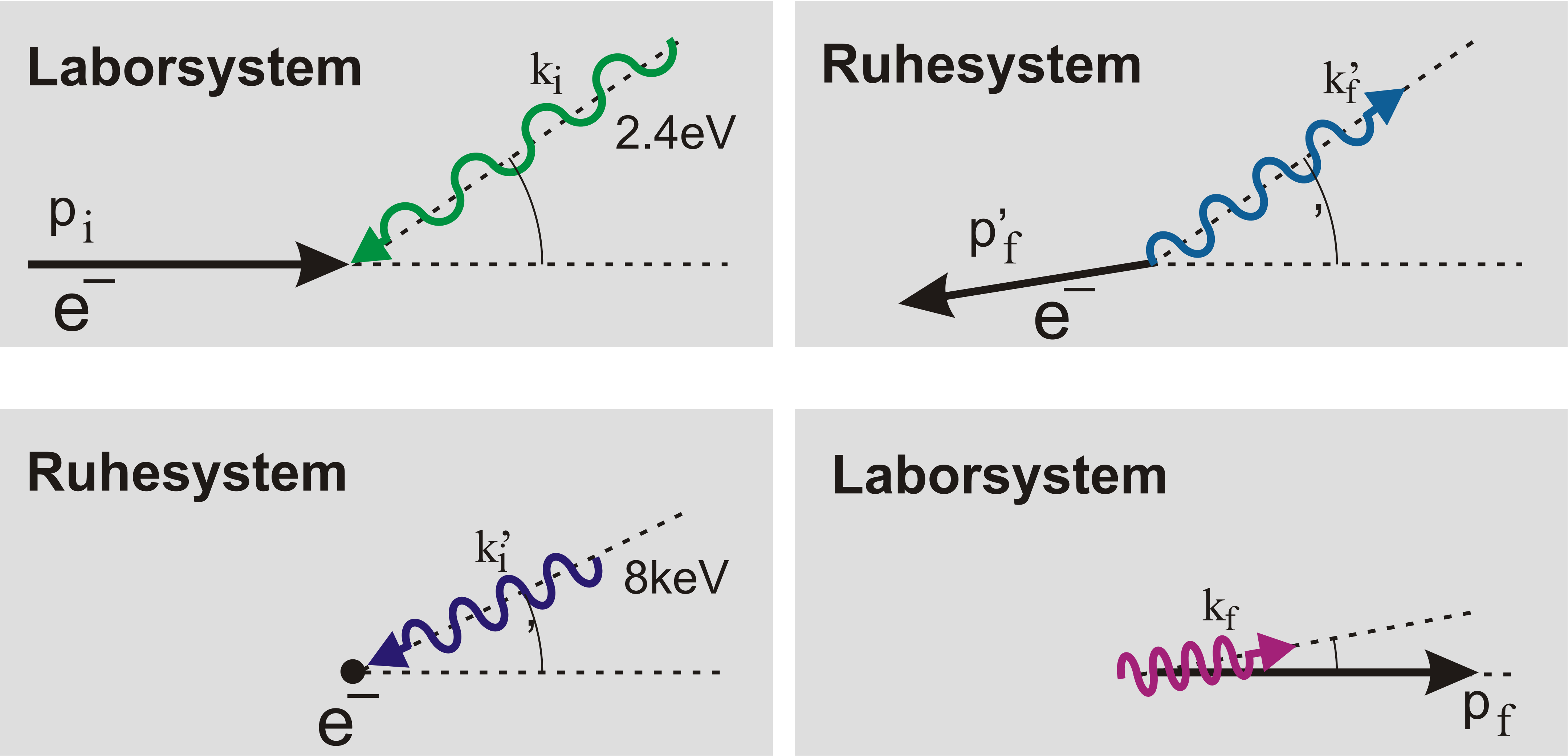
Comptonstreuung



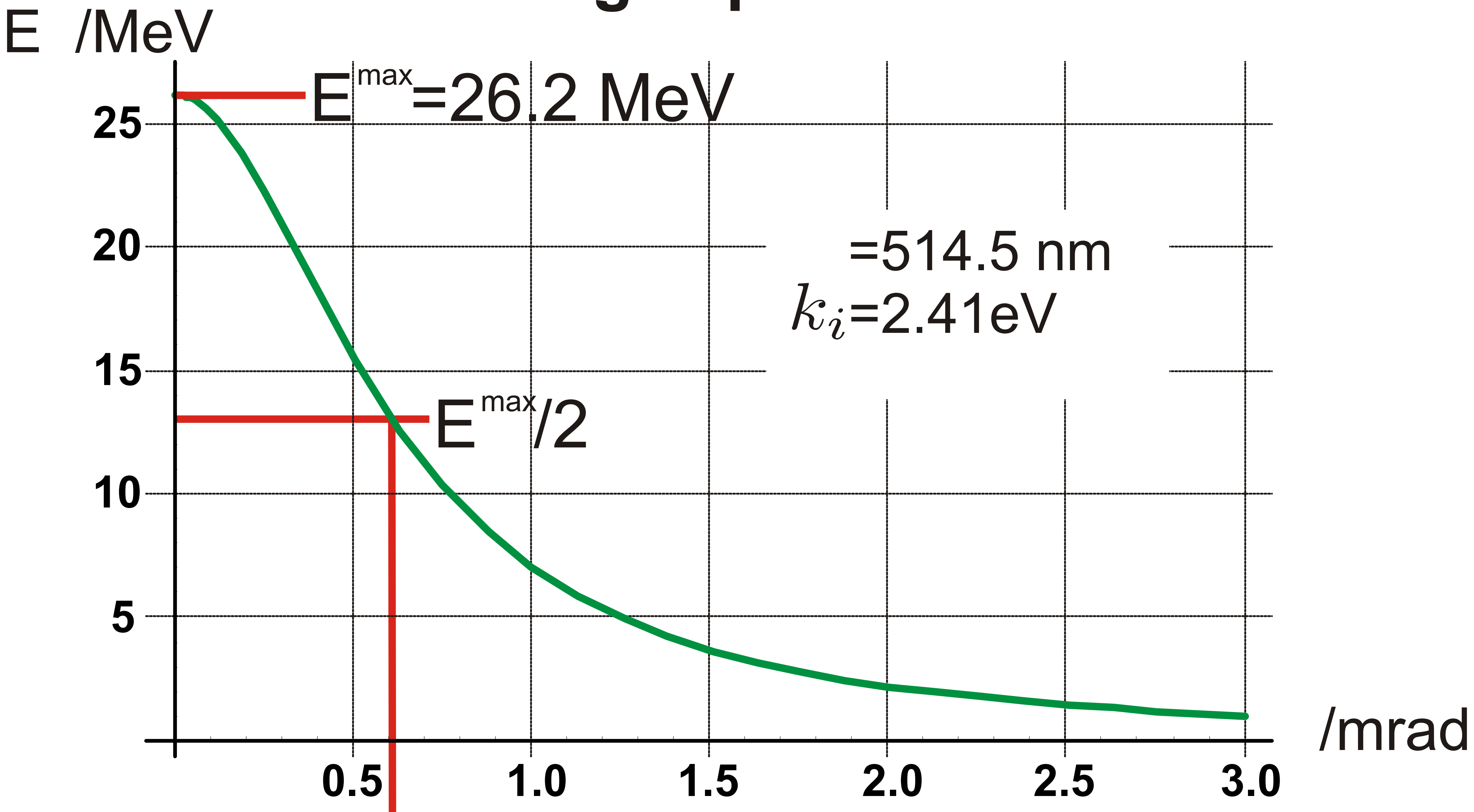
Kinematik

vor der Streuung

nach der Streuung


Laborsystem
k_i
2.4eV
p_i
e^-
Ruhesystem
k'_f
p'_f
e^-
Ruhesystem
k'_i
8keV
e^-
Laborsystem
k_f
p_f

Energiespektrum

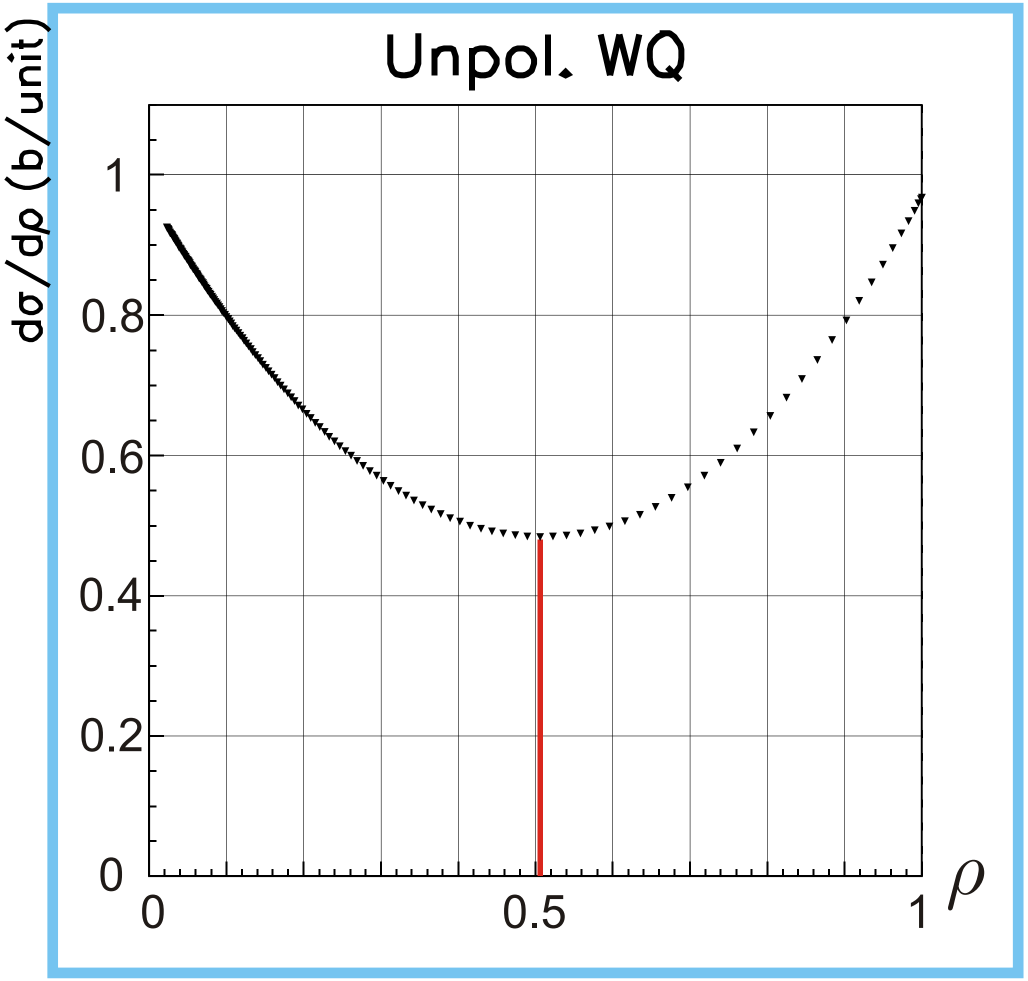


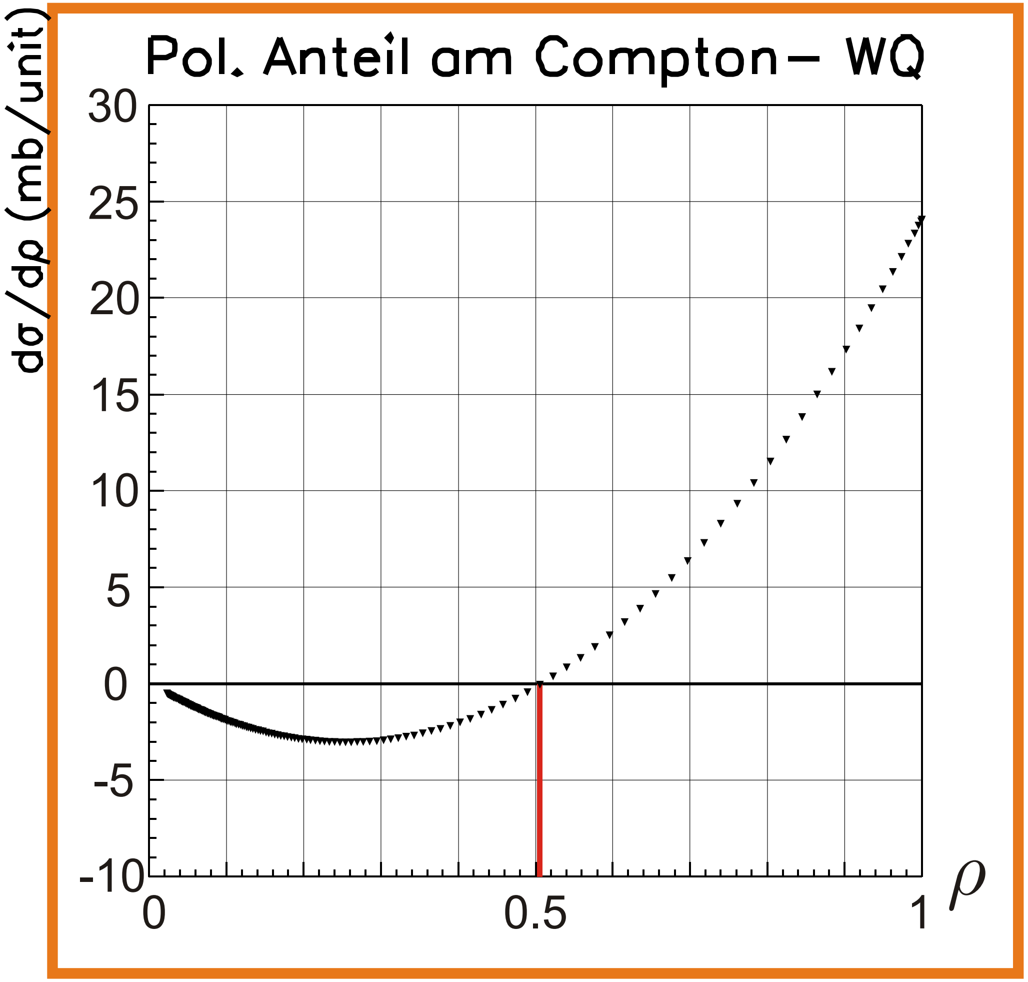
$$\boxed{\theta_\gamma = \frac{1}{\gamma} = 0.6\, mrad}$$

$$\rho = \frac{E}{E^{max}}$$

Wirkungsquerschnitt

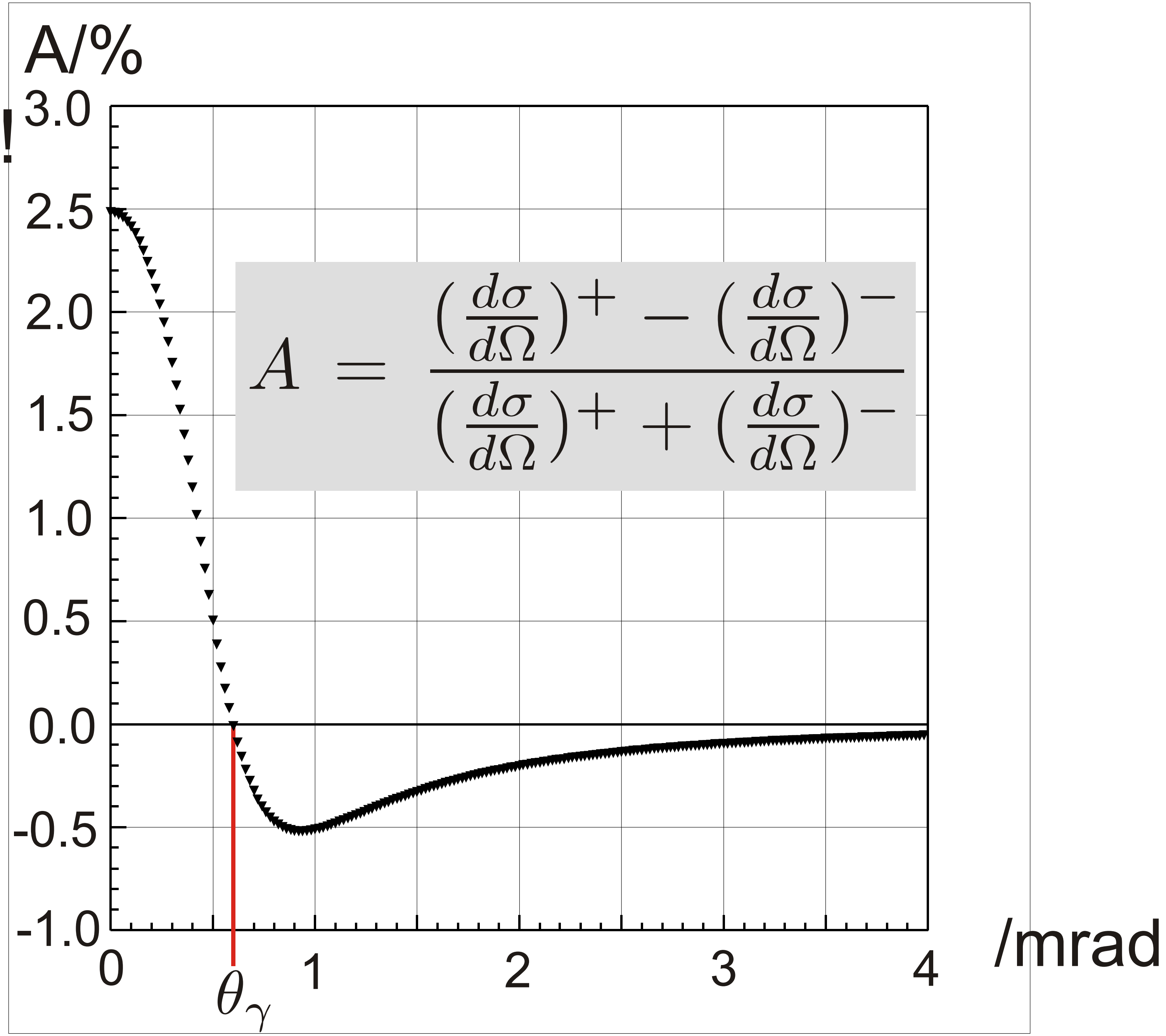
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} \mp P_{long} P_\gamma \frac{d\sigma_p}{d\Omega} \mp P_{trans} P_\gamma \cos\theta'_f \frac{d\sigma_a}{d\Omega}$$


Unpol. WQ


Pol. Anteil am Compton– WQ

Streuasymmetrie

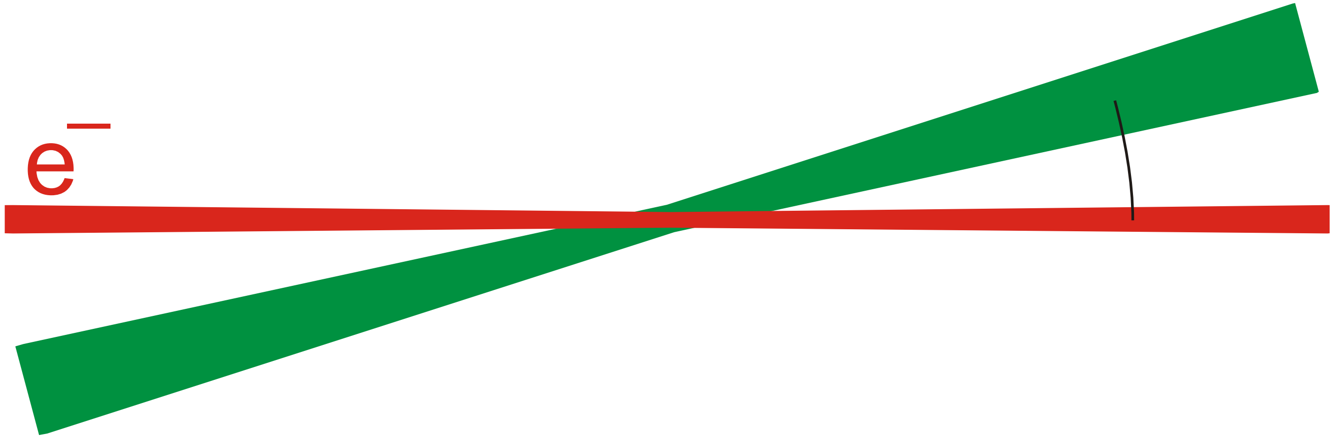
Formel für Asymmetrie!!



$$A = \frac{\left(\frac{d\sigma}{d\Omega}\right)^{+} - \left(\frac{d\sigma}{d\Omega}\right)^{-}}{\left(\frac{d\sigma}{d\Omega}\right)^{+} + \left(\frac{d\sigma}{d\Omega}\right)^{-}}$$

Luminosität

$$\mathcal{L} = \int v_{rel}\,\rho_1(x,y,z)\,\rho_2(x,y,z)\,d^3x$$

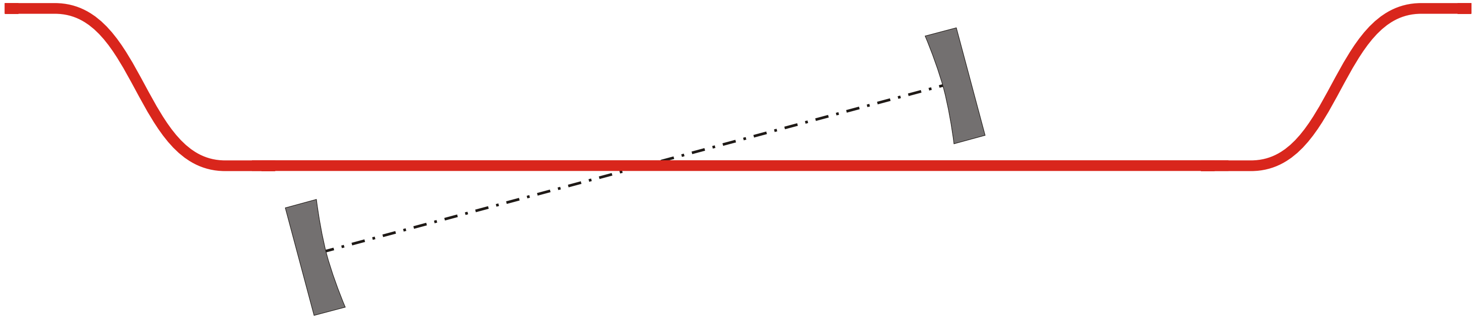


$$\dot{N}_{\gamma r}/P_{Laser} = 147\ Hz/W$$

Mögliche Lösungen

verschiedene Konzepte:

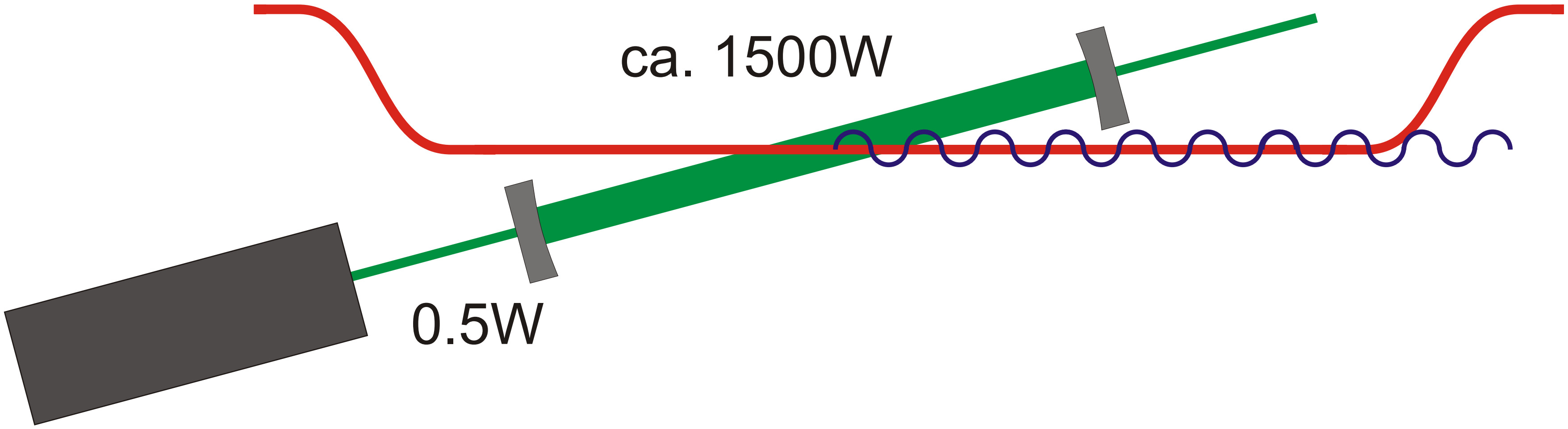
externer Fabry-Pérot Resonator



Mögliche Lösungen

verschiedene Konzepte:

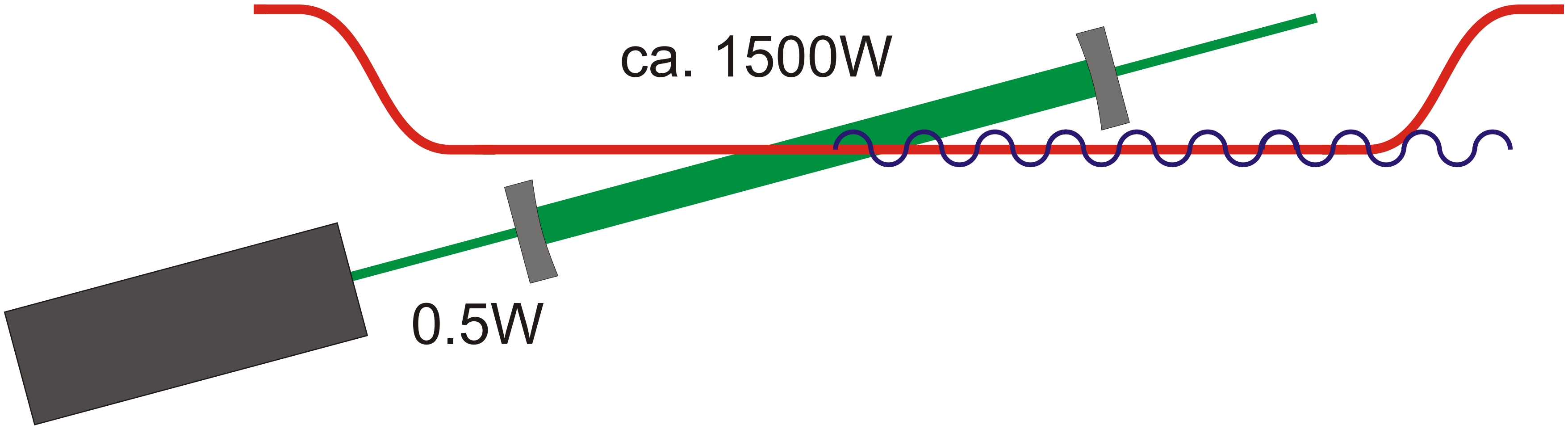
externer Fabry-Pérot Resonator


ca. 1500W
0.5W

Mögliche Lösungen

verschiedene Konzepte:

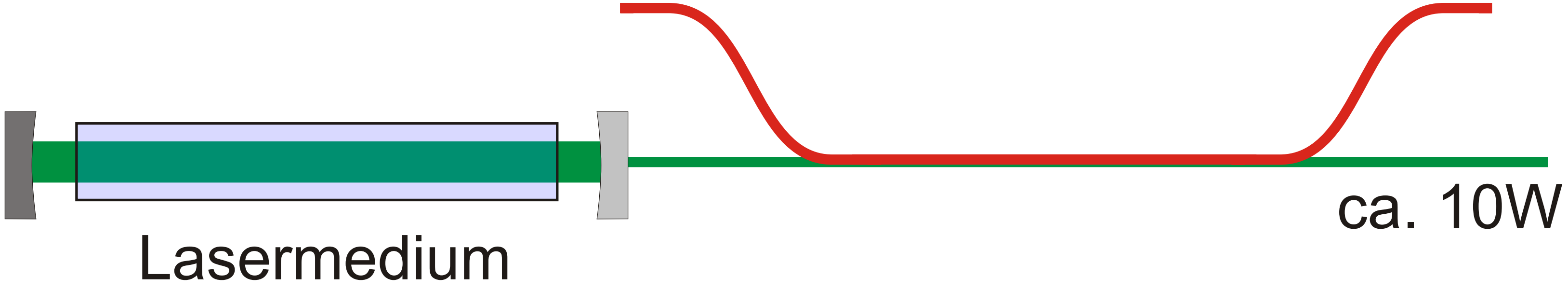
externer Fabry-Pérot Resonator



ca. 1500W

0.5W

intra-cavity Polarimeter



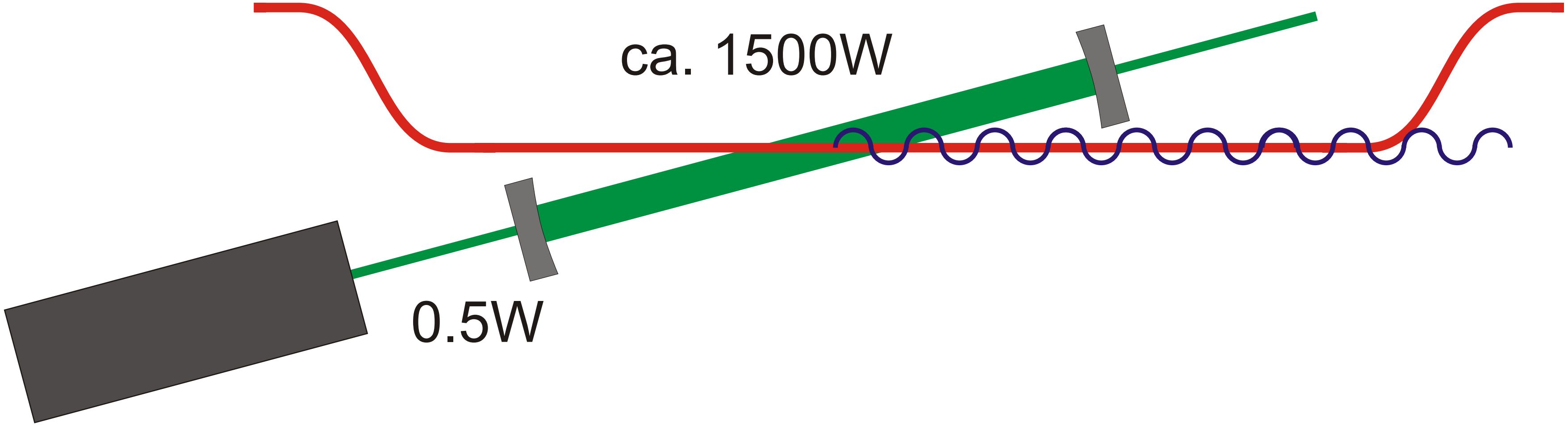
Lasermedium

ca. 10W

Mögliche Lösungen

verschiedene Konzepte:

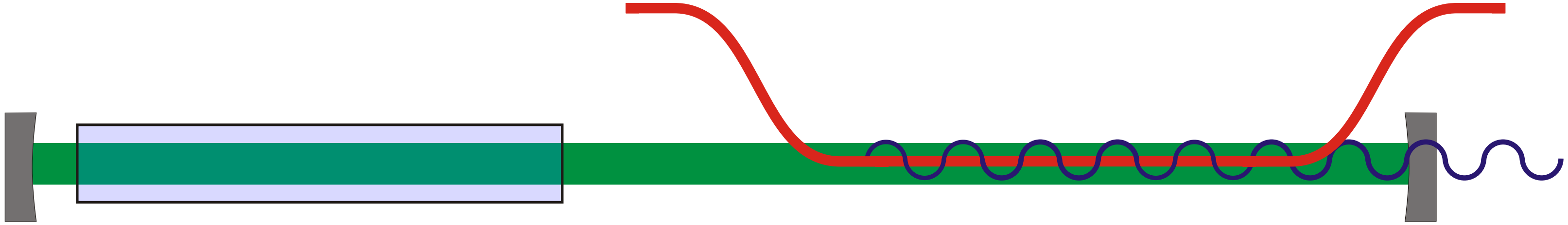
externer Fabry-Pérot Resonator



ca. 1500W

0.5W

intra-cavity Polarimeter

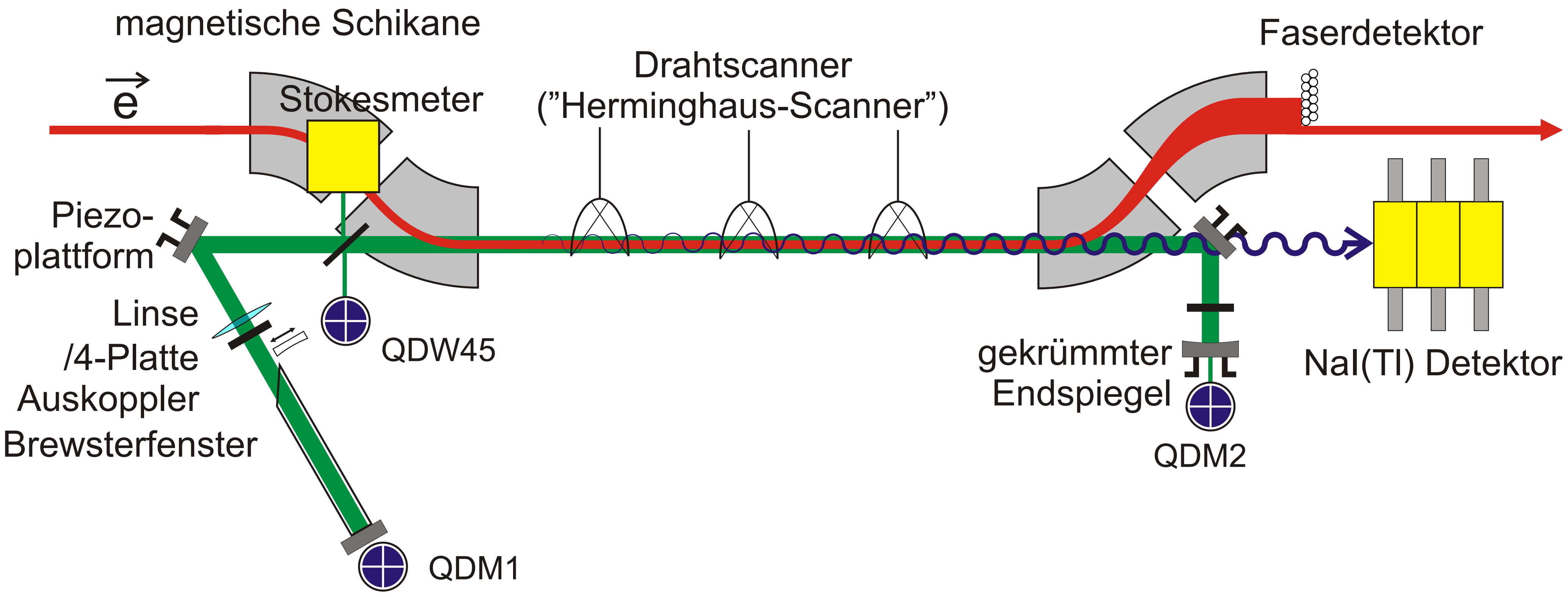


Lasermedium

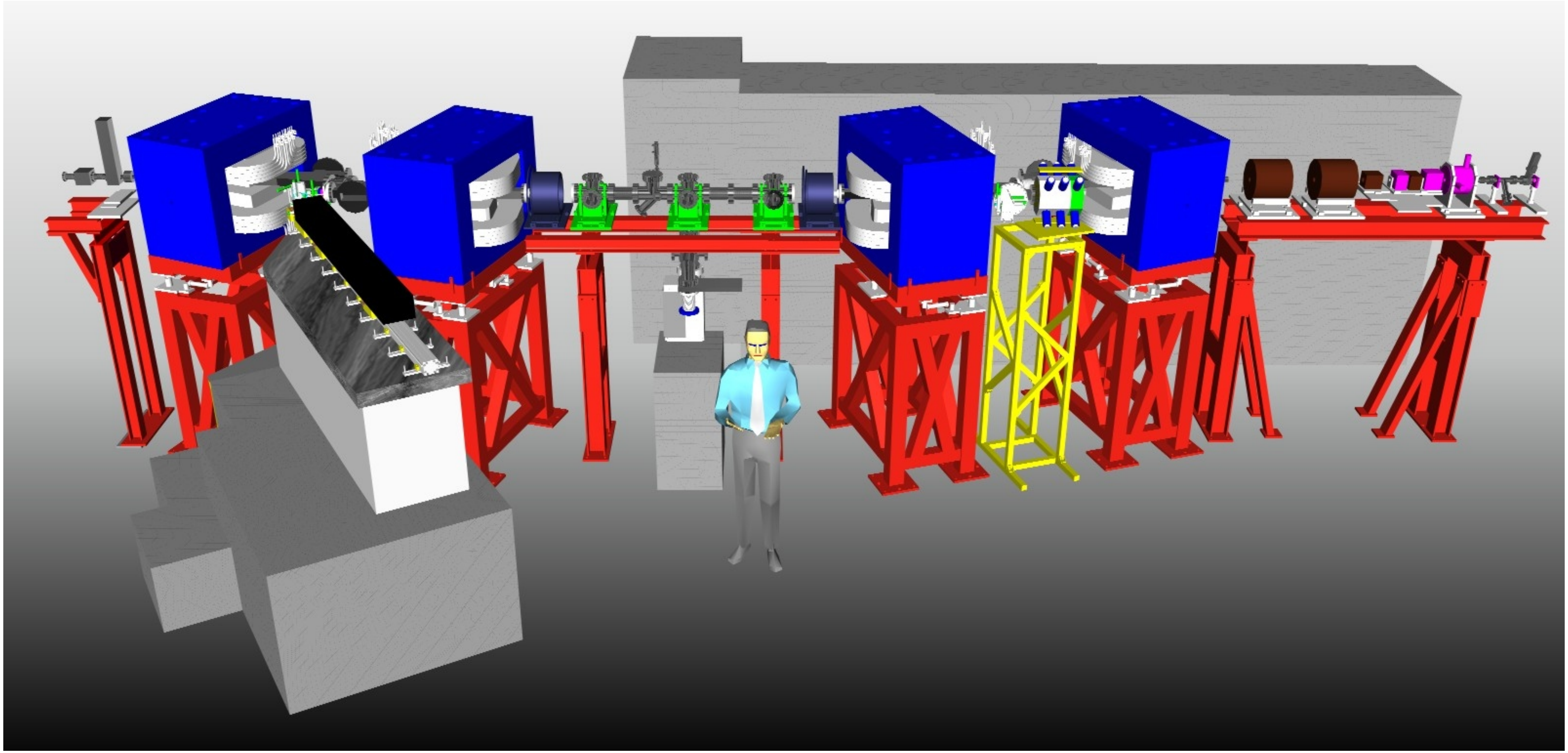
ca. 100W

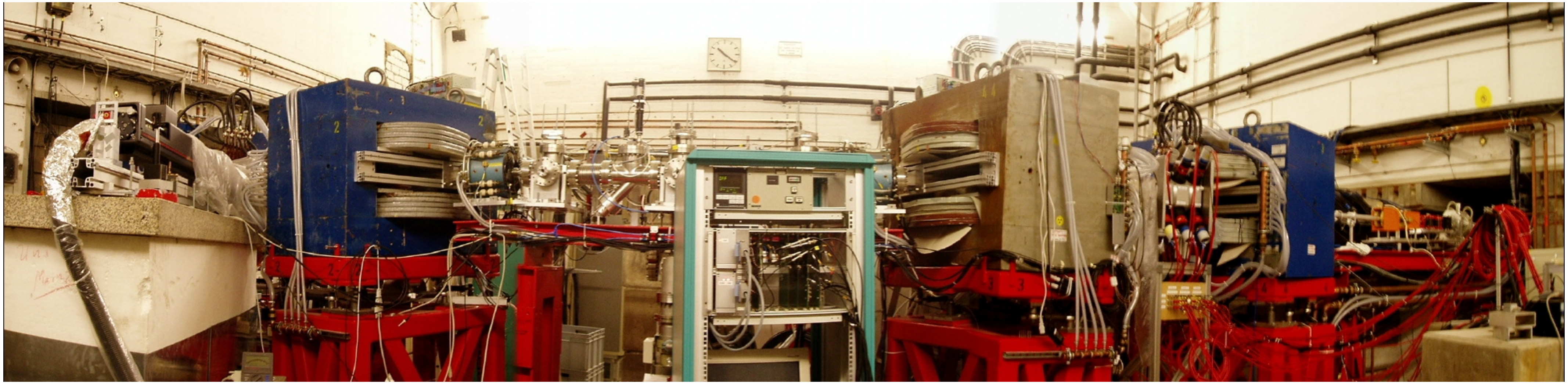
Konzept und Aufbau des intra-cavity-Comptonrückstreupolarimeters

Konzept und Aufbau des intra-cavity-Comptonrückstreupolarimeters

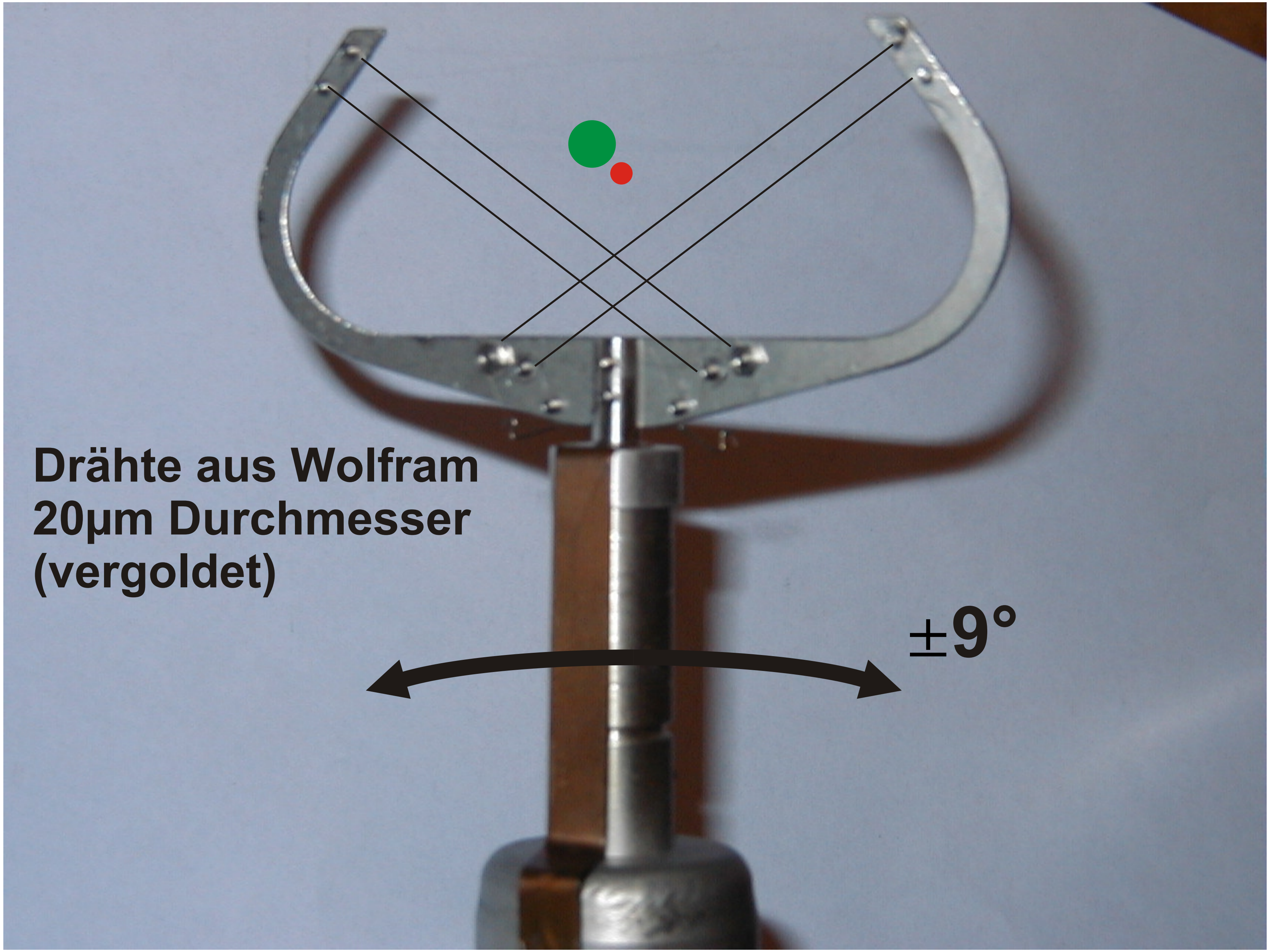

magnetische Schikane
$\vec{e}$
Stokesmeter
Drahtscanner
("Herminghaus-Scanner")
Faserdetektor
Piezo-
plattform
Linse
/4-Platte
Auskoppler
Brewsterfenster
QDW45
gekrümmter
Endspiegel
NaI(Tl) Detektor
QDM2
QDM1

Gesamtlänge Resonator: 7.8 m
Rayleighlänge in der Wechselwirkungszone: 2.5 m
Auskoppelspiegel zur Grobjustierung der Optik
Stokesmeter zur Messung des Polarisationszustands des Laserlichtes
Regelung zur Stabilisierung der Laserstrahllage



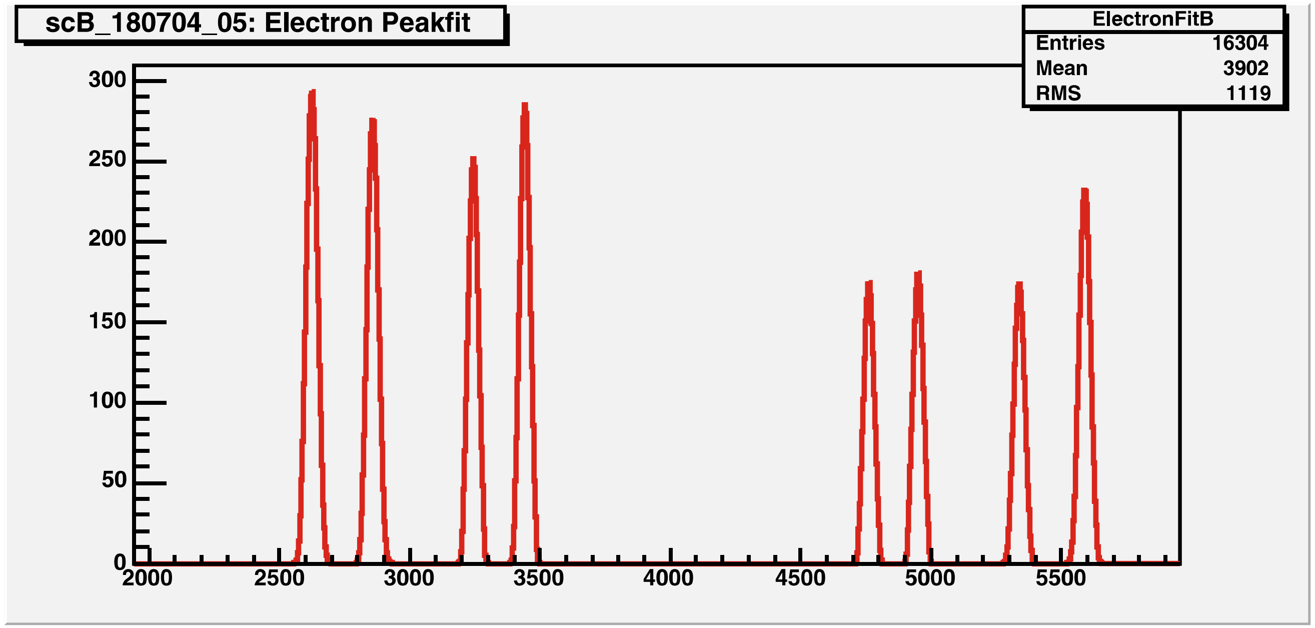


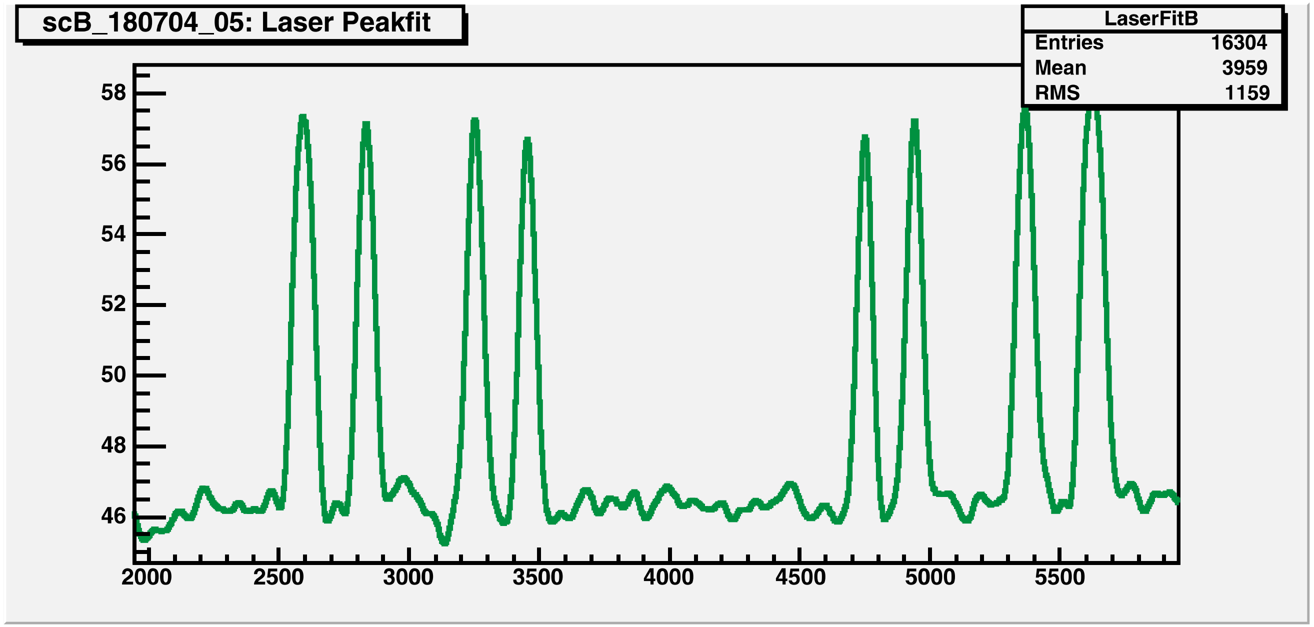
Kontrolle des Strahlüberlapps mit Drahtscannern



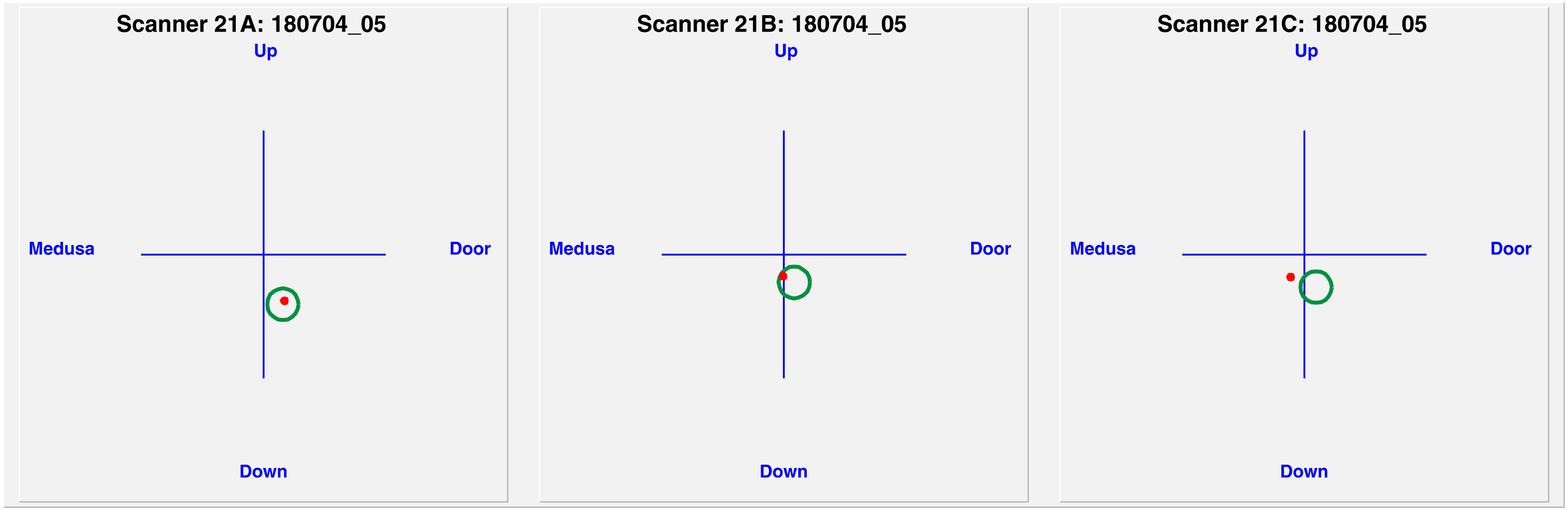
**Drähte aus Wolfram
20µm Durchmesser
(vergoldet)**

Rohdaten einer Scannermessung

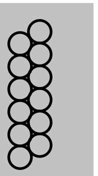




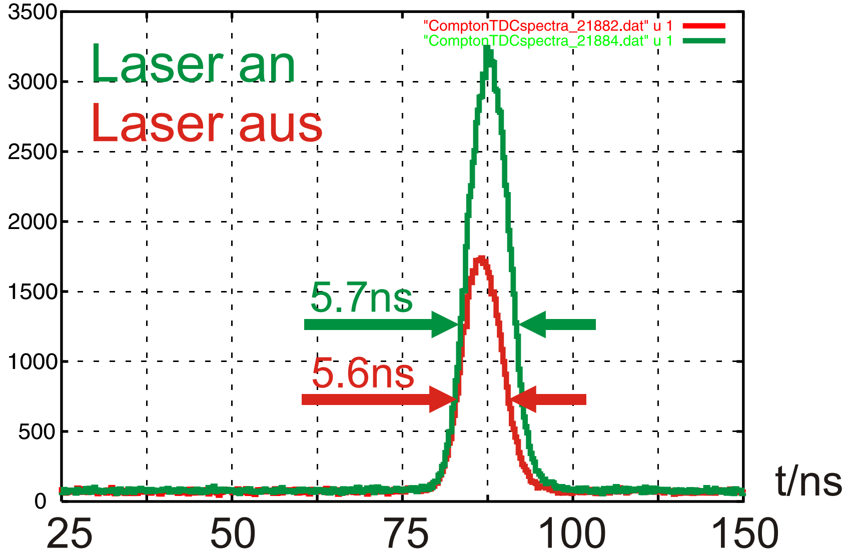
Ergebnis einer Scannermessung

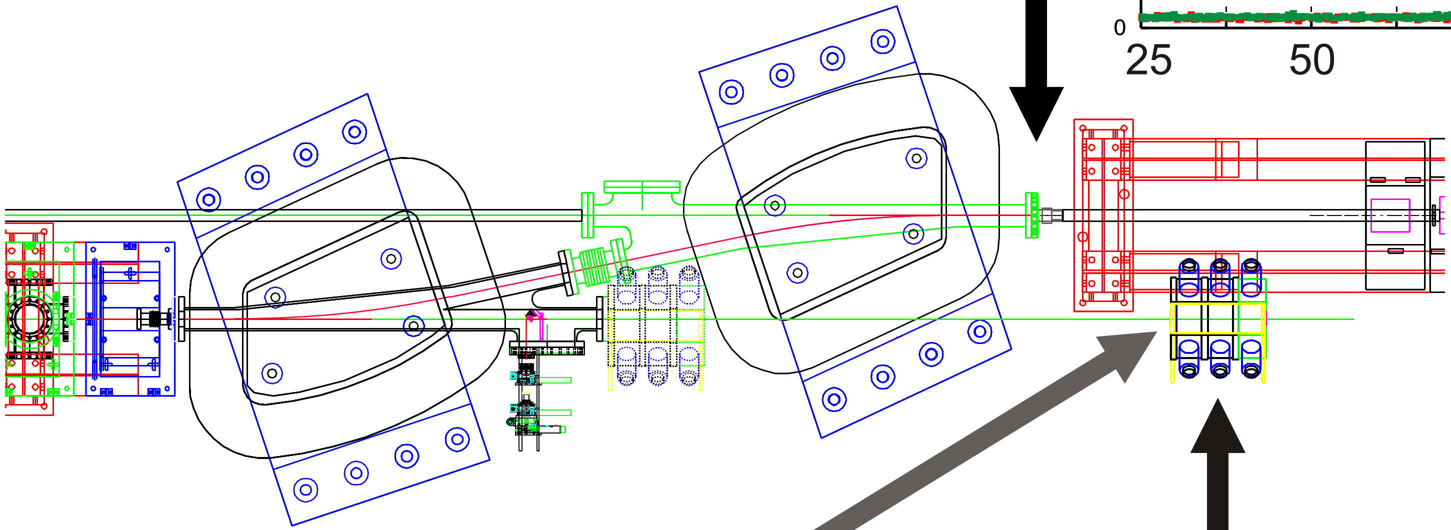


Elektronendetektor:



szintillierende Kunststoffasern
Faserdurchmesser 1 mm
24 Fasern in zwei Lagen zu je 12 Fasern
Energieauflösung bei 855 MeV
Strahlenergie ca. 2 MeV/Faser





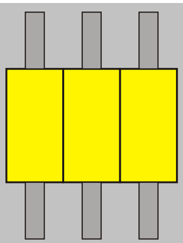
geplant:

ortsauflösender Photonendetektor:

Konverter mit Si-Streifendetektor (?)

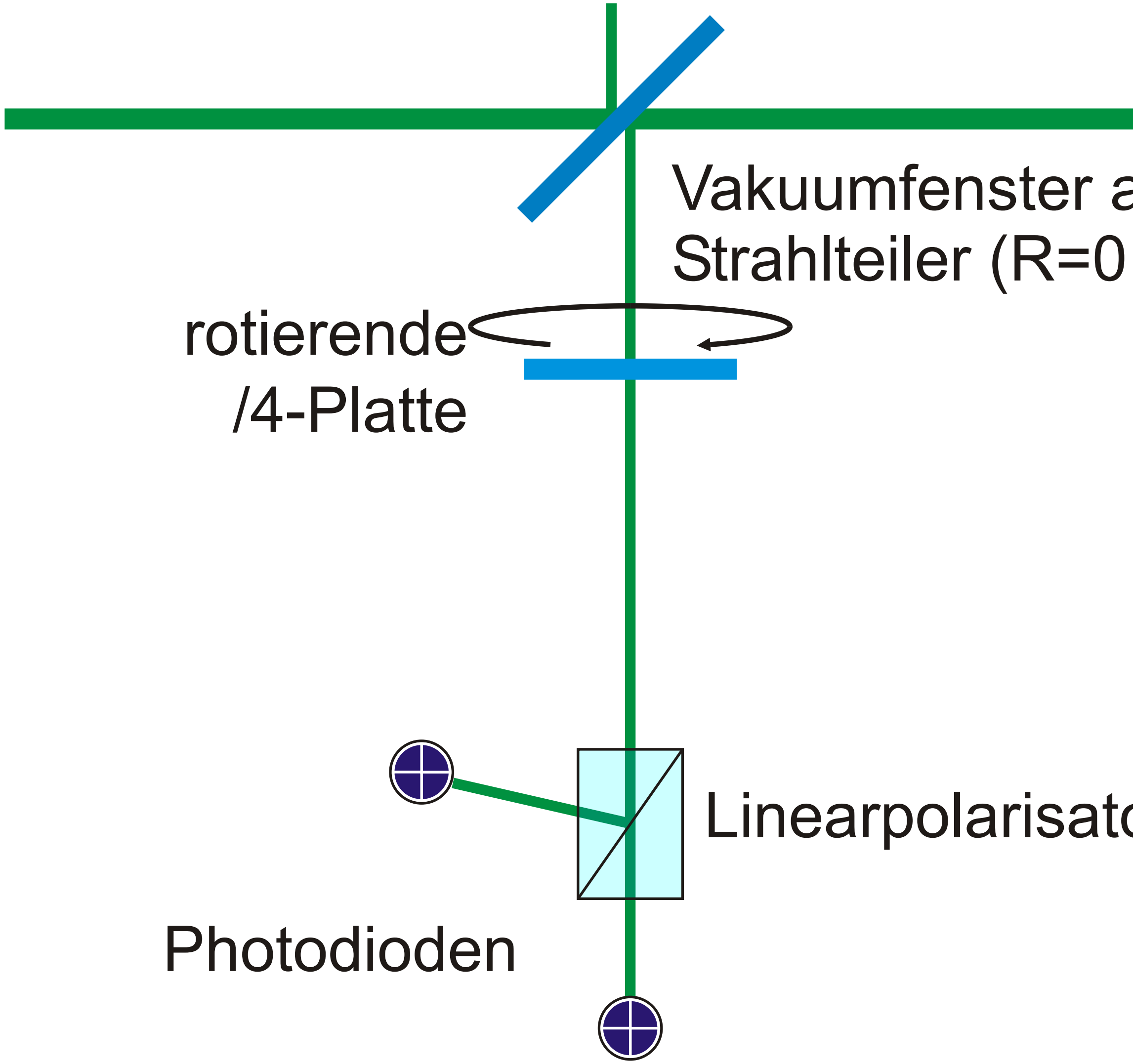
Messung der transversalen Polarisation

Photonendetektor:



NaI(Tl) Kalorimeter
12 Strahlungslängen (wg. Schauerentwicklung!)
Durchmesser 4.4 Moliereradien
segmentiert (3 Kristalle), 12 PMT

Messung der Polarisation des Laserlichts

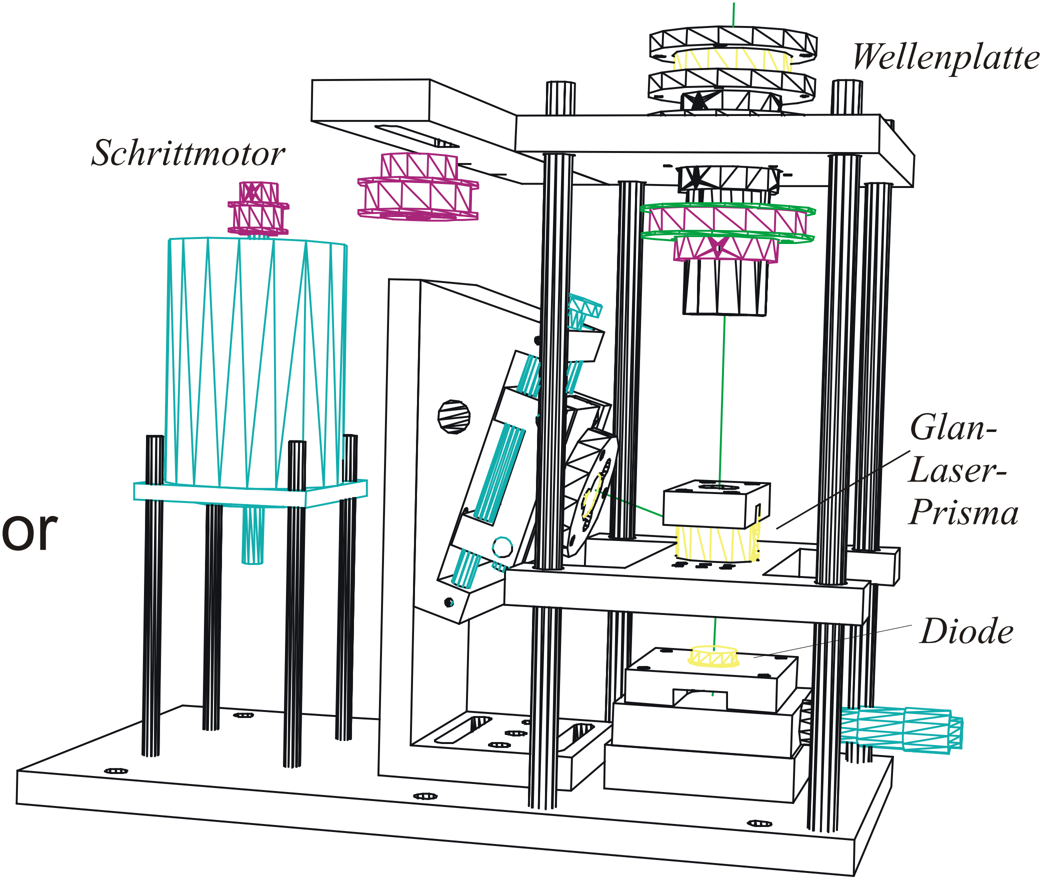


Vakuumfenster als
Strahlteiler (R=0.6%)

rotierende
/4-Platte

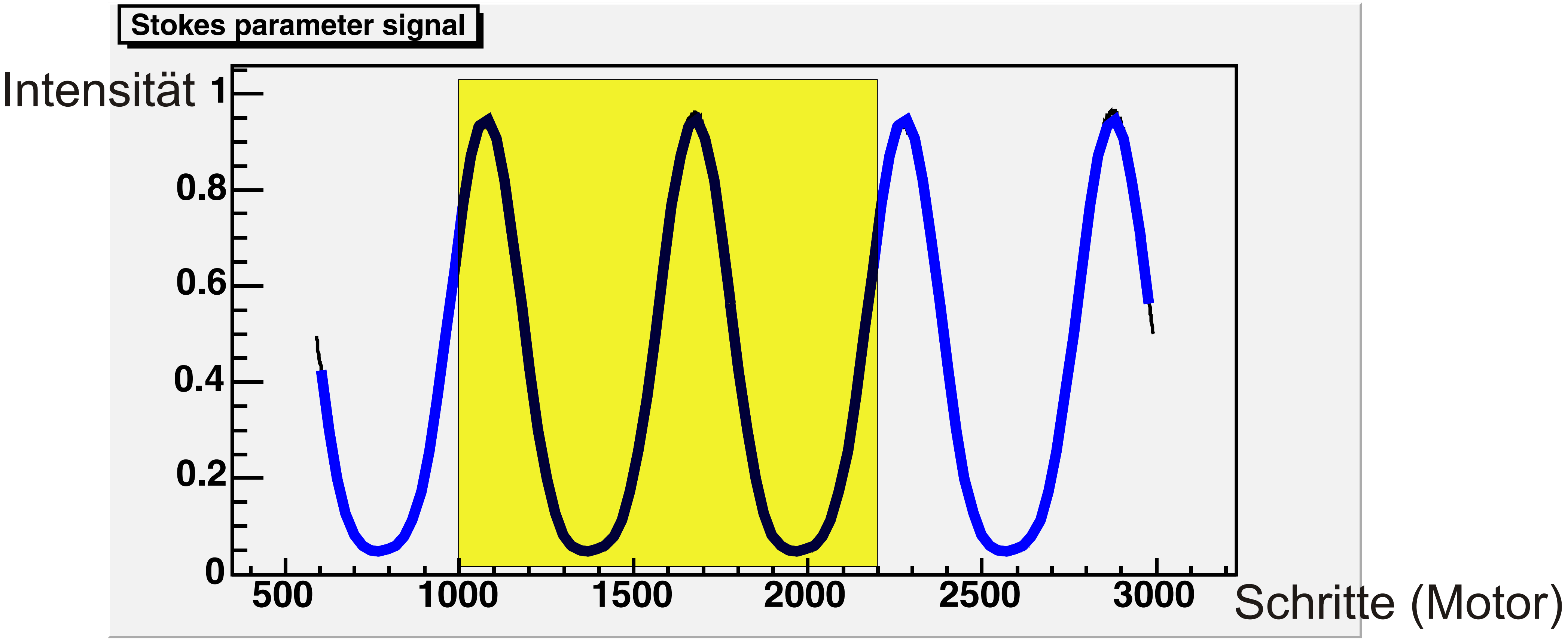
Linearpolarisator

Photodioden

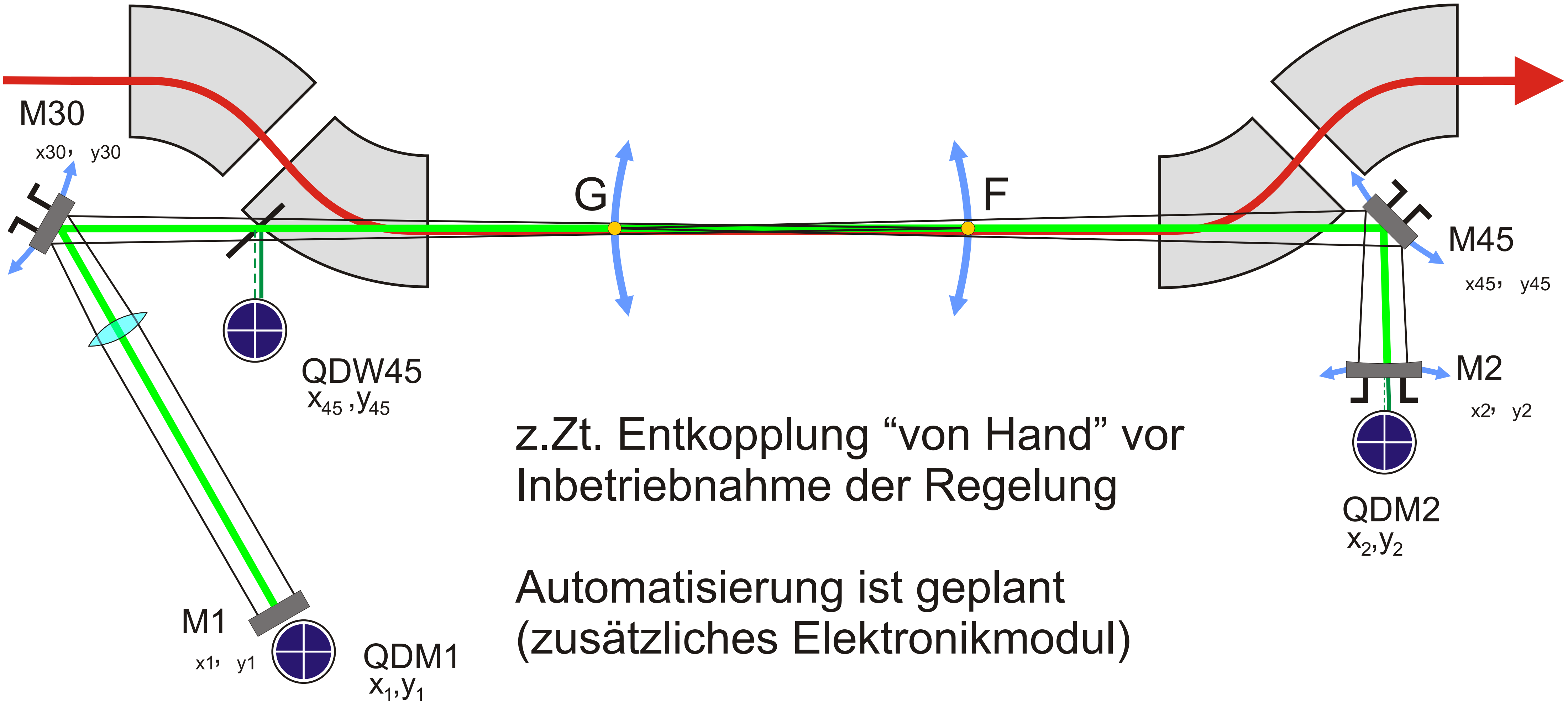

Wellenplatte
Schrittmotor
Glan-
Laser-
Prisma
Diode

Zirkularpolarisiertes Licht im Stokesmeter

$$I' = \frac{1}{4}\left[(2I+Q) - \boxed{\overset{\text{zirkularpol. Anteil}}{2V\sin 2\theta}} + U\sin 4\theta + Q\cos 4\theta\right]$$



Stabilisierung der Laserstrahllage

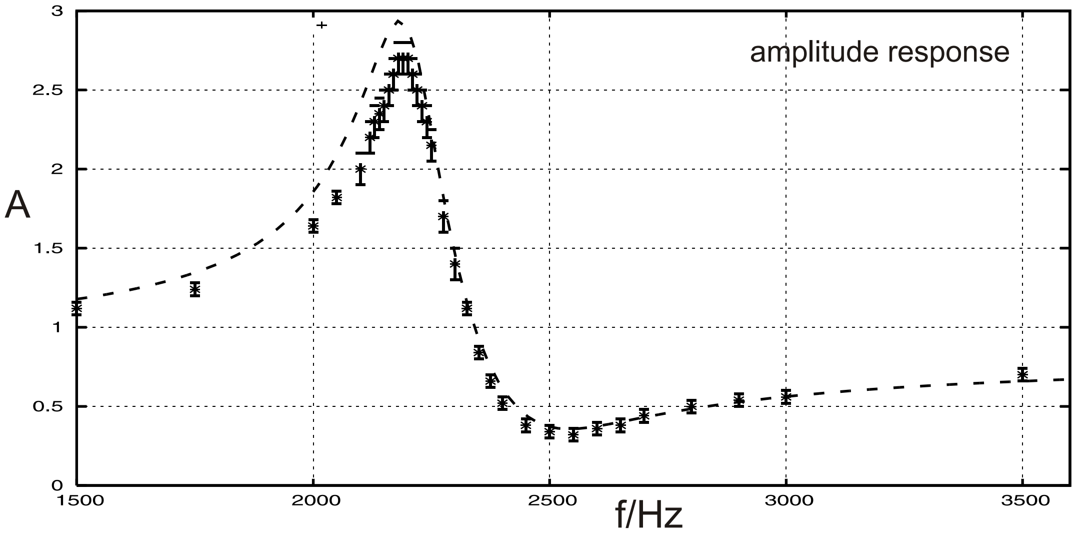

M30
x30, y30
G
F
M45
x45, y45
QDW45
x_{45}, y_{45}
M2
x2, y2
QDM2
x_2, y_2
M1
x1, y1
QDM1
x_1, y_1

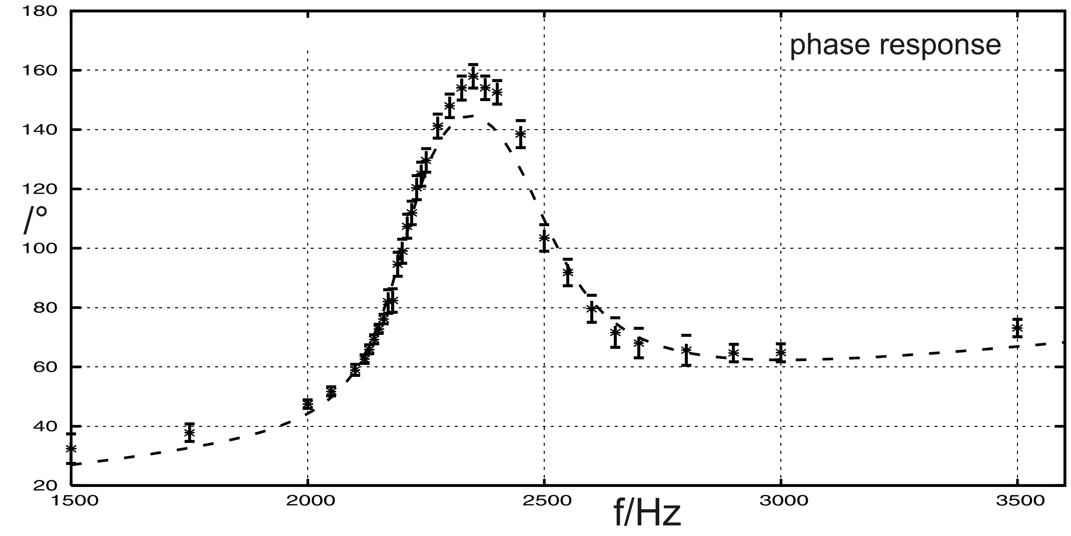
z.Zt. Entkopplung “von Hand” vor Inbetriebnahme der Regelung

Automatisierung ist geplant (zusätzliches Elektronikmodul)

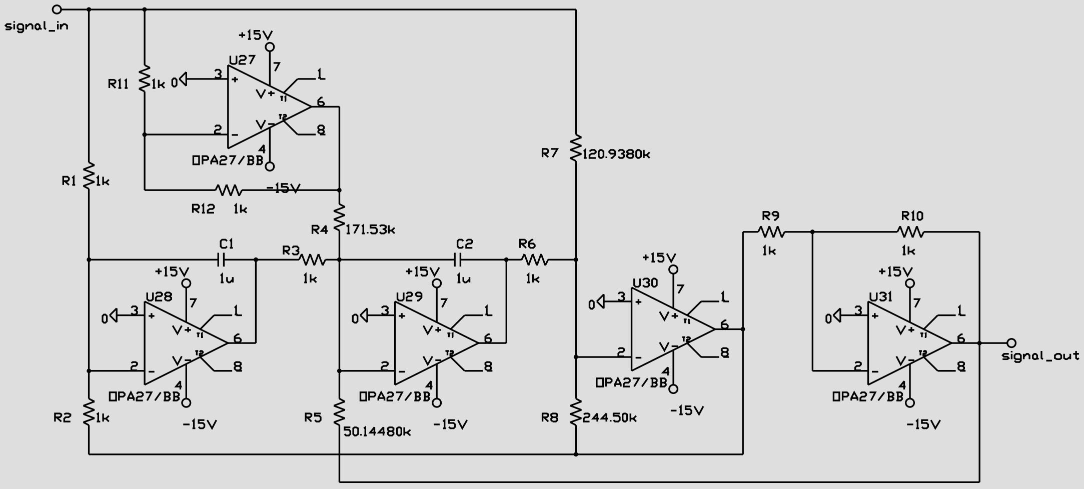
$$\begin{pmatrix} x_0 \\ x_{30} \\ x_2 \end{pmatrix} = \frac{1}{l_0} \begin{pmatrix} -l_2 f & -l_1 f - l_1 l_0 & -fR \\ l_1 l_2 & l_1^2 + l_1 l_0 & l_1 R \\ -l_2 R - l_2 l_0 & -l_1 R & -R^2 - R l_0 \end{pmatrix} \begin{pmatrix} \theta_{45} \\ \theta_{30} \\ \theta_2 \end{pmatrix}$$

Resonanz Piezo/Spiegel

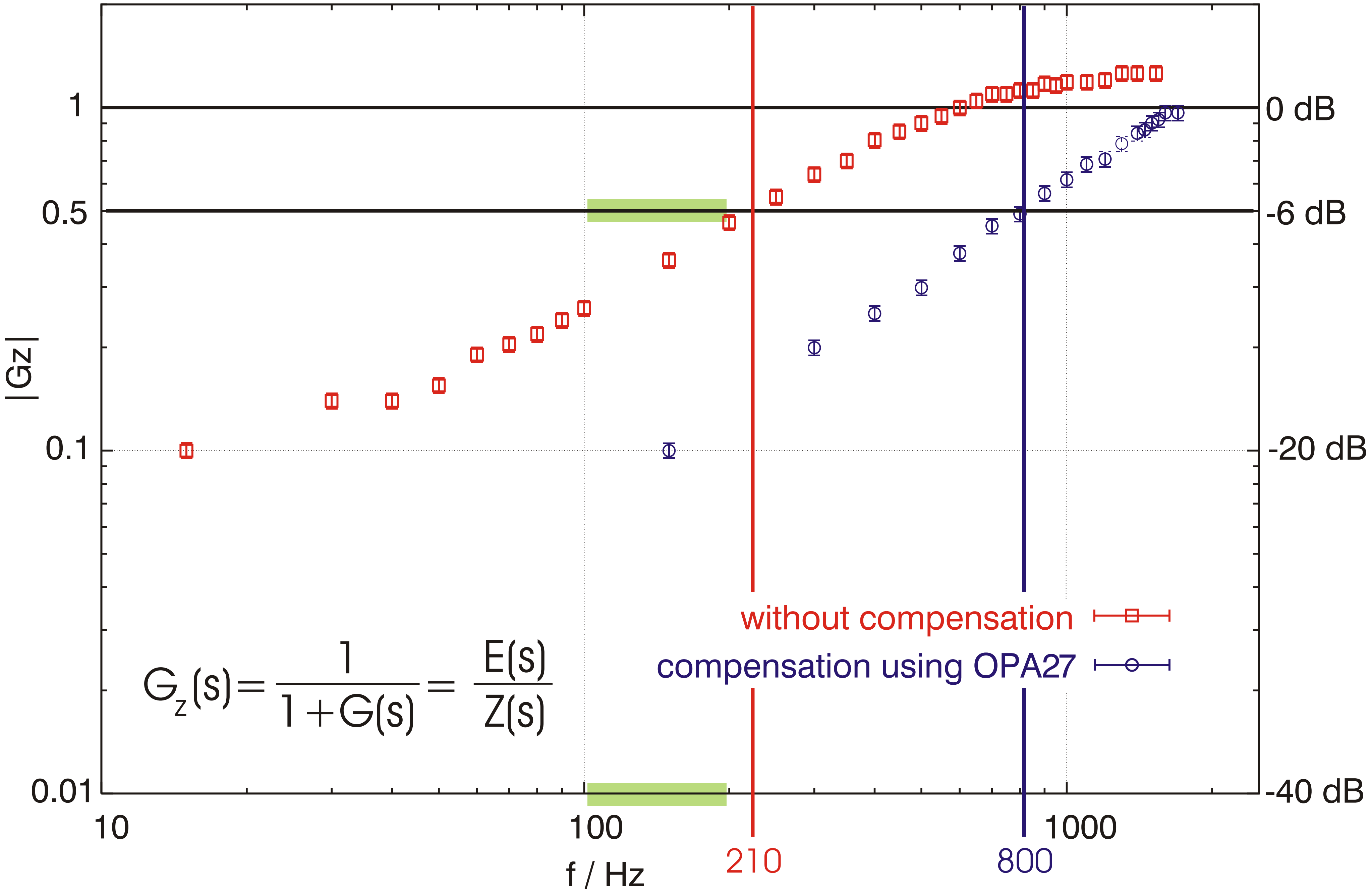




elektronische Nachbildung des Kehrwertes der Übertragungsfunktion der Resonanz

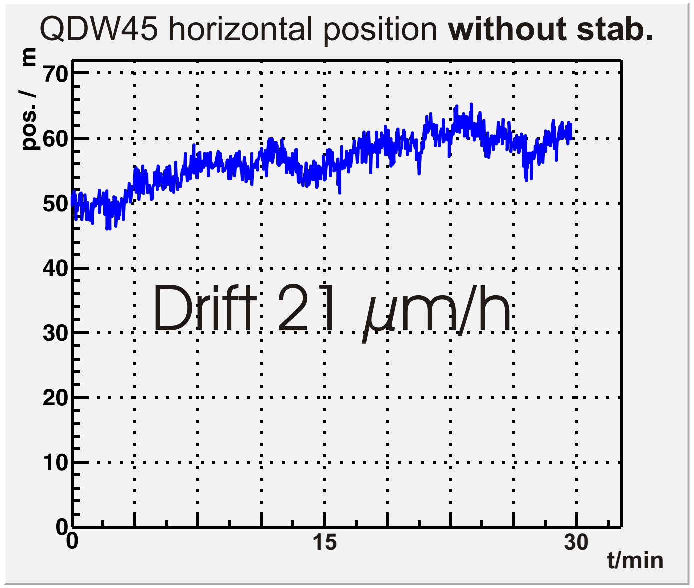

signal_in
R11 1k
R12 1k
R1 1k
R2 1k
R3 1k
R4 171.53k
R5 50.14480k
R6 1k
R7 120.9380k
R8 244.50k
R9 1k
R10 1k
C1 1u
C2 1u
U27
U28
U29
U30
U31
OPA27/BB
+15V
-15V
0
V+
V-
signal_out

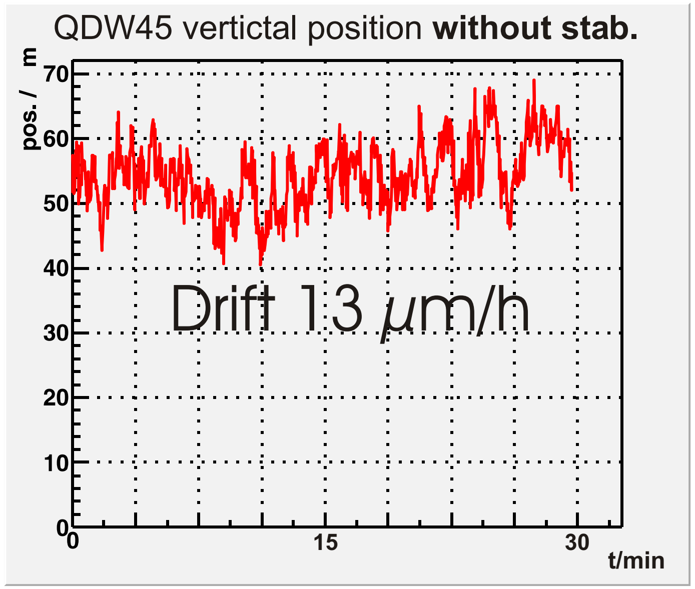
Störübertragungsfunktion mit/ohne Kompensation der Resonanz

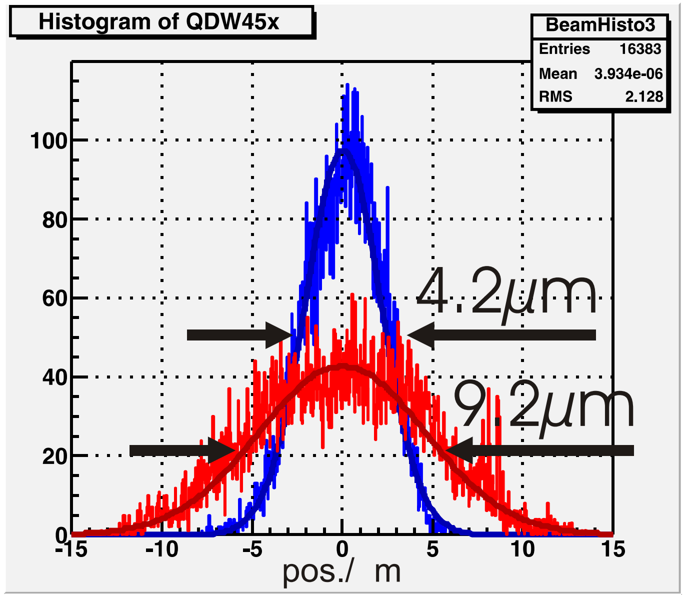


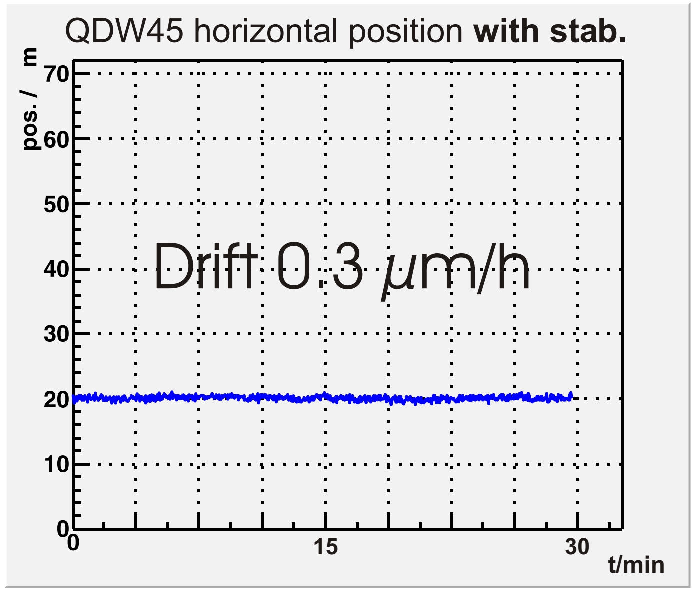
$$G_z(s) = \frac{1}{1+G(s)} = \frac{E(s)}{Z(s)}$$

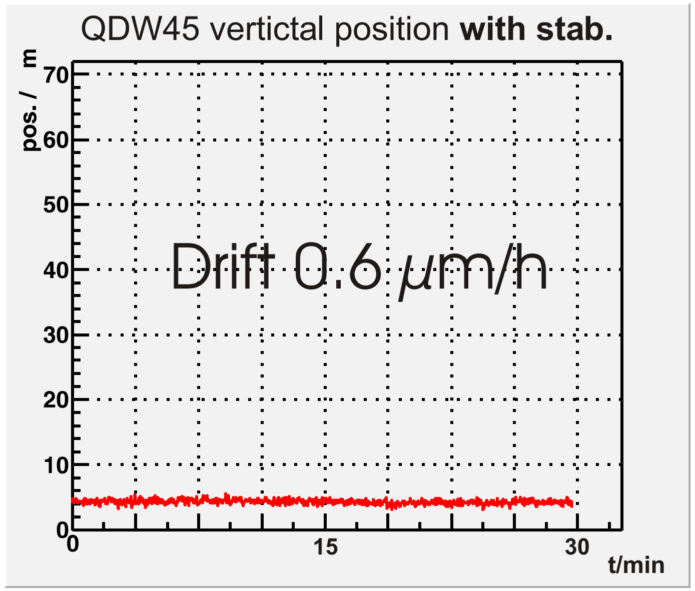
Testbetrieb der Spiegelstabilisierung

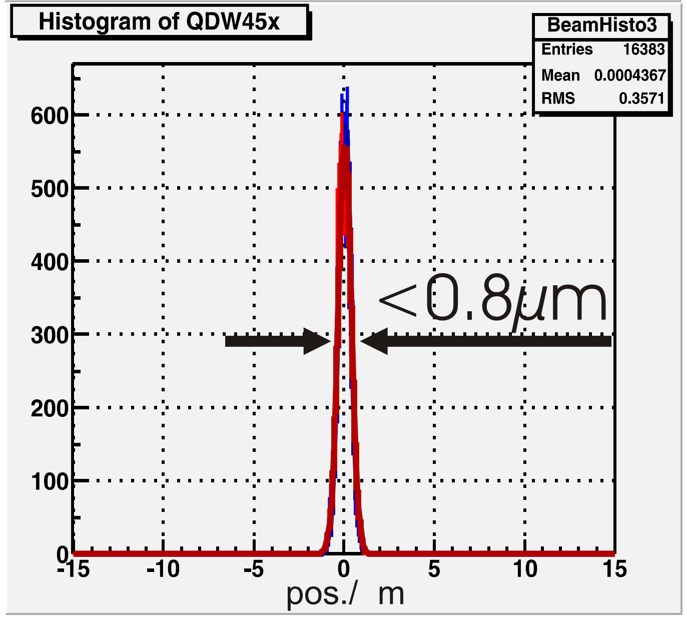






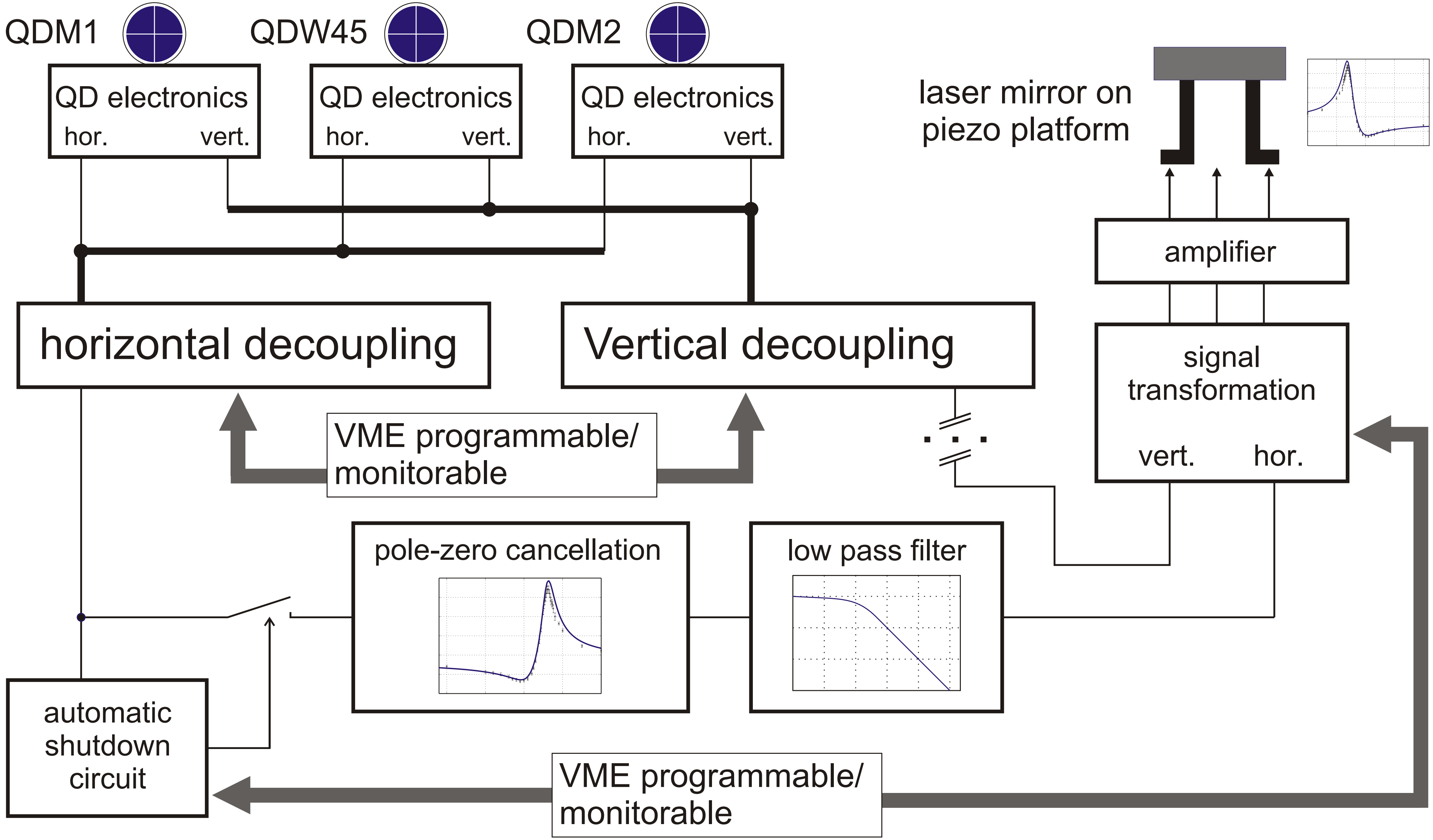






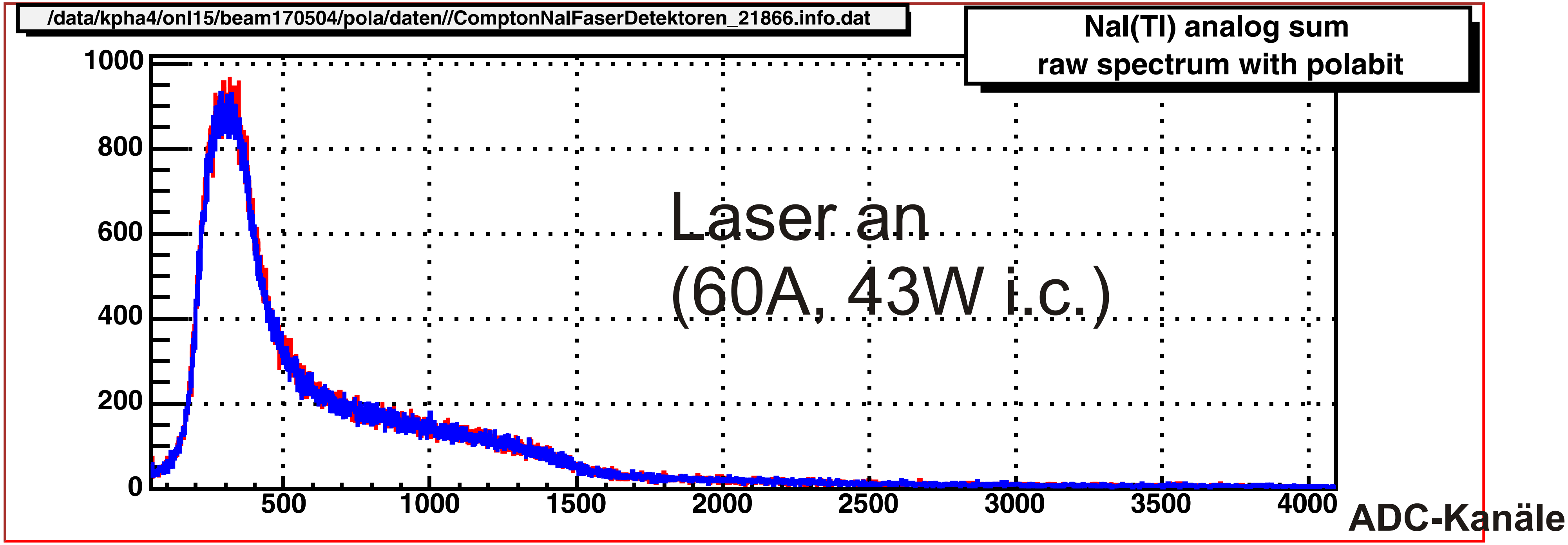
Stabilisierte Spiegel: M30, M2; Quadrantendioden: QDM1, QDW45; ISA-ADC: 9.7 Sa/s

Blockschaltbild der Spiegelregelung

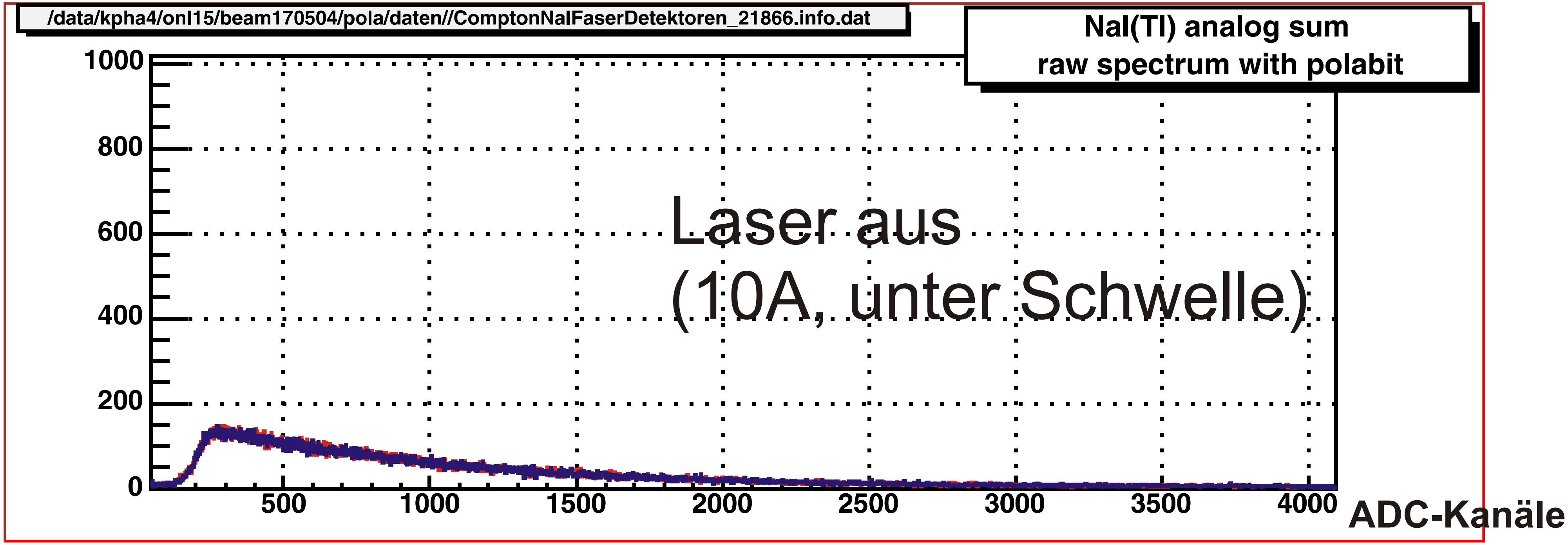

QDM1
QDW45
QDM2
QD electronics
hor.
vert.
QD electronics
hor.
vert.
QD electronics
hor.
vert.
laser mirror on piezo platform
amplifier
horizontal decoupling
Vertical decoupling
signal transformation
vert.
hor.
VME programmable/ monitorable
pole-zero cancellation
low pass filter
automatic shutdown circuit
VME programmable/ monitorable

Erste Ergebnisse

Energiespektren Laser an / aus (Rohdaten)

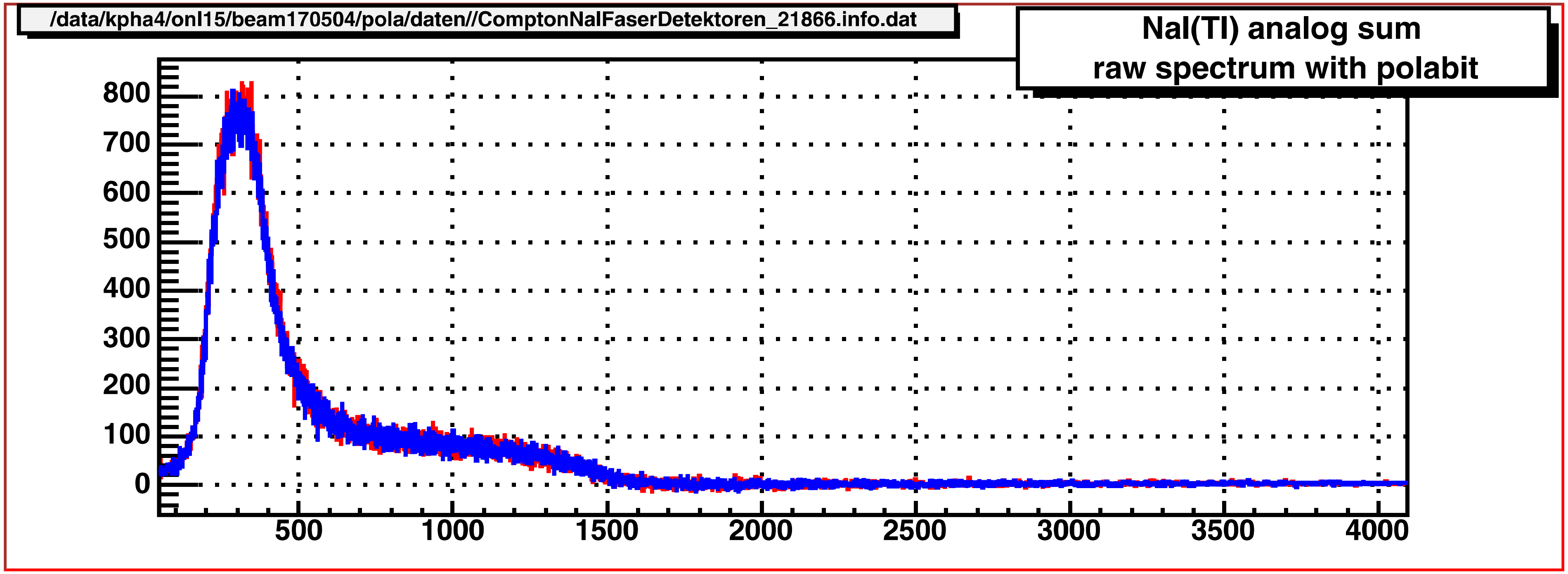


Laser an
(60A, 43W i.c.)

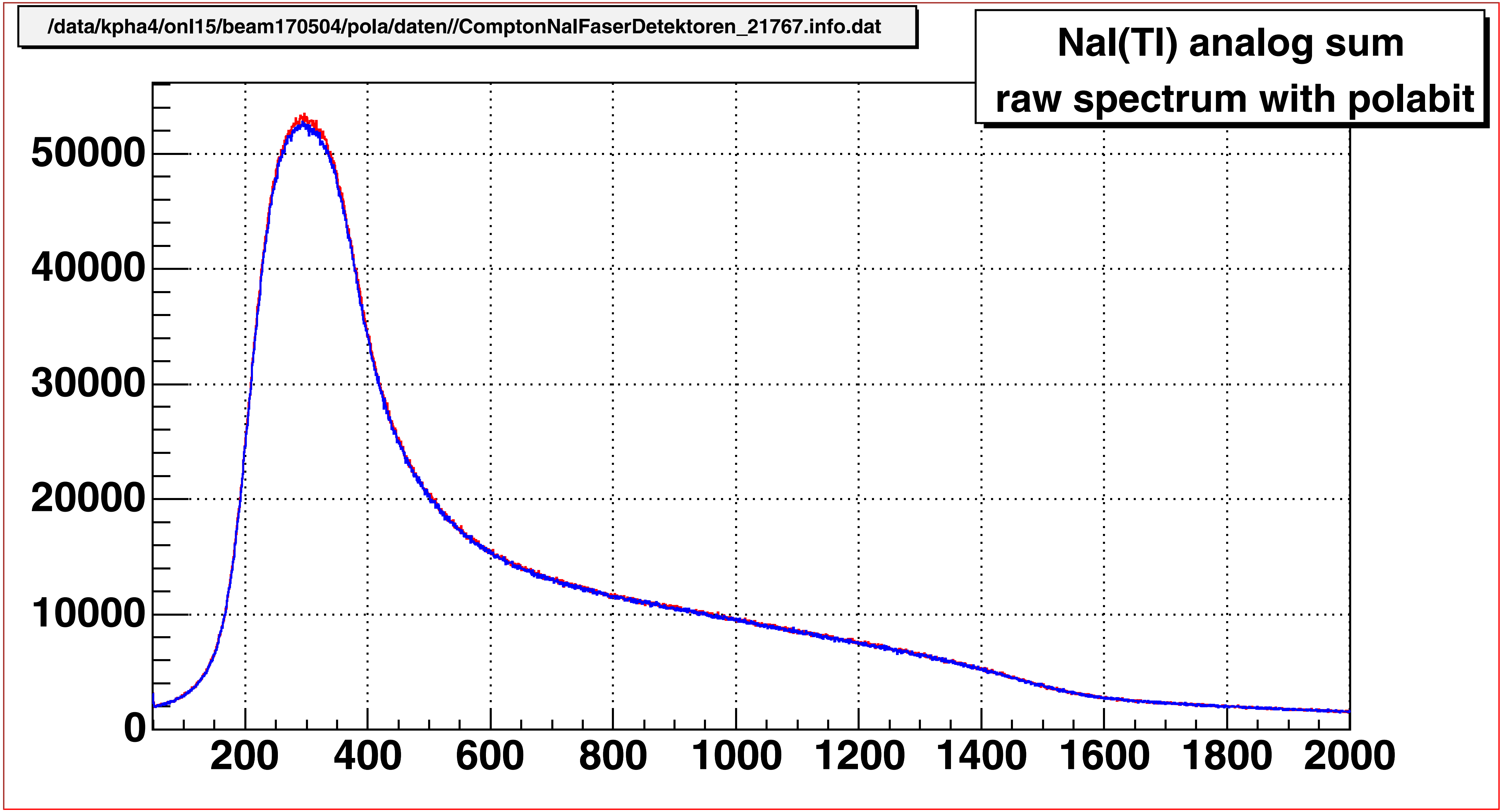


Laser aus
(10A, unter Schwelle)

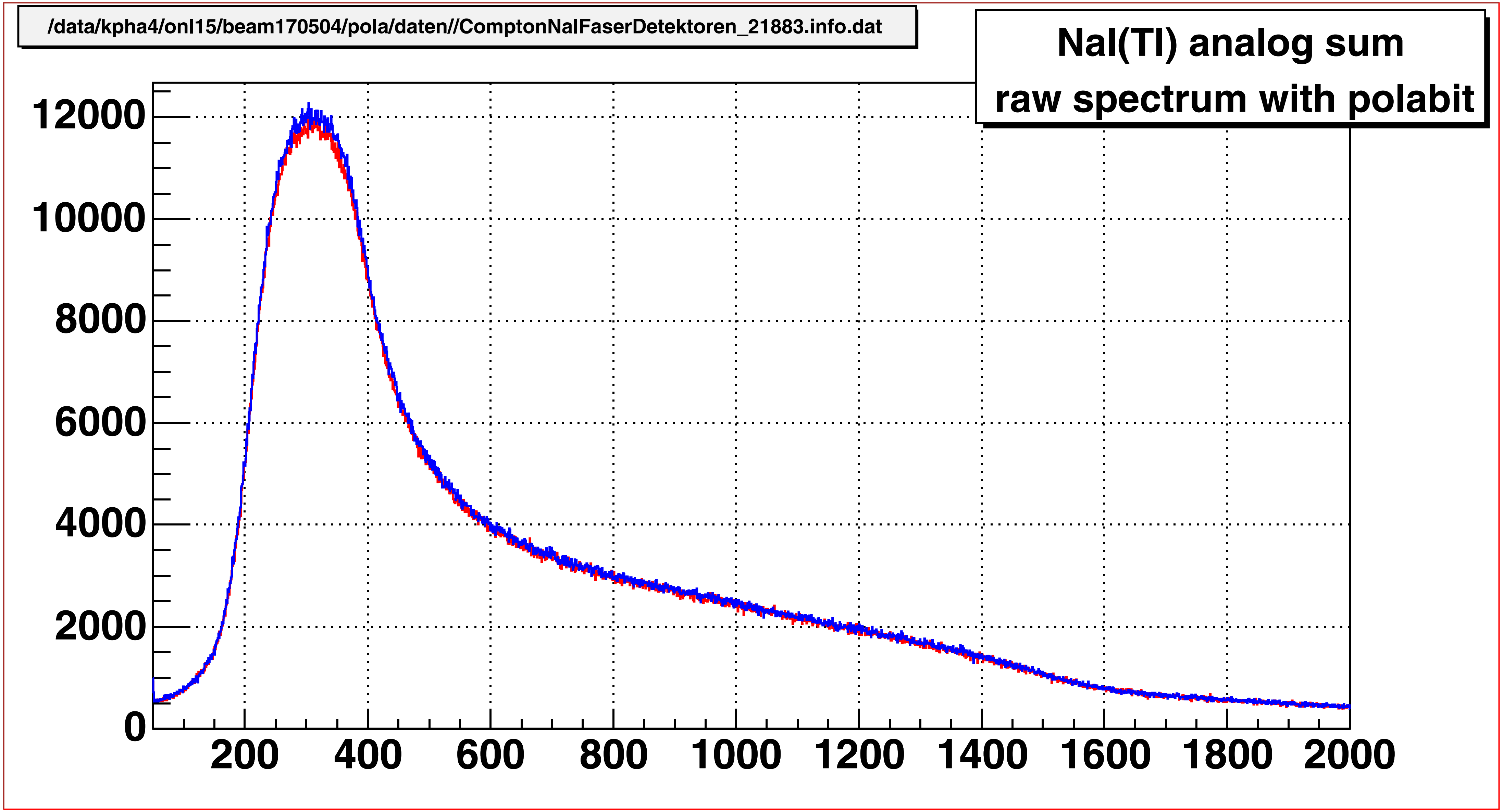
Differenz Laser an minus Laser aus (aus Rohdaten)



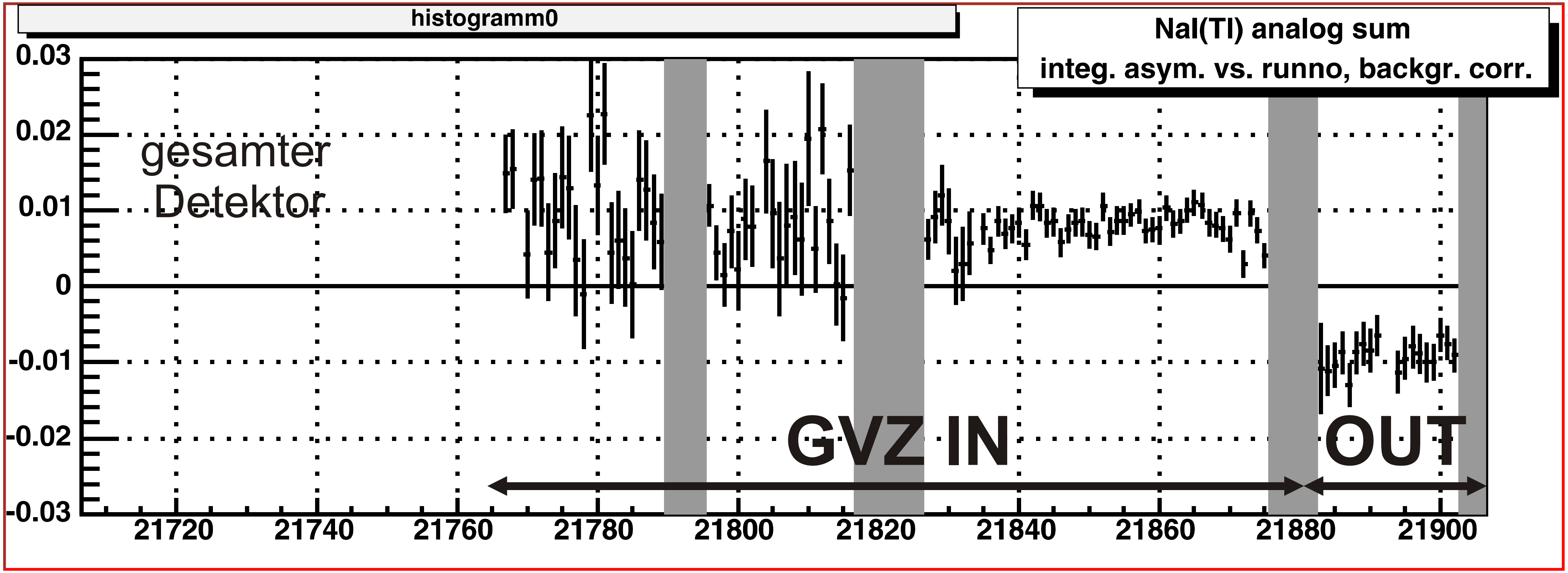
Summe aller Rohdaten (GVZ in)



Summe aller Rohdaten (GVZ out)



Erste gemessene Asymmetrien



GVZ IN $A = +7.4(3) \cdot 10^{-3}$

GVZ OUT $A = -9.9(4) \cdot 10^{-3}$

Zusammenfassung und Ausblick I

- Herstellung und Optimierung des Strahlüberlapps → Routineprozedur
- Permanente Überwachung von Laserstrahllage und Laserpolarisation
- Besseres Verständnis der Polarisationsmessung (Stokesmeter)
- Spannungsdoppelbrechung (?)
- Routinebetrieb der Laserstrahllageregelung
- Möglicherweise Rückkehr zum Multilinebetrieb (höhere Laserleistung?)
- Erweiterung der Triggerelektronik des Faserdetektors (24 statt 12 Kanäle)
- Implementation eines Softwaretriggers

Zusammenfassung und Ausblick II

- Compton-Laserrückstreupolarimeter in der ExHalle 3 installiert
- Strahlqualität auf dem Target (ExHalle 4) nicht beeinträchtigt
- Simultane Lagemessung (Laser/Elektronenstrahl) mit Drahtscannern
- August 2003: erstmals rückgestreute Photonen nachgewiesen
- Elektronendetektor installiert
- Vakuum verbessert ($3 \cdot 10^{-7}$mbar→$3 \cdot 10^{-8}$mbar)
- Signal/Untergrund Verhältnis zur Zeit bei ca. 1:5.4
- Juli 2004: erste Asymmetriemessung (rel. Genauigkeit <15%/5min)

Danksagung

A2-Kollaboration
B1-Kollabortaion und alle MAMI-Operateure
B2-Kollaboration

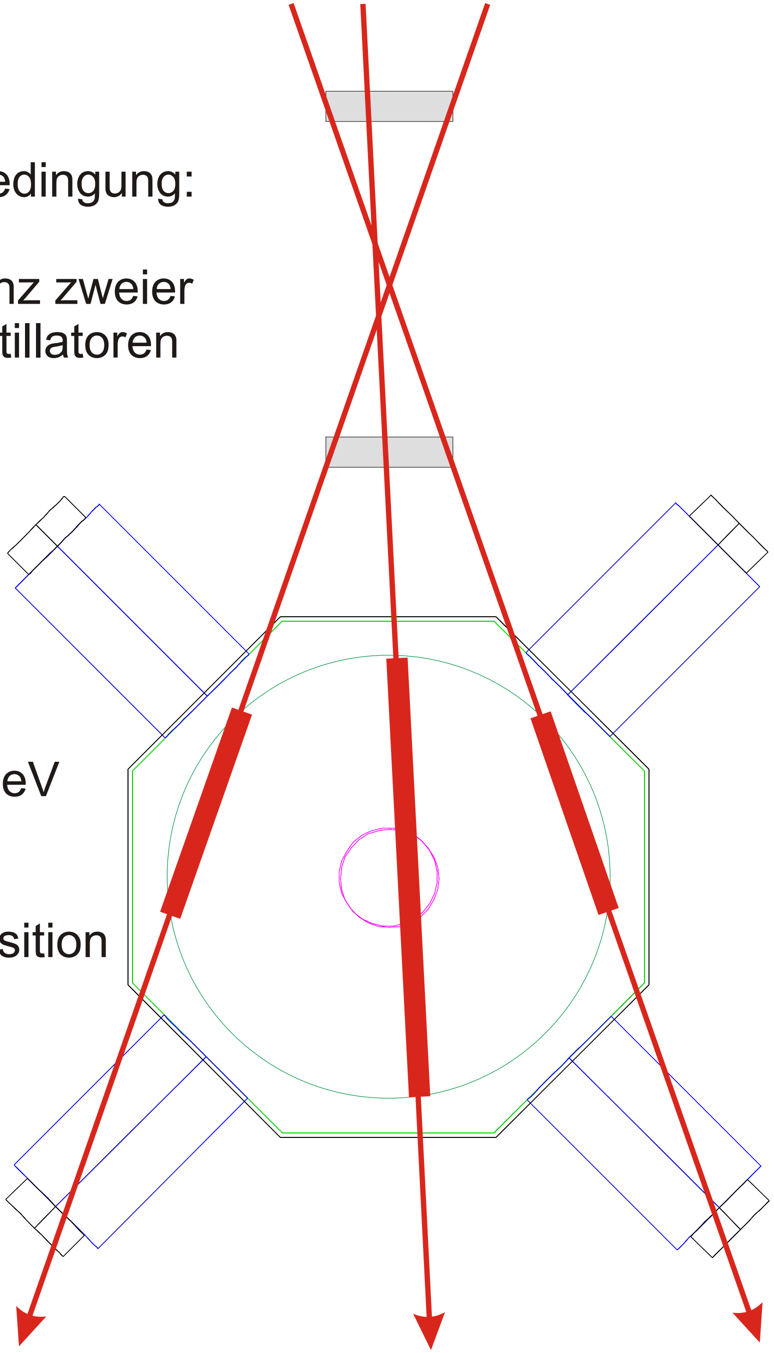
Elektronik-Werkstatt
Mechanische Werkstatt
Beschleuniger-Werkstatt
Vakuum-Werkstatt

S. Kowalski (MIT-Bates, JLAB)
S. Taylor (MIT-Bates, JLAB)

Kalibration der Detektoren

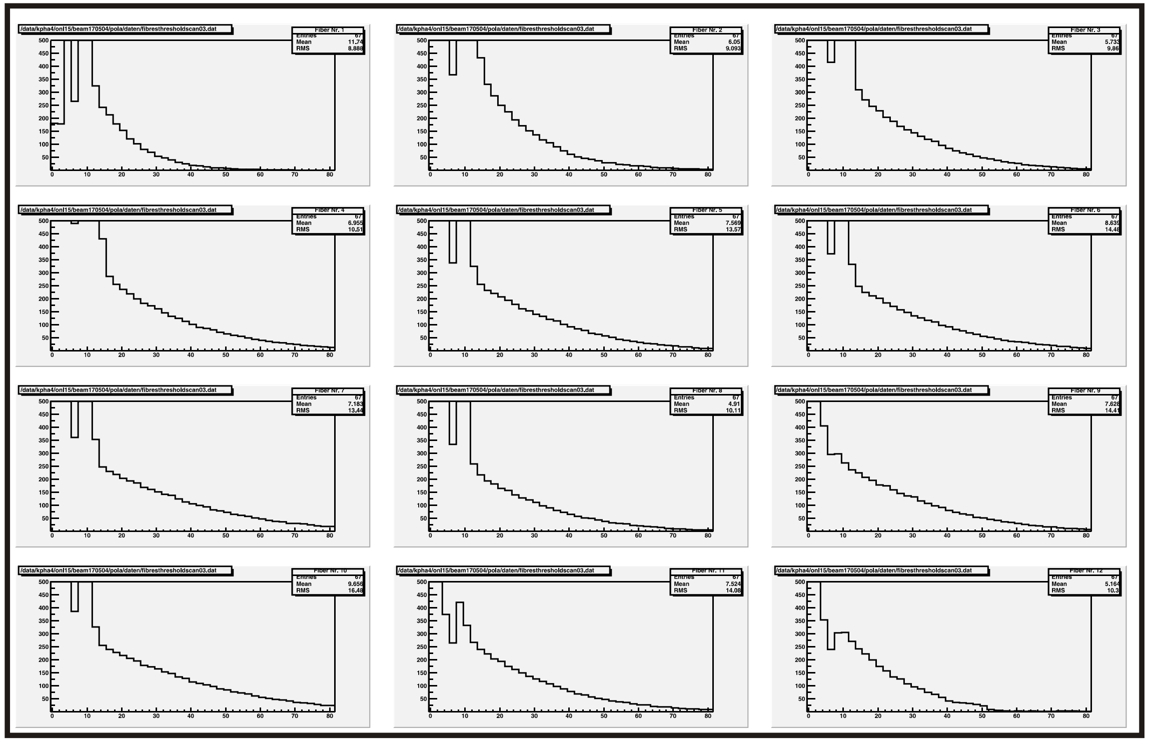
Triggerbedingung:

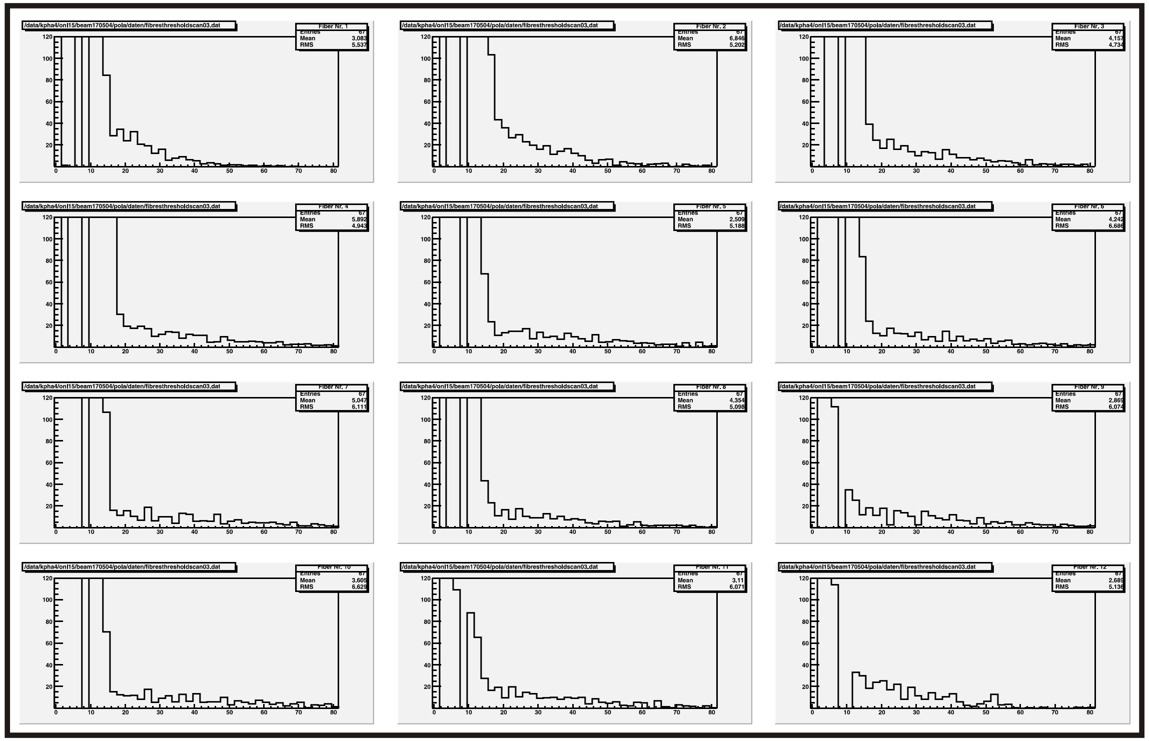
Koinzidenz zweier Plastszintillatoren



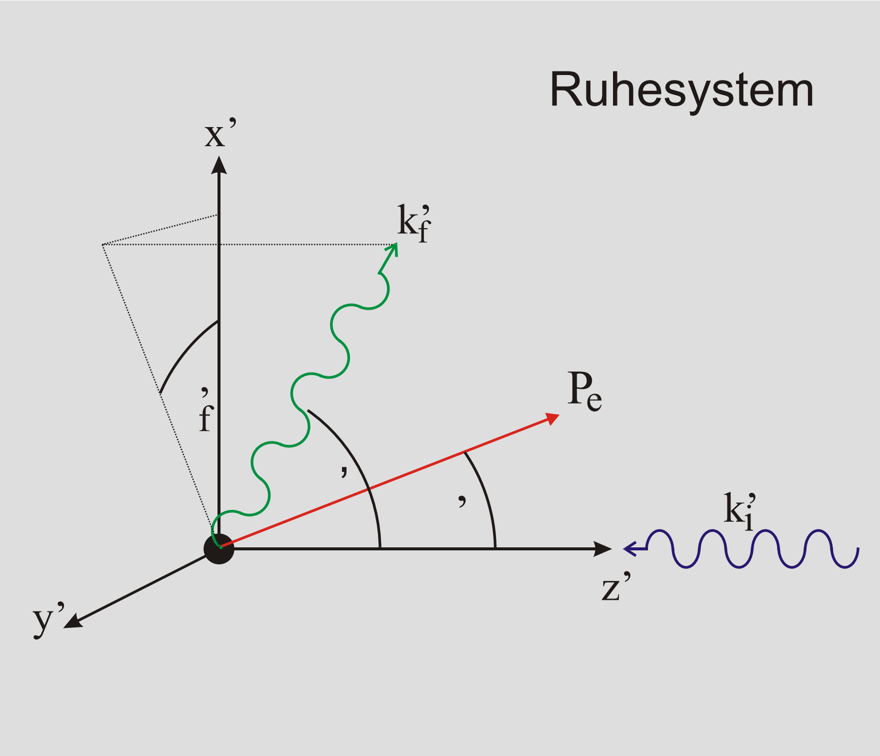
Myonen >1GeV (mip)

Energiedeposition ca. 200 MeV





Kinematik, Luminosität usw.



$$\mathcal{E}_\gamma^{real\,max.} = \frac{2\lambda}{4\pi} \approx 26\pi \cdot 10^{-9}\, m\,rad$$

$$\mathcal{L}_\infty = \frac{1}{\mathcal{E}_e + \mathcal{E}_\gamma}\,\frac{I_e P_\gamma \lambda}{2\pi e \hbar c^2}$$

$$\frac{\mathcal{L}}{\mathcal{L}_\infty} = \frac{2}{\pi}\arctan\left(\frac{l}{2 z_R}\right)$$

$$\frac{d\sigma_0}{d\Omega} = \frac{r_0^2}{2}\left(\frac{k'_f}{k'_i}\right)^2 \left\{1 + \cos^2\theta' + \frac{(k'_i - k'_f)^2}{k'_i k'_f}\right\}$$

$$k'_f = \frac{k'_i}{1 + \frac{k'_i}{m_e}(1 + \cos\theta')}$$

$$\frac{d\sigma_p}{d\Omega} = \frac{r_0^2}{2}\left(\frac{k'_f}{k'_i}\right)^2 \left(\frac{k'_f}{k'_i} - \frac{k'_i}{k'_f}\right)\cos\theta'$$

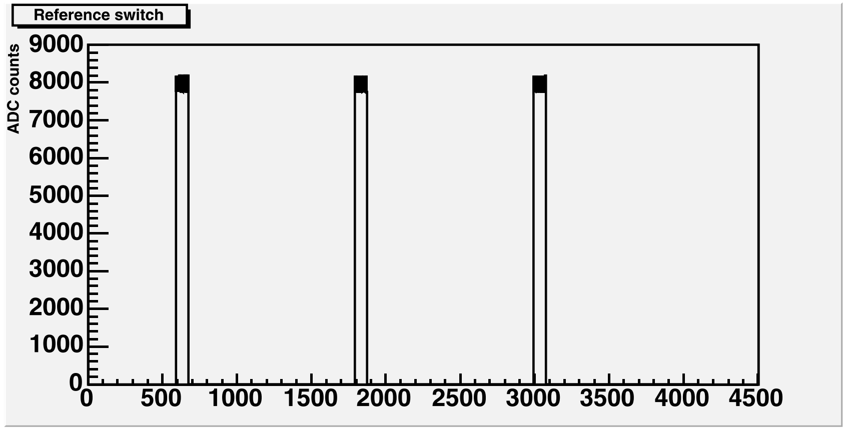
longitudinale Polarisation

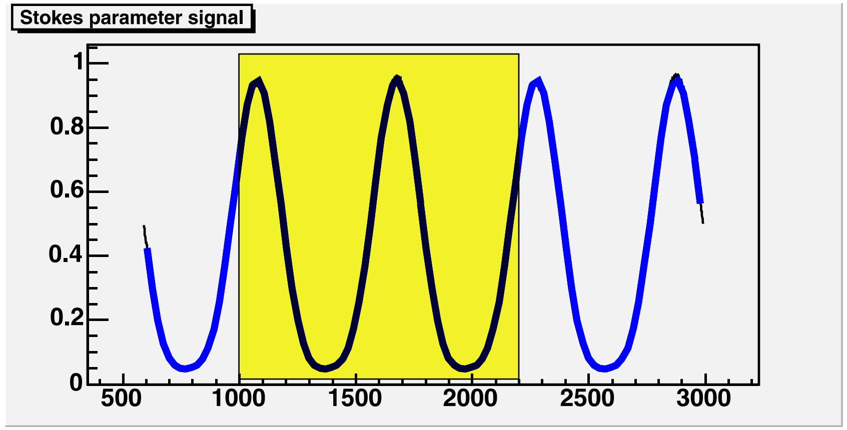
$$k_f = \frac{k_i \gamma^2 (1 + \beta\cos\theta')(1 + \beta)}{1 + \frac{k_i \gamma (1+\beta)}{m}(1 + \cos\theta')}$$

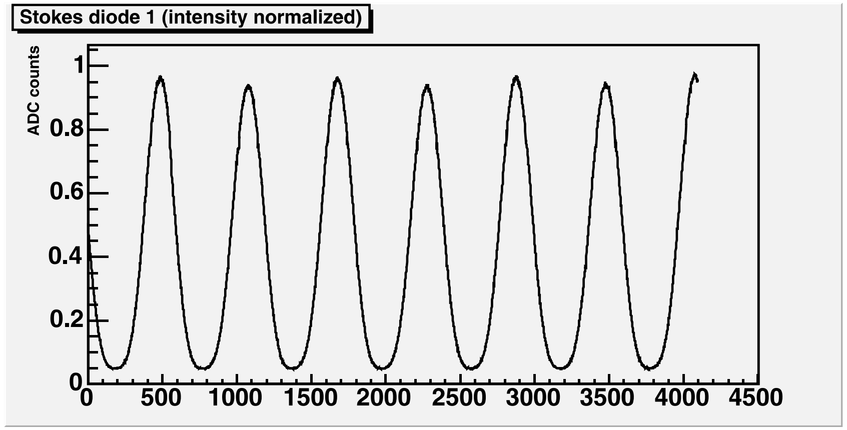
$$\frac{d\sigma_a}{d\Omega} = \frac{r_0^2}{2}\left(\frac{k'_f}{k'_i}\right)^2 \left(1 - \frac{k'_f}{k'_i}\right)\sin\theta'$$

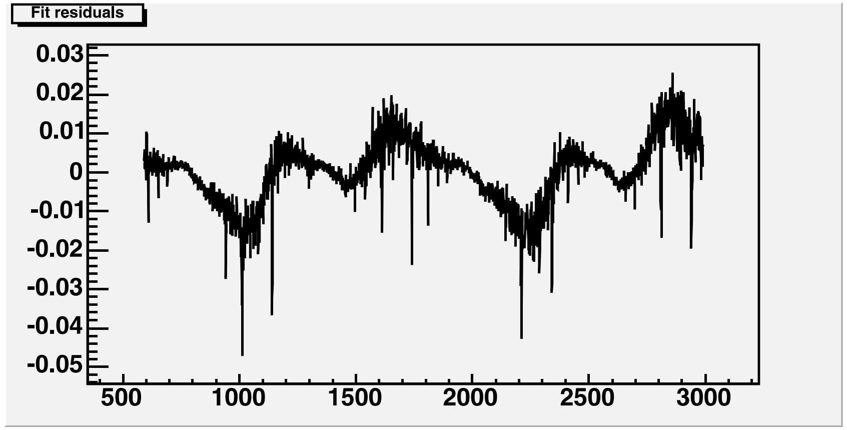
transversale Polarisation

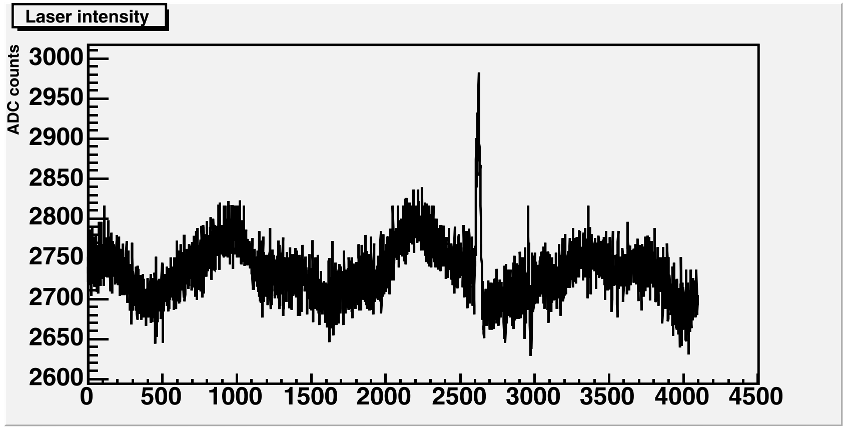
Stokes-Daten

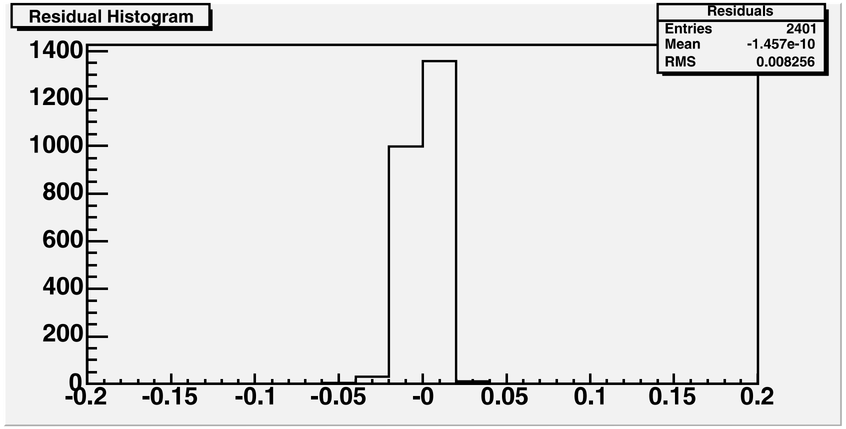

Reference switch


Stokes parameter signal

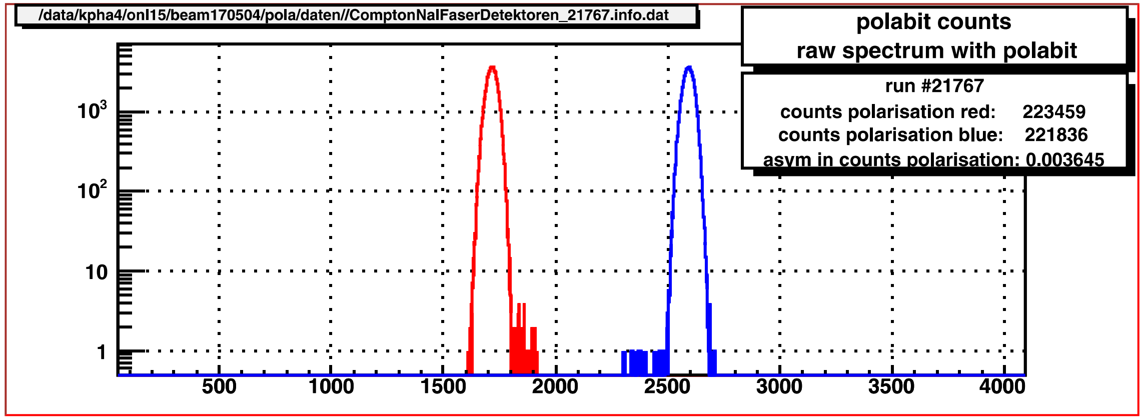

Stokes diode 1 (intensity normalized)

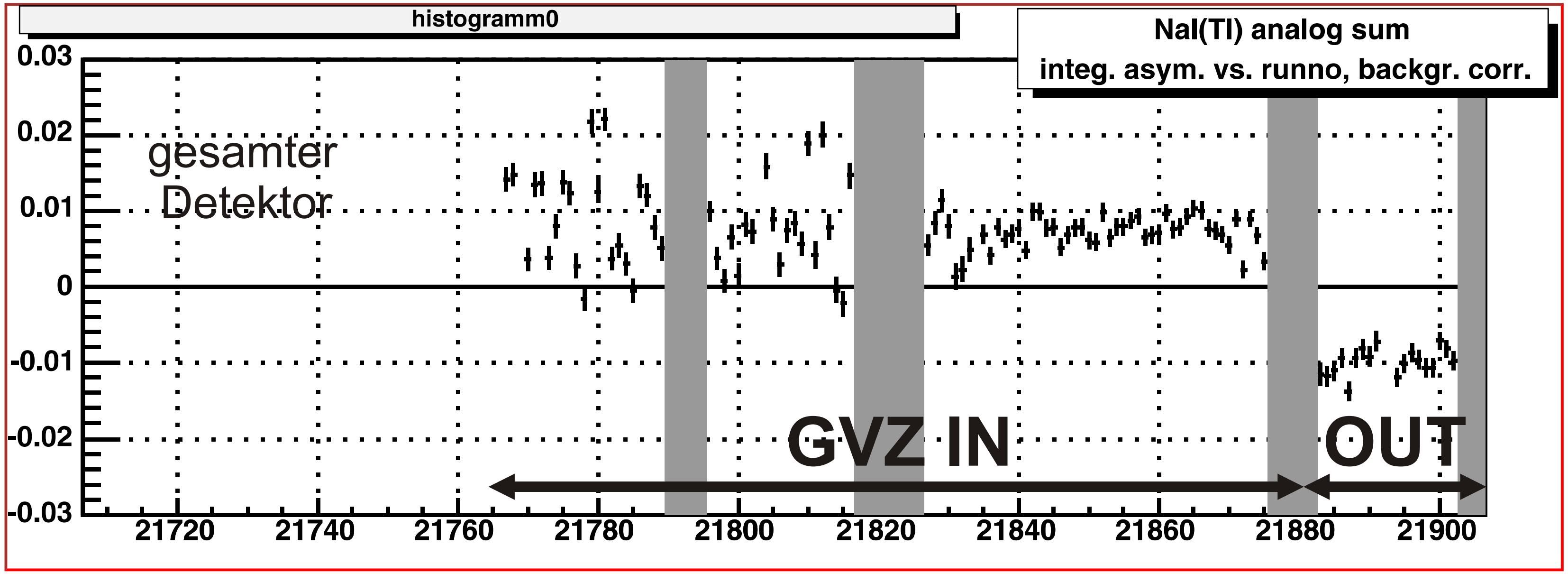

Fit residuals


Laser intensity


Residual Histogram

Polabitkorrektur



ohne Polabitkorrektur