Measurement of the Polarization **Vector** of the Positrons from the Decay of Polarized Muons

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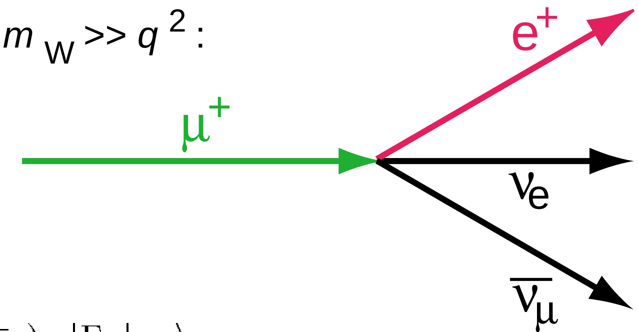
Contents:

Theory of Muon-Decay

In the limit of small momentum transfer $m_W >> q^2$:
μ-decay described using approximation
of four fermion point interaction:



general matrix element:

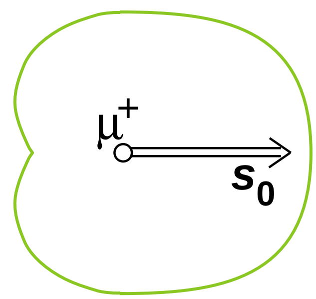
$$\mathcal{M} = \frac{4G_F}{\sqrt{2}} \sum_{\substack{\gamma=S,V,T \\ \epsilon,\mu=R,L}} g^{\gamma}_{\epsilon\mu} \langle \bar{e}_\epsilon | \Gamma^\gamma | (\nu_e)_n \rangle \langle (\bar{\nu}_\mu)_m | \Gamma_\gamma | \mu_\mu \rangle$$

$g^{\gamma}_{\epsilon\mu}$: 10 dimensionless coupling constants

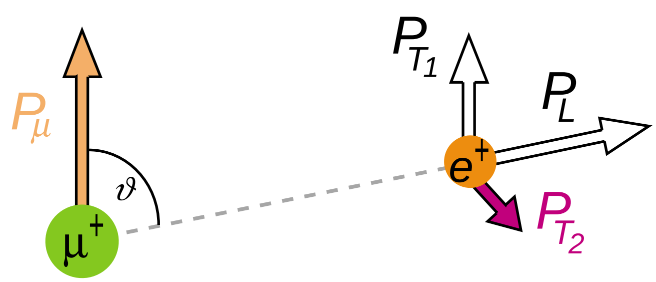
in standard model: $g^V_{LL} = 1$, all others 0

decay asymmetry: polarized positive muons emit the decay positron preferably in the direction of the muon spin

$$\frac{d\Gamma}{d\cos\vartheta} \sim 1 + 1/3\, P_\mu \cos\vartheta$$



Polarized Positrons from the Decay of Polarized Muons



in standard model: $\langle P_{T_1} \rangle = 0{,}003$

$P_{T_2} = 0$

$P_L = 1$ for $x = 1$

x : reduced positron energy $x = \frac{E_{e^+}}{E_{max}}$

Motivation for the Experiment at PSI

1. search for new couplings beyond V - A :

   assuming only one addditional scalar coupling

   ⟶ Michel parameter $\eta = \frac{1}{2} Re\left\{g^S_{RR}\right\}$

2. model independent determination of the Fermi coupling constant G_F :

$$G_F = \sqrt{192\,\pi^3 \frac{1}{\tau_\mu\, m_\mu^5}\left(1 - 4\eta\frac{m_e}{m_\mu}\right)}$$

contributions to $\left(\frac{\Delta G_F}{G_F}\right)^2$:

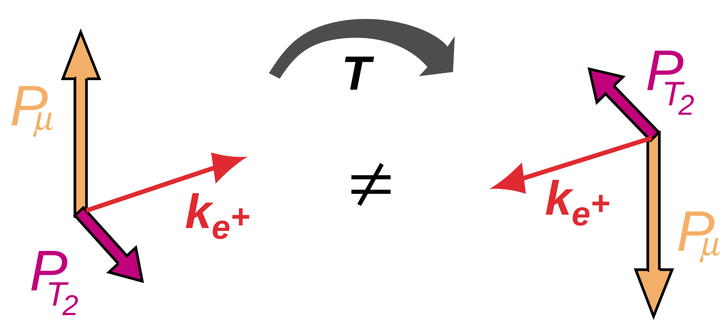
$\Delta\tau_\mu : \; 8 \cdot 10^{-11}$

$\Delta m_\mu : \; 6 \cdot 10^{-13}$

$\Delta\eta : \; 1{,}6 \cdot 10^{-8}$

η can be determined via measurement of P_{T_1}

3. violation of time reversal invariance :

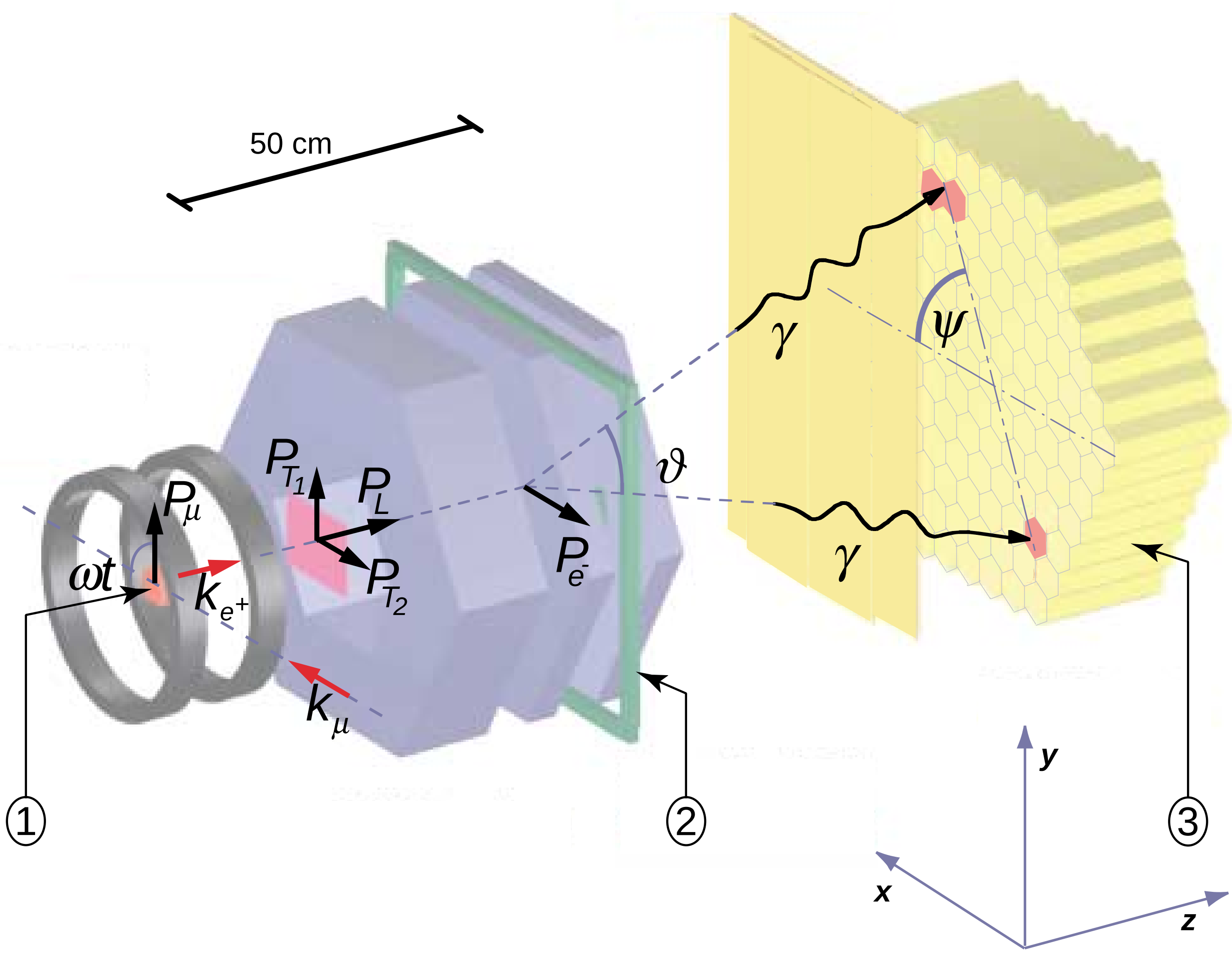


a non-zero P_{T_2} violates time reversal invariance !

⟶ measure P_{T_1} and P_{T_2}

\+ measure P_L as a check of consistency and to complete the polarization vector

Setup of the Experiment
and Principle of Measurement



① : Beryllium stop target within spin precession magnet

② : magnetized Vacoflux foil within iron return yoke

③ : calorimeter consisting of 127 BGO crystals

Experimental Methods

Measure the complete polarization vector

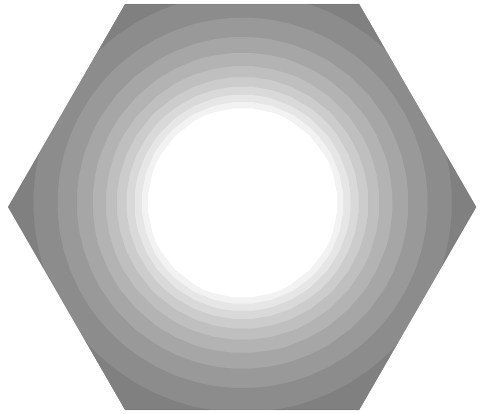
$$\boldsymbol{P}_{e^+} = \begin{pmatrix} P_{\mathsf{T}_1} \\ P_{\mathsf{T}_2} \\ P_{\mathsf{L}} \end{pmatrix} \equiv \begin{pmatrix} P_{\mathsf{T}} \cdot \cos\varphi \\ P_{\mathsf{T}} \cdot \sin\varphi \\ P_{\mathsf{L}} \end{pmatrix}$$

with 3 simultaneous and independent measurements:

Observable	Method
P_{T}	Time dependence of annihilation
φ	Remnant μSR effect
P_{L}	Spatial dependence of annihilation

Measurement of $|P_T|$

simulations of photon intensity
distributions on BGO - wall :

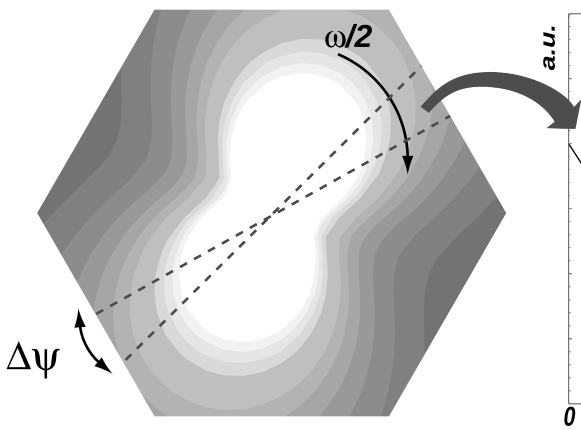


$|P_T| = 0$

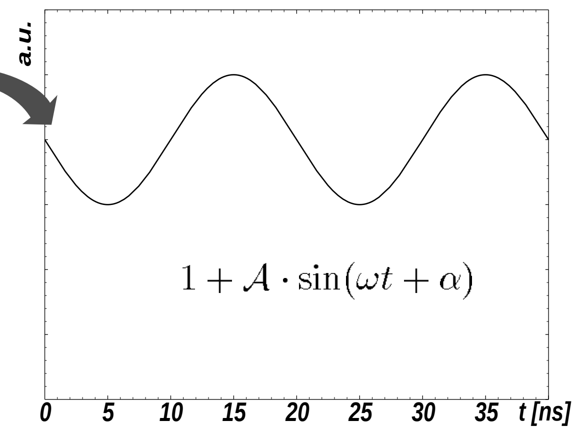
Assumptions:

P_T@ 45 ^{o}, $E_{\gamma_1} = E_{\gamma_2}$ = 10 MeV,

e^- - polarisation in magn. foil =100%



$|P_T|$ =1



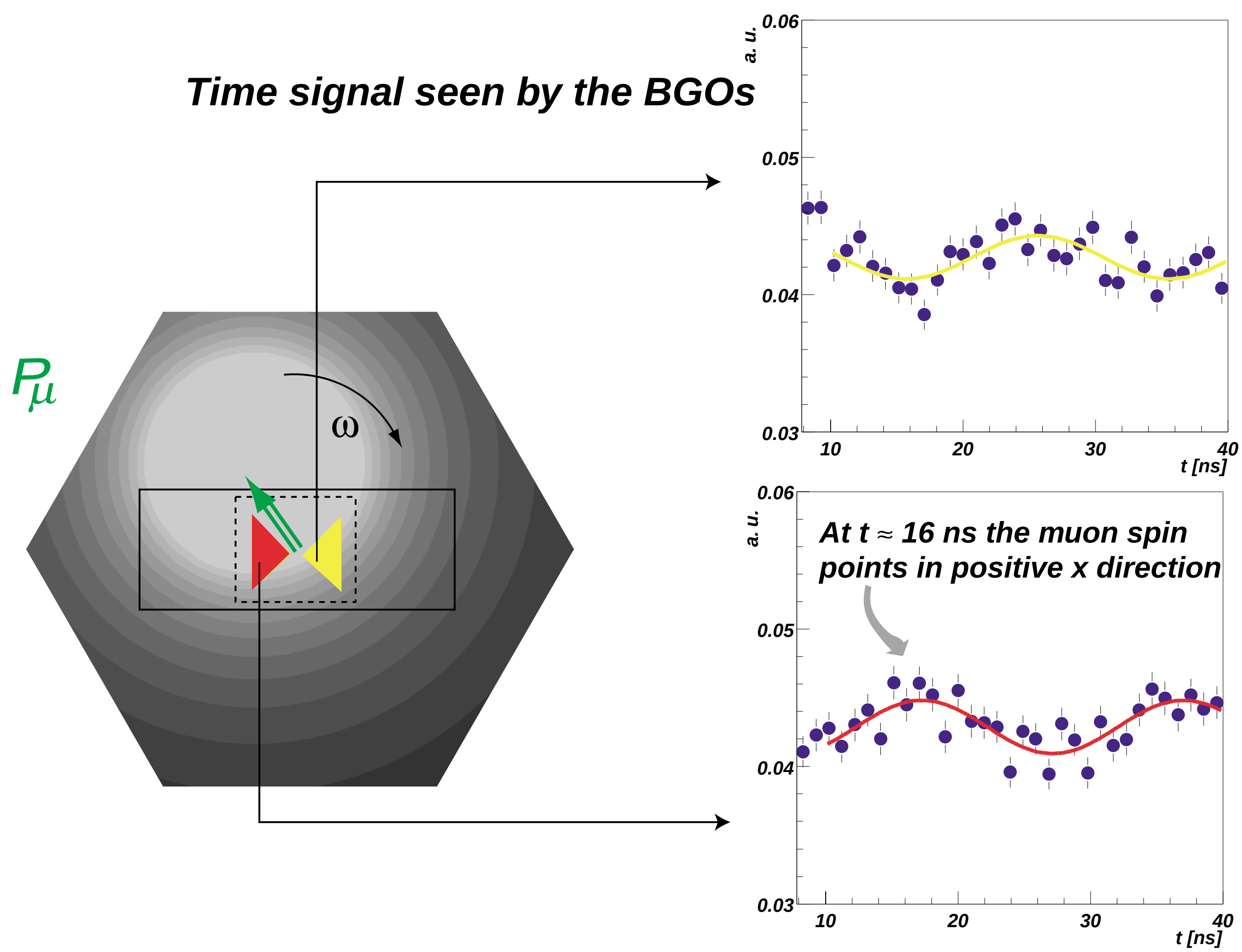
time spectrum for a given $\Delta\Psi$
$\mathcal{A}$ and α are functions of P_{T_1} and P_{T_2}

ω : frequency of muon spin precession
t : time between stop of muon and its decay

→ determination of two perpendicular transverse polarization components P_1 , P_2 at the time of annihilation

Determination of Phase φ of $\boldsymbol{P_T}$

μSR Effect is used to find the direction of the muon spin

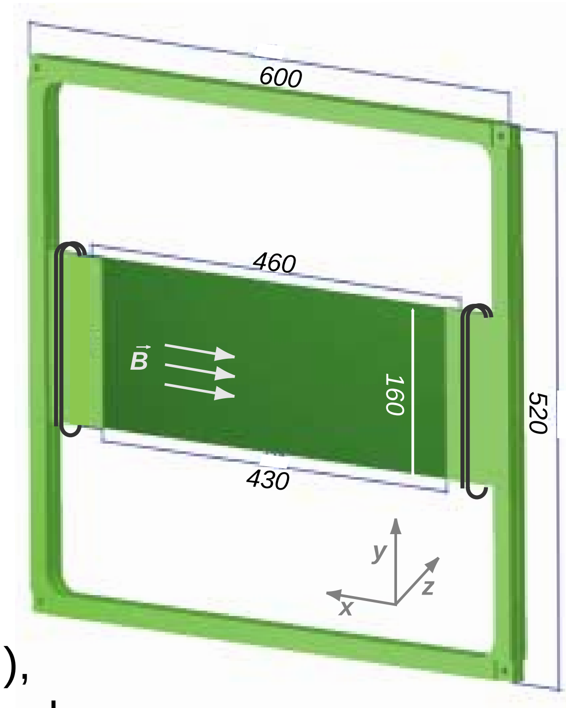


results from 1999 data : $t_0 = 15.717 \pm 0.517$ ns

→ determination of the transverse polarization components P_{T1}, P_{T2}

Measurement of the Longitudinal Polarization

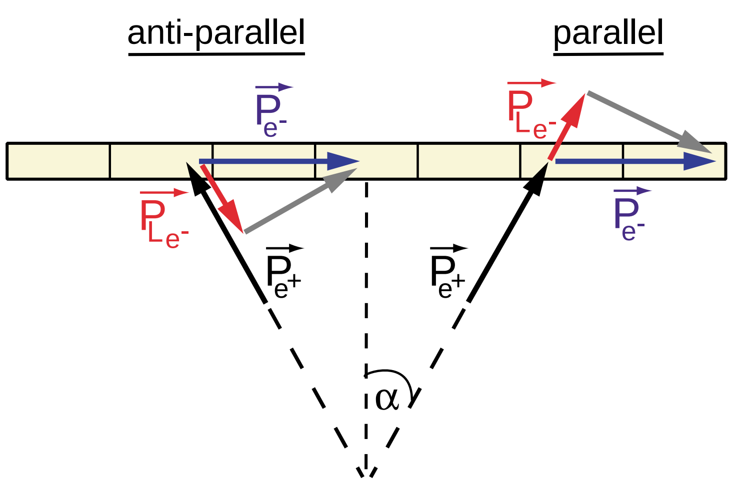
using information about position on magnetized Vacoflux foil (determined by tracks reconstructed from drift-chamber data) where annihilations take place



area on foil taken into account: 140^2 mm^2

area divided into rectangular bins (ij), 17 bins in x- and y-direction, respectively

Tracks that do not hit the center of the foil 'see' a longitudinal component $P_{L_{e^-}}$ of the polarized electrons in the foil.
This $P_{L_{e^-}}$ can either be parallel or anti-parallel to the positron polarization.



Longitudinal Polarization P_L of the Positrons

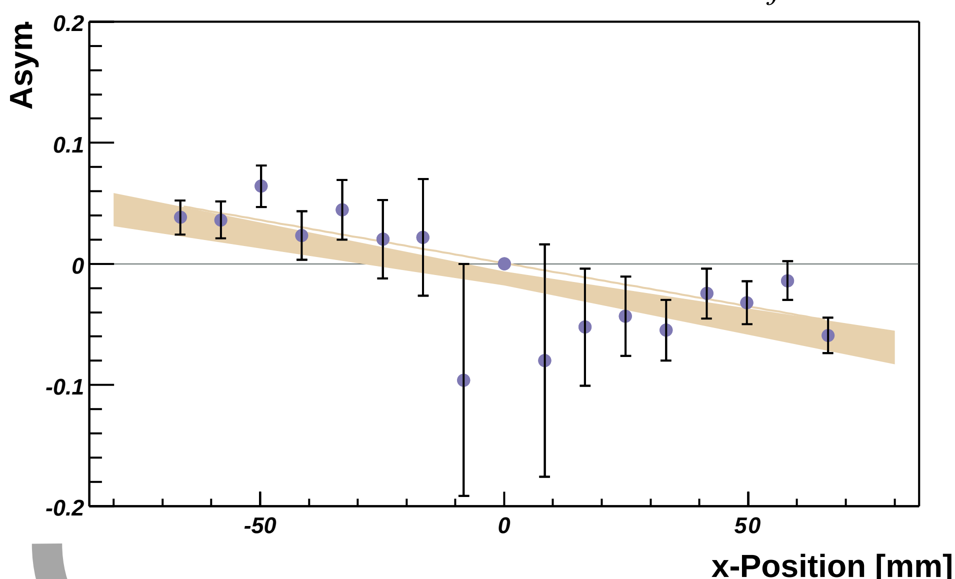
annihilation cross section depends on relative orientations of spins;
it is larger if both spins are anti-parallel

Asymmetry: $$A_{ij} = \frac{\frac{n_{ij}^{-}}{N^{-}} - \frac{n_{ij}^{+}}{N^{+}}}{\frac{n_{ij}^{-}}{N^{-}} + \frac{n_{ij}^{+}}{N^{+}}}$$

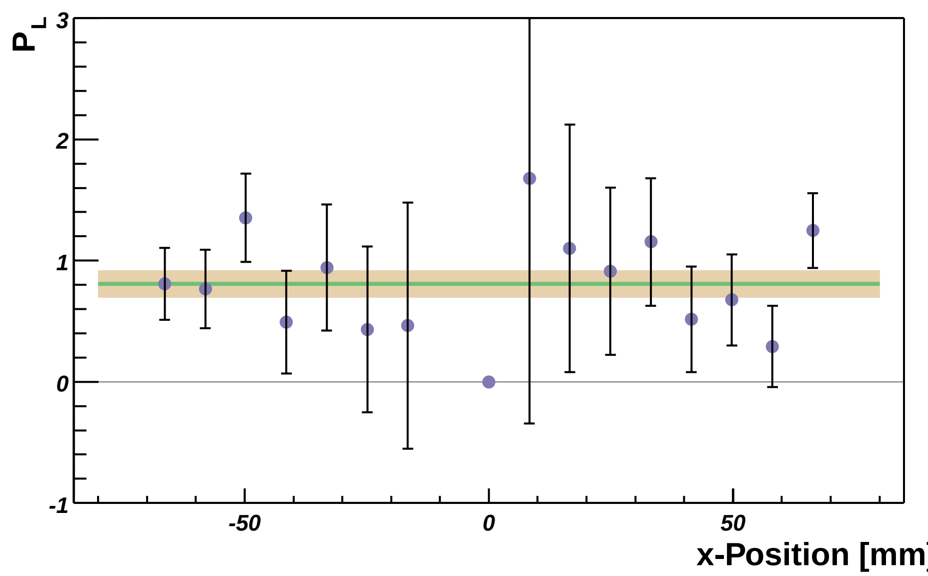
where n_{ij}^{+} : number of annihilations in bin *ij* for positive foil polarization

N^{+} : total number of annihilations for positive polarization

n_{ij}^{-}, N^{-}: same for negative polarization



- angle α
- elektron polarisation in foil (P_{e-} = 8.2 %)
- analysing power of 0.79
- background factor of 0.75 (background ratio 25 %, mainly due to bremsstrahlung)



$P_L = 0.81 \pm 0.11$

Run 1999 → Run 2000
("Conlusion and Outlook")

Results of data-taking in 1999

total number of raw annihilation events:	233×10^6
annihilation events used for analysis:	13.7×10^6

$$< P_{\mathrm{T}_1} > = 0.020 \pm 0.013$$
$$< P_{\mathrm{T}_2} > = 0.004 \pm 0.013$$
$$\eta = 0.007 \pm 0.055$$

Aims for data-taking of 27.09. - 22.11.2000

number of "good" annihilation events that can be used for analysis:	$\approx 150 \times 10^6$

$$\longrightarrow \quad \Delta < P_{\mathrm{T}_1} > = 0.003$$
$$\Delta < P_{\mathrm{T}_2} > = 0.003$$
$$\Delta\eta = 0.009$$

How to reach this, improvements for the current run

- new DAQ - system
- longer time of data-taking
  $\approx$ 30 days compared to 18 days 1999
- improved slow-control - system

New Data Aquisition System

Frontend: RIO2 (Power PC)
- Lynx OS (real time operating system)
- MBS (DAQ basic software from GSI)

Backend: Dual Pentium PC
- LINUX
- event analyser
- DIX (spectrum display utility)

Offline: Dual Pentium PC
- LINUX
- data analysis routines, ROOT

Measured Performance: **~** 6.9 MB/s (limitation comes from FERA)
= increase by a factor of ~200 compared to CAMAC (anticipated: ~ 50)

Slow Control System

based on LabVIEW - graphical programming
environment by National Instruments

fulfils the following tasks:

- controling LED-Pulser device that steers LEDs that are in included in each of the BGO-modules and are used for monitoring the gain stability of the BGOs
- control of power supply and flux-meter to change and monitor magnetization of Vacoflux foil

  foil polarization can be changed automaticaly without an operator beeing present, foil status is sent to DAQ and included in raw data structure
- remote control of the two C.A.E.N HV-crates supplying HV to the $\approx$ 170 single detectors
- supervising and logging the temperature inside the wodden BGO-box and the temperature outside the box

1. Collaborators

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