The Feasiblity of the TRIC Experiment at COSY

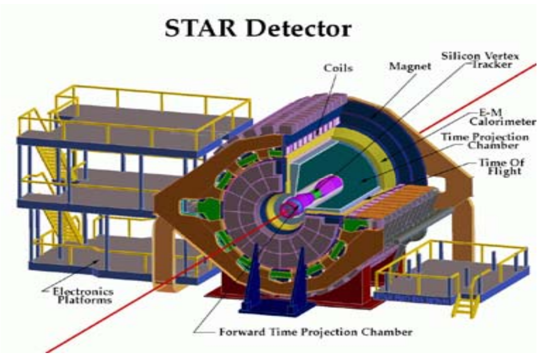
A P-even Time-Reversal Invariance Test at COSY

- Some Introductory Remarks
- The Quantity of Interest for a True P-even/T-odd Null-Test
- Some Experimental Details
- First Test of a Novel Measuring Method for Total Cross-Sections
- Data Analysis
- Summary

Some Introductory Remarks

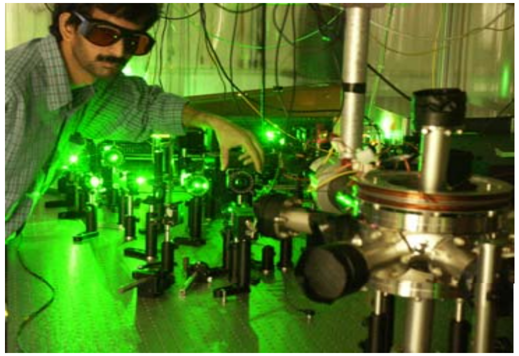
> **"Go right to the frontiers of science**
> **and you will learn soon what is missing"**
> Georg Christoph Lichtenberg (1742-1799)

High Energy Frontier



⇔

Precision Frontier



TRI and Parity Tests

+ − +	correlation in ^{57}Fe	$\bar{\alpha}_{\not T} \leq 5 \cdot 10^{-6}$	
Detailed Bal.	in p + ^{27}Al = ^{4}He + ^{24}Mg	$\bar{\alpha}_{\not T} \leq 10^{-3}$	
P − A	in $\vec{p}$ - p scattering	$\bar{g}_{\not T} \leq 3 \cdot 10^{-2}$	
Neutron EDM		$\bar{g}_{\not T \not P} \leq 10^{-11}$	$\bar{g}_{\rho \not T} \leq 1.5 \cdot 10^{-3}$
Atomic EDM	in ^{199}Hg		$\bar{g}_{\rho \not T} \leq 1 \cdot 10^{-2}$
CSB	, A for $\vec{n}$ - p and $\vec{p}$ - n scatt.		$\bar{g}_{\rho \not T} \leq 6.7 \cdot 10^{-3}$
$\vec{n}$ - transm.	through $^{165}\vec{\mathrm{Ho}}$	$\bar{g}_{\not T} \leq 2.8 \cdot 10^{-4}$	$\bar{g}_{\rho \not T} \leq 2.3 \cdot 10^{-2}$

Null-tests

A_L	in $\vec{p}$ - p scattering	(-A 0 2⊡10^{-8})
$A_{y,xz}$	in $\vec{p}$ - $\vec{d}$ scattering	(potentially **0.1** $\cdot\, \bar{g}_{\rho \not T}$ of $^{165}\vec{\mathrm{Ho}}$)

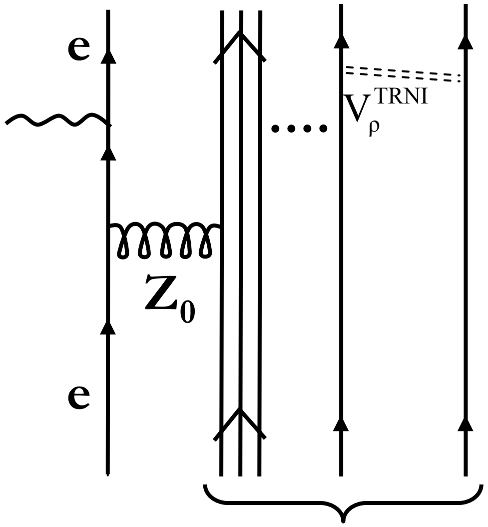
$\bar{\alpha}_{\not T}$ Strength of eff. T-violating N-core potential

$\bar{g}_{\not T / \not T \not P}$ Strength of T-violating / TP-violating NN potential

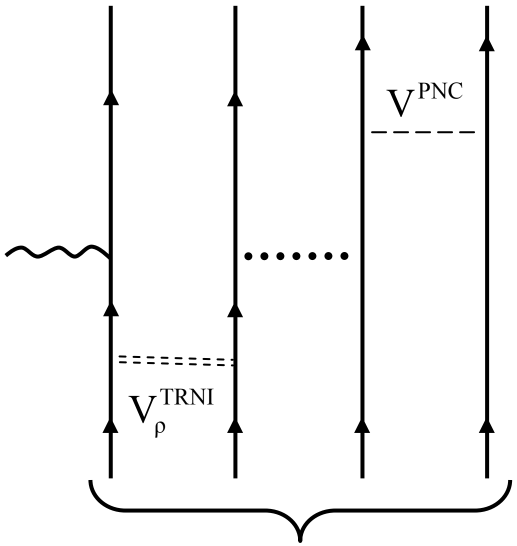
$\bar{g}_{\rho \not T}$ Strength of T-violating G-MN coupling constant

Violation of TRI can be related to the ρ Meson

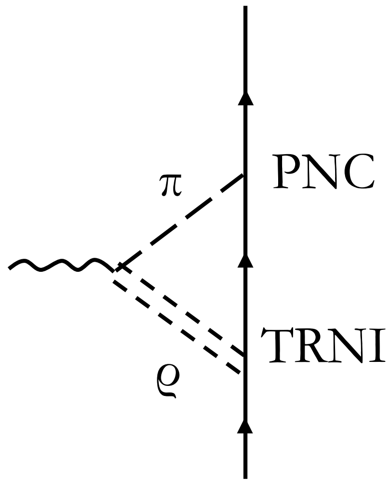
The atomic EDM	The nuclear EDM	The nucleon EDM



nucleus



nucleus



Null-Tests in True P-even/T-odd TRI Experiments

But :

- There is no Null-Experiment for a reaction with two particles in and two particles out.

  F.Arash, M.J. Moravcsik, and G.R. Goldstein, Phys.Rev.Lett. ***54*** *(1985) 2649*

Loophole:

The proof from above relies on the construction of cross-sections from bilinear products of scattering amplitudes.

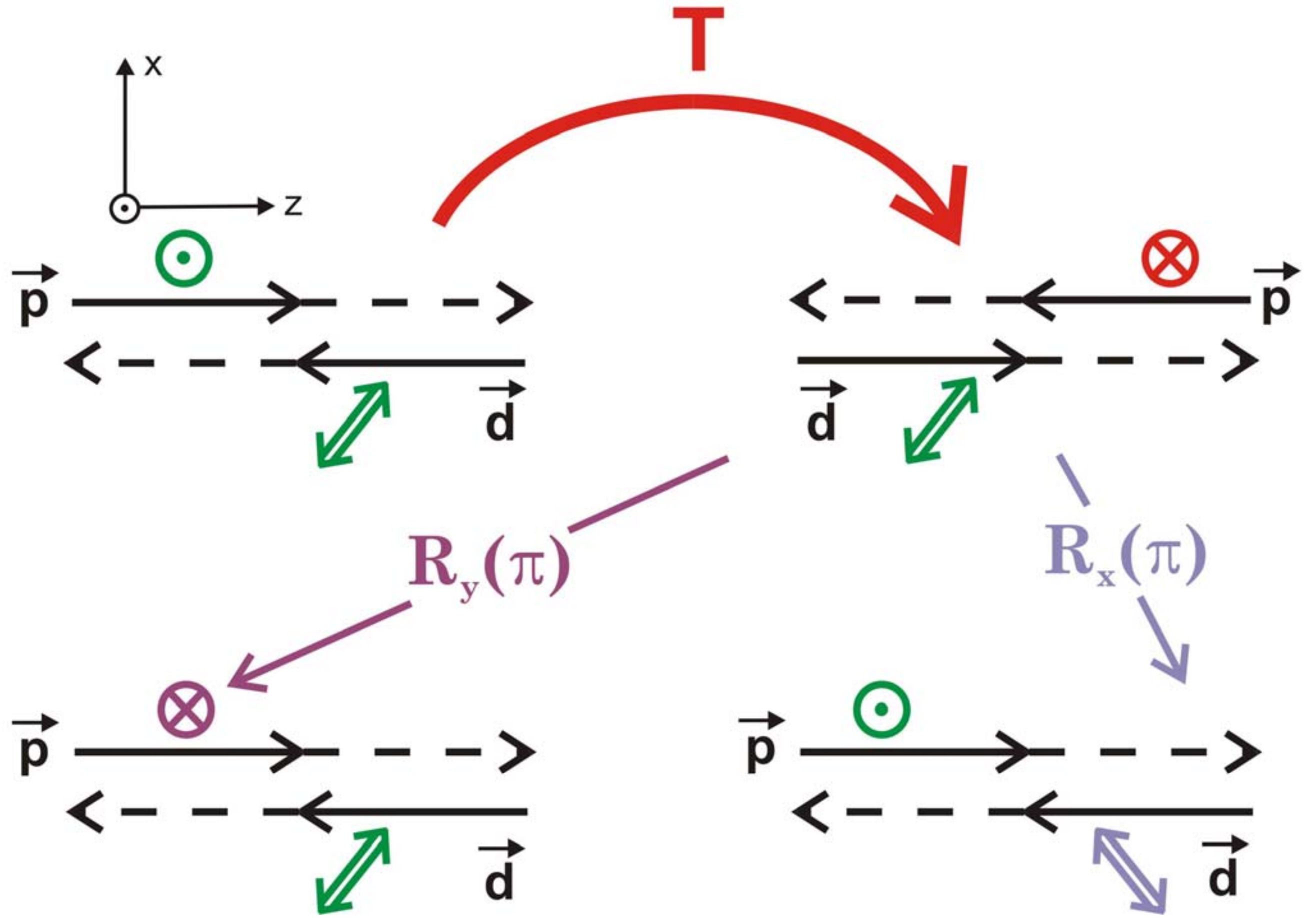
- In forward scattering the total cross-section can be measuered via the optical theorem.

  H.E. Conzett, Phys. Rev. C ***48*** *(1993) 423*

The Feasiblity of the TRIC Experiment at COSY

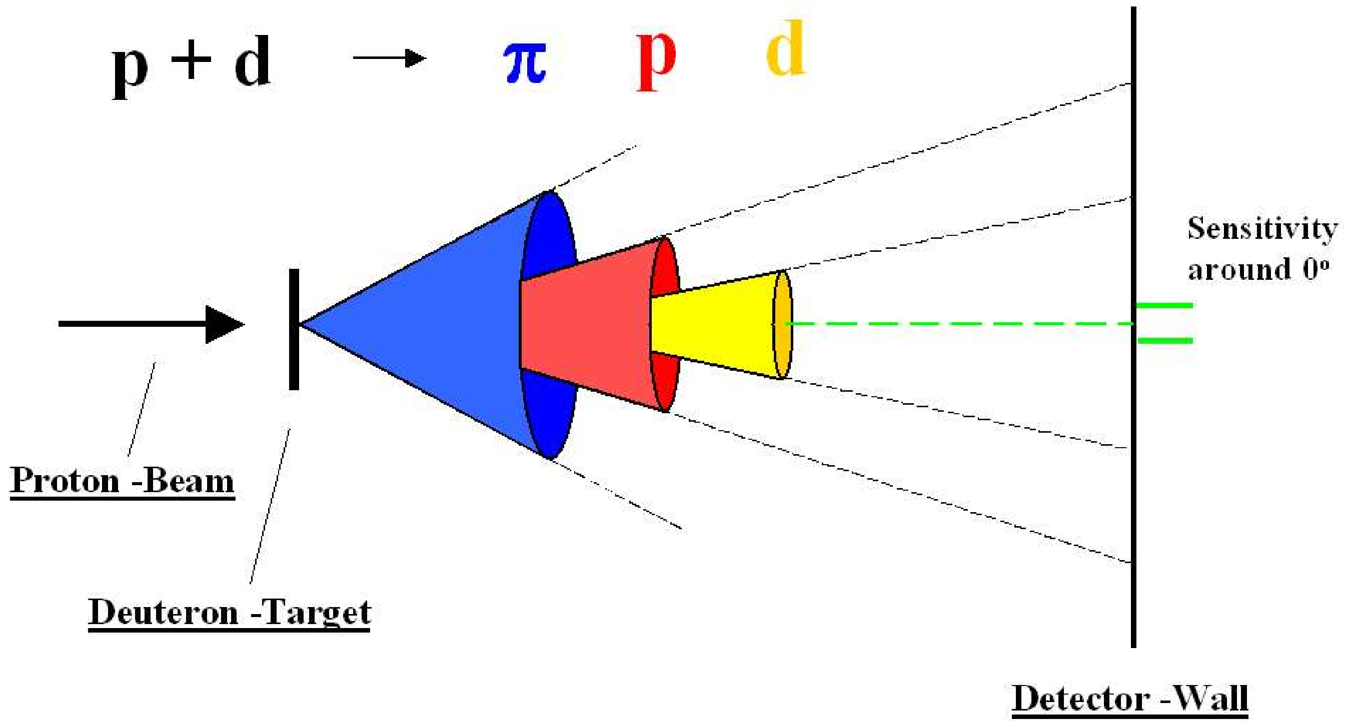
The Quantity of Interest for a True P-even/T-odd Null-Test

The Principle of the Time Reversal Invariance test at COSY (TRIC)

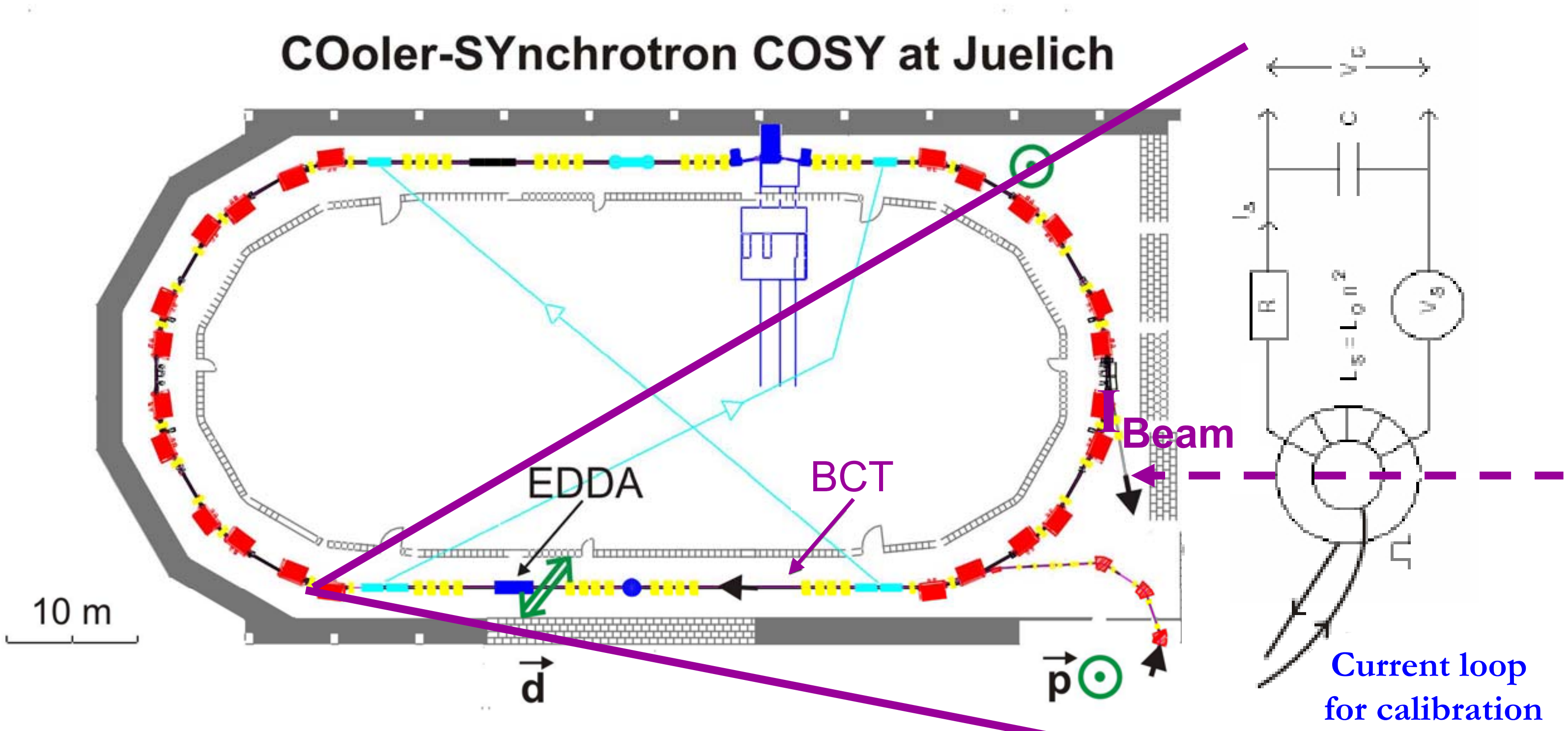


External Fixed Target

Scattering-Cones and Detector-Sensitivity



The Experimental Setup



BCT - Beam Current Transformer
EDDA - Cylindrical Polarimeter with **Tensor** Polarized Atomic **Deuteron** Beam

The Feasiblity of the TRIC Experiment at COSY

Internal σ_{tot} Measurements are Related to Precise Current Measurements

The total pol. correlation $A_{y,\,xz}$ is measured via the forward scatt. amplitude $\mathcal{F}(0)$

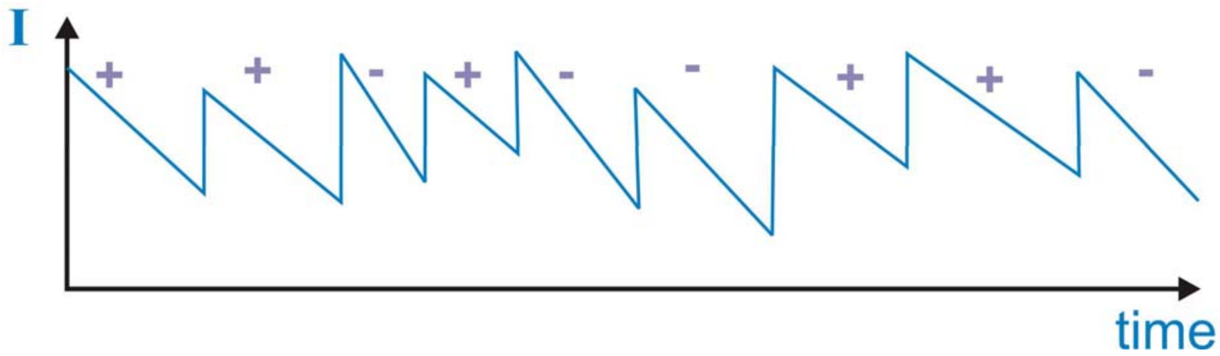
$$\sigma_{tot} = \frac{4\pi}{k} Im F(0) \quad \rightarrow \quad \frac{4\pi}{k} Im\, tr(\rho\, \mathcal{F}(0))$$

$F(0)$ - Forward scatt. amplitude for unpolarized particles

ρ - Density matrix

$\mathcal{F}(0)$ - Forward scatt. amplitude (matrix) for polarized particles

$A_{y,\,xz}$ is proportional to the relative difference of the current slopes of the circulating proton beam with respect to the chosen polarization configuration (+/-) of the proton beam and deuteron target.



The Feasiblity of the TRIC Experiment at COSY

Initial Estimation of Precision

$$A_{y,xz} = \frac{1}{2} \cdot \frac{1}{\sigma_0 \cdot \rho d \cdot P_y P_{xz}} \cdot \frac{1}{N} \cdot \left(\frac{dI^+}{I_0^+} - \frac{dI^-}{I_0^-} \right)$$

Demand for long life-time (e-cooling)

$$\delta(\Delta T) = |-S| \cdot \delta A_{y,xz} \cong \frac{1}{\sqrt{2}} \cdot \frac{\delta I}{I}$$

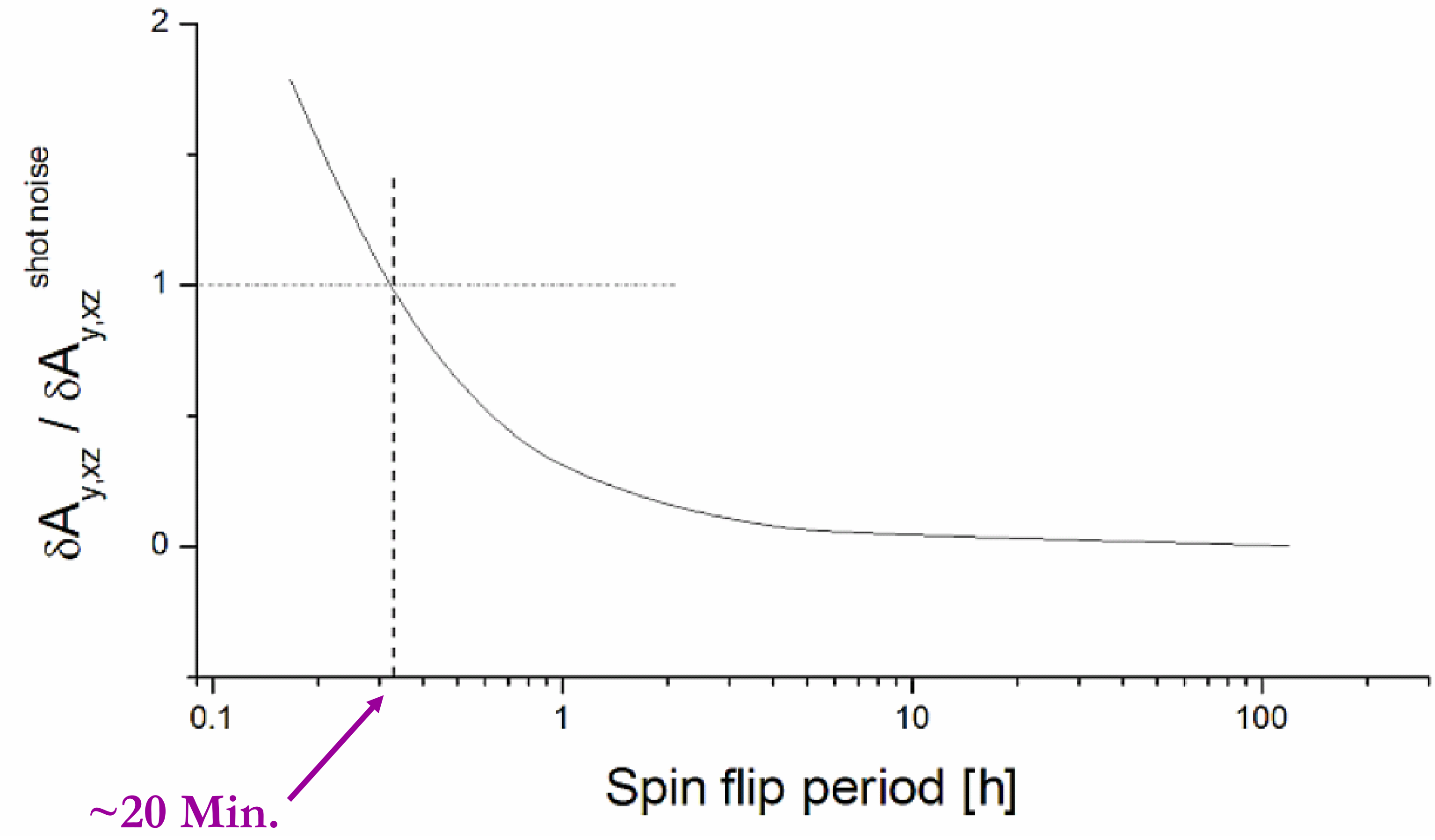
Demand for precise current measurement

Relative accuracy of current in 1 s measurement: $3 \cdot 10^{-4}$

$A_{y,xz}$ can thus be measured with an accuracy of 10^{-6} in 10 days

The Feasiblity of the TRIC Experiment at COSY

Choice of Spin-Flip Period



The Feasiblity of the TRIC Experiment at COSY

Basic Error Analysis

$I_{0,0}$	$A_{0,X}$	$A_{0,Y}$	$A_{0,Z}$
$A_{X,0}$	$A_{X,X}$	$A_{X,Y}$	$A_{X,Z}$
$A_{Y,0}$	$A_{Y,X}$	$A_{Y,Y}$	$A_{Y,Z}$
$A_{Z,0}$	$A_{Z,X}$	$A_{Z,Y}$	$A_{Z,Z}$

$A_{0,XX}$	$A_{0,YY}$	$A_{0,ZZ}$	$A_{0,XY}$	$A_{0,YZ}$	$A_{0,XZ}$
$A_{X,XX}$	$A_{X,YY}$	$A_{X,ZZ}$	$A_{X,XY}$	$A_{X,YZ}$	$A_{X,XZ}$
$A_{Y,XX}$	$A_{Y,YY}$	$A_{Y,ZZ}$	$A_{Y,XY}$	$A_{Y,YZ}$	$A_{Y,XZ}$
$A_{Z,XX}$	$A_{Z,YY}$	$A_{Z,ZZ}$	$A_{Z,XY}$	$A_{Z,YZ}$	$A_{Z,XZ}$

Line cancels because of : Protonspinflip

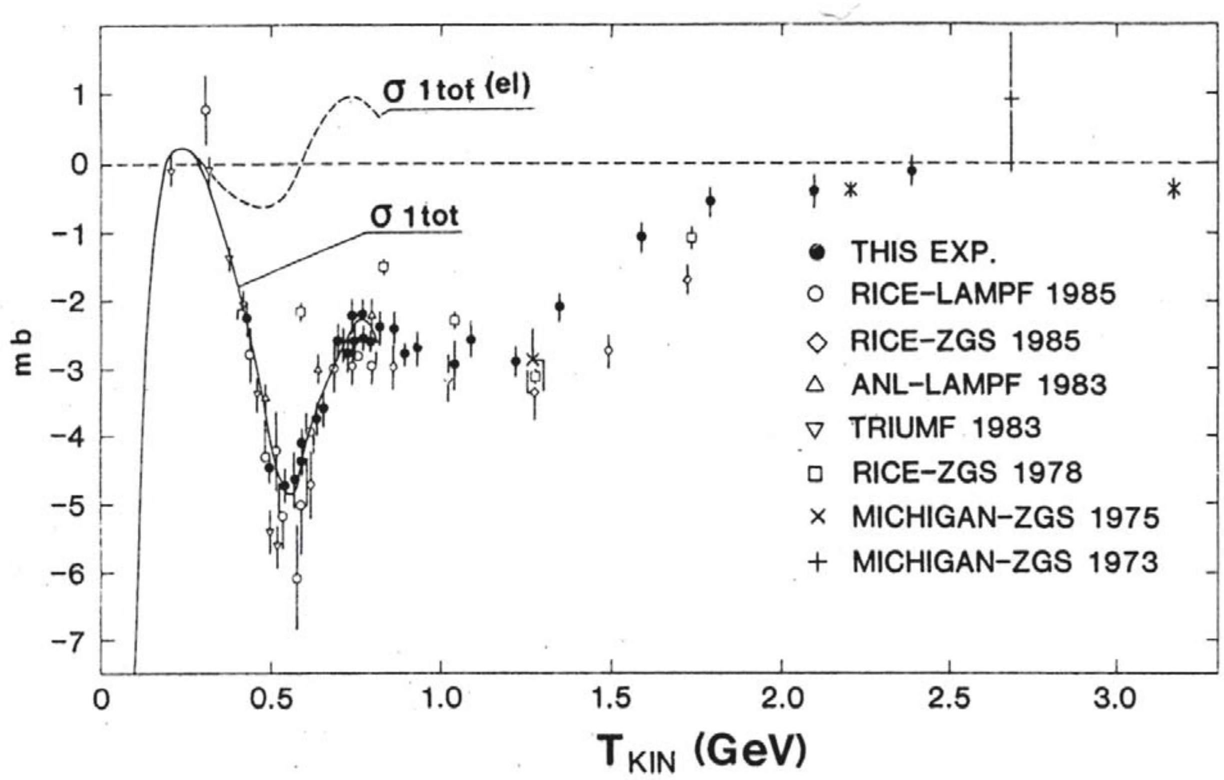
p_x, p_z negligible for protons

Quantity cancels because of : ~~R~~, ~~P~~

The Feasiblity of the TRIC Experiment at COSY

Total cross section σ_{1tot} = $½ $\Delta\sigma_{tot}$ in p-p Scattering

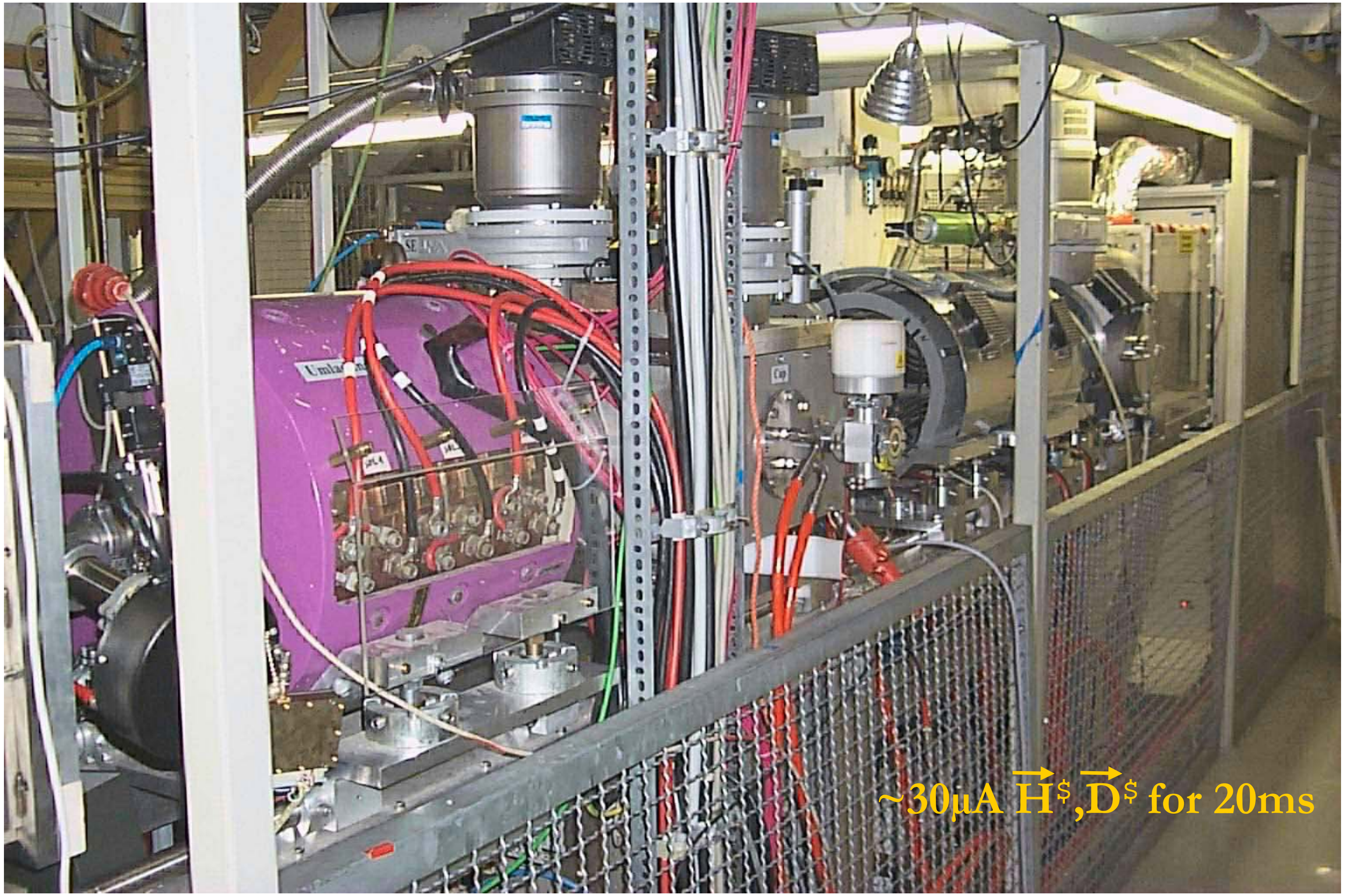
Ay,y
in p-p scattering



*F. Perrot et al., Nucl. Phys. B **278** (1986) 881*

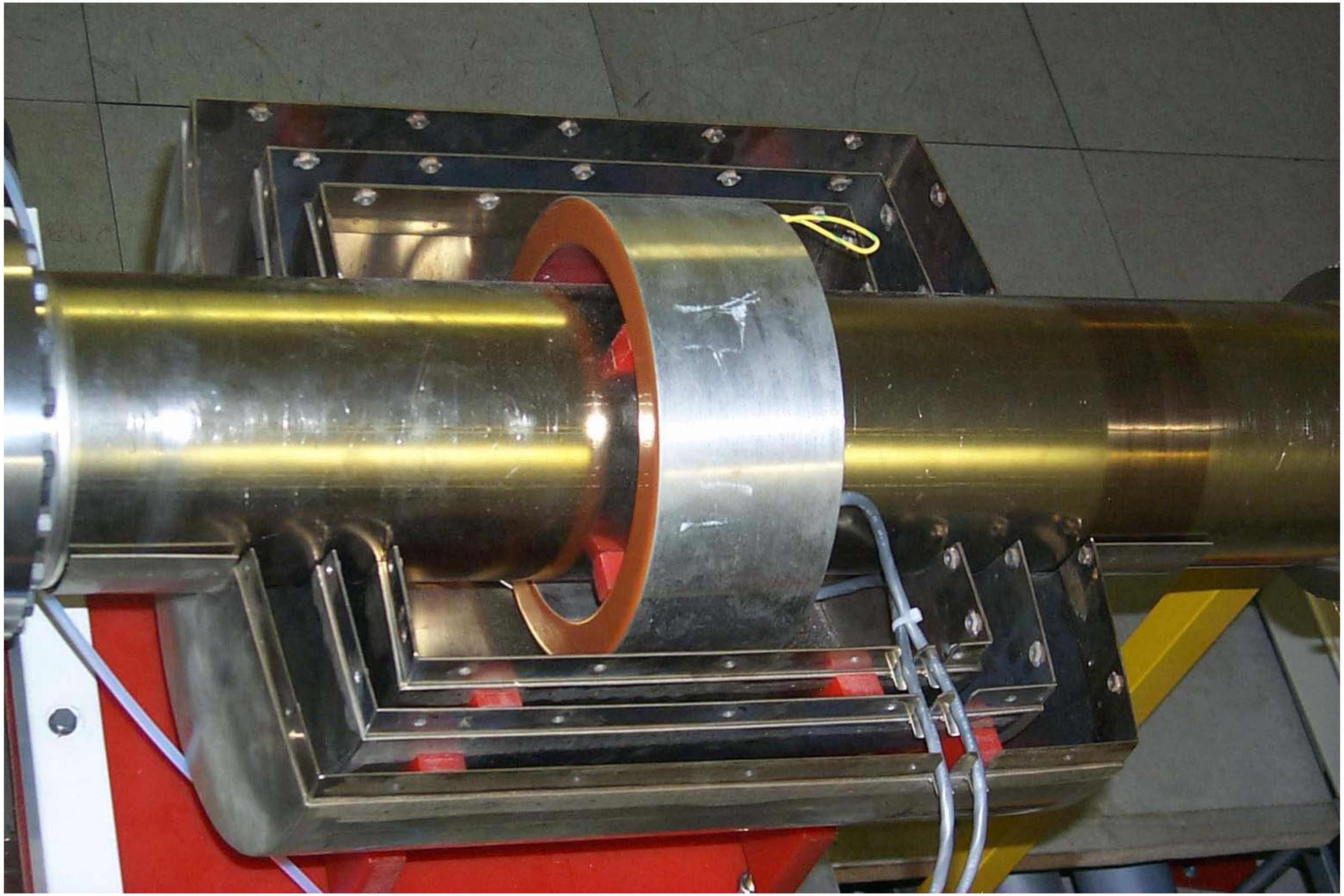
The Feasiblity of the TRIC Experiment at COSY

The $H^{\$}$ Source for $\vec{p}$ and $\vec{d}$ for COSY



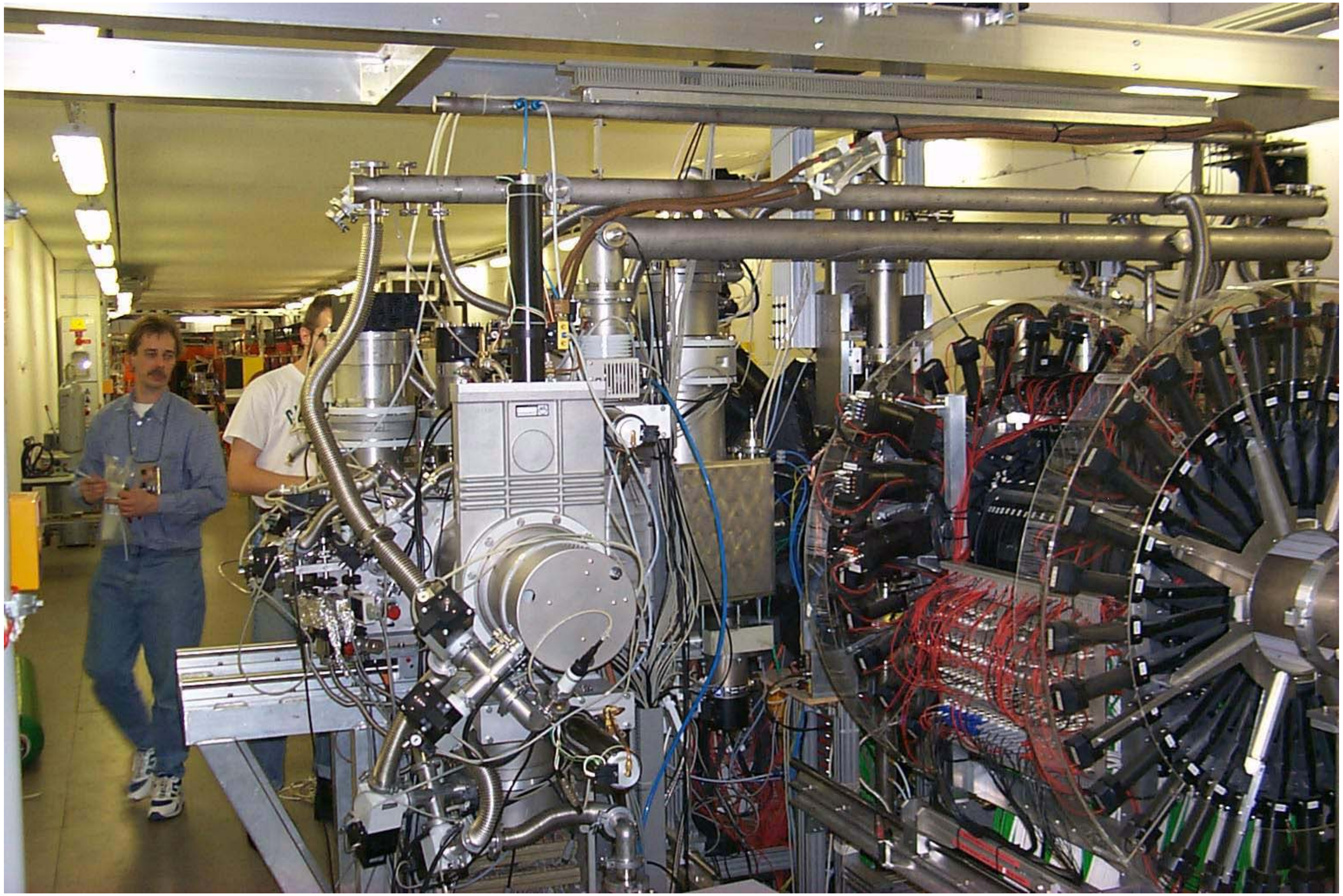
The Feasiblity of the TRIC Experiment at COSY

The Precision Beam Current Transformer (BCT)



The Feasiblity of the TRIC Experiment at COSY

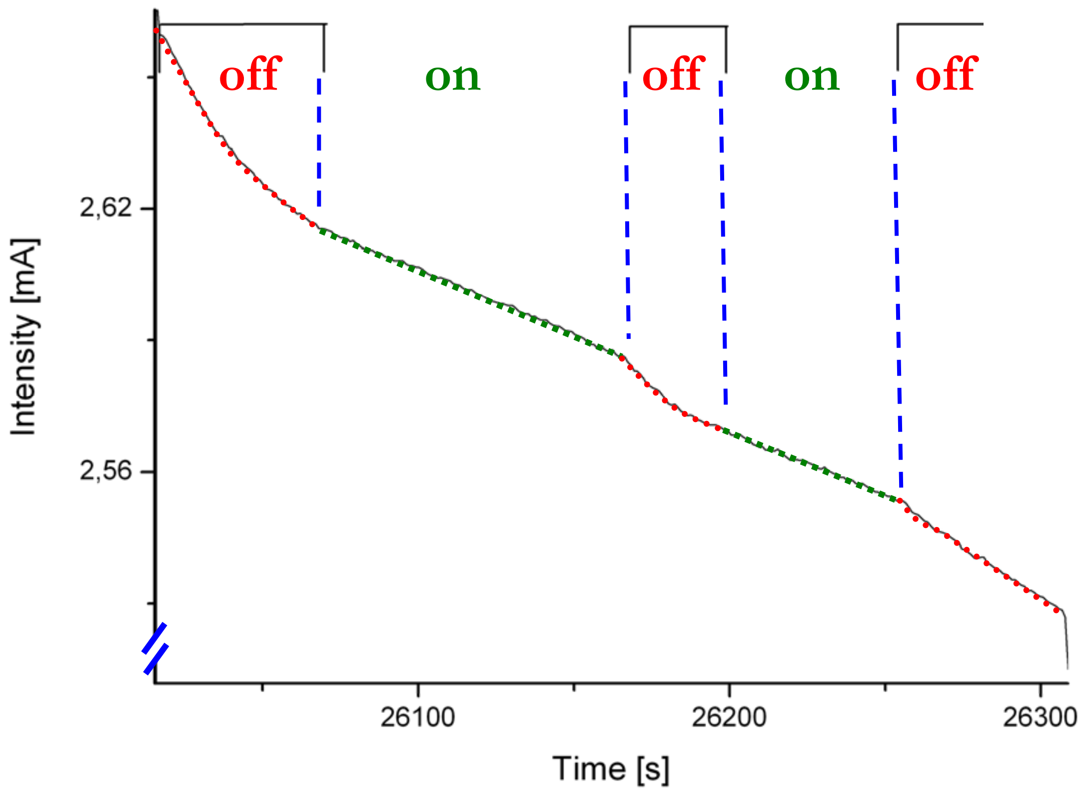
The Atomic Beam Target with the EDDA Detector



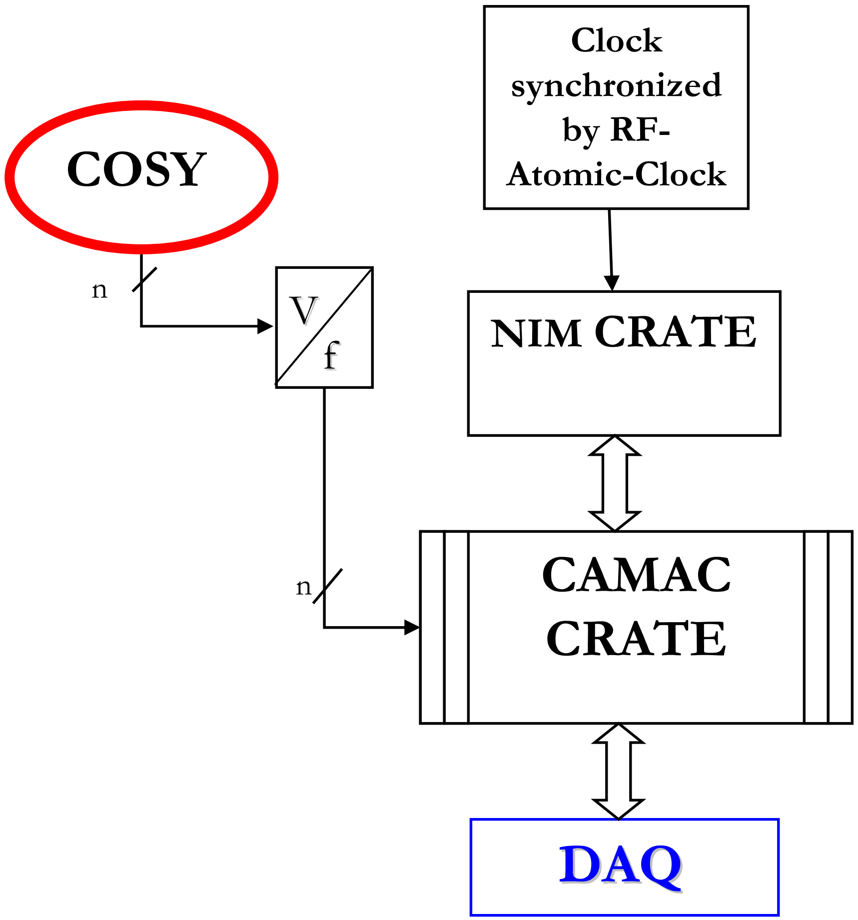
Run Nov. 2006, Single Run, Target & Beamdump Closed

e – cooling

on / off



The Principle of the TRIC Data Acquisition



- The **real time** data acquisition system with **WinXP** developed for this experiment worked **without any problem**.

The Feasiblity of the TRIC Experiment at COSY

Uncorrected Calculated Lifetimes

$A_{y,y}$
in $\vec{p}$-$\vec{p}$ scattering

$$\sigma_{tot} = \sigma_0(1 + A_{y,y}\, C P_B\, P_T)$$

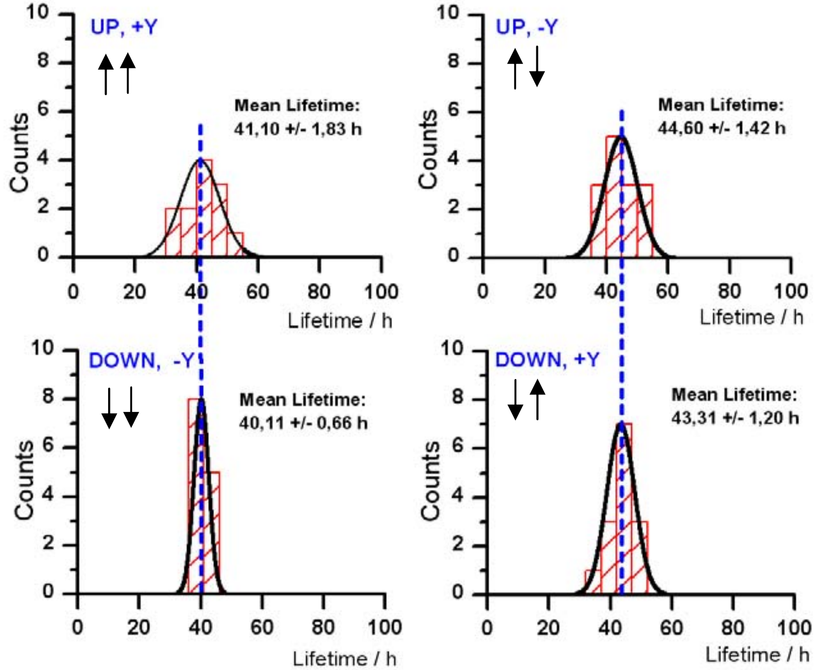
$$\sigma_{\uparrow\uparrow} = \sigma_{\downarrow\downarrow}$$

and

$$\sigma_{\downarrow\uparrow} = \sigma_{\uparrow\downarrow}$$

and for $P_T = P_x$

$$\sigma_{tot} = \sigma_0$$



Looks promising BUT:

The Feasiblity of the TRIC Experiment at COSY

BUTs:

- **Differences of the lifetimes are too big.**

  Substantial corrections are due.

- **There are different distribution widths for the various spin configurations.**

- **The standard deviation of a single measurement is much smaller than the distribution width of the lifetimes.**

  There are undiscovered error contributions.

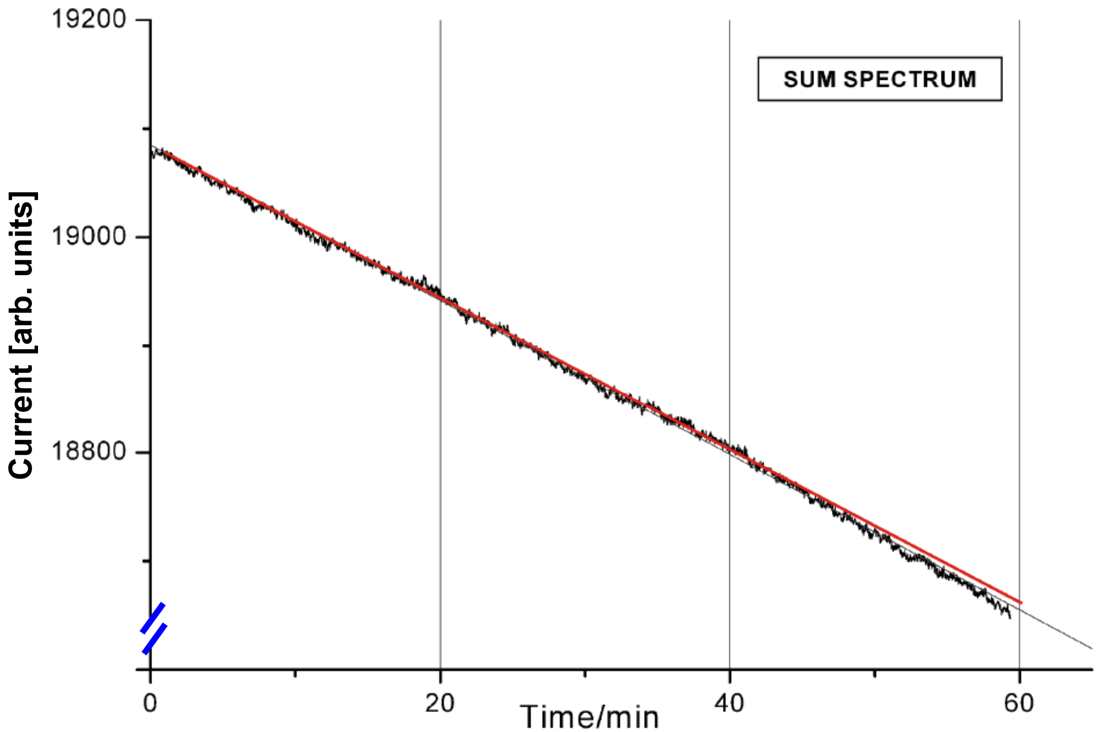
- **Measurements with target polarization P_x do not fit in the cross section scheme.** $\sigma_{parallel} < \sigma_{y,x} < \sigma_{antiparallel}$

$$\sigma = \sigma_0 (1 + A_{y,y} \cdot P_{Beam} P_{Target})$$

  There are systematic errors.

The Feasiblity of the TRIC Experiment at COSY

Sum of all Current Measurements



Polarization Scheme

P_{Beam}:	$\pm P_y$	$\pm P_y$	$\pm P_y$
P_{Target}:	$+P_y$	$P_y	$+P_x$

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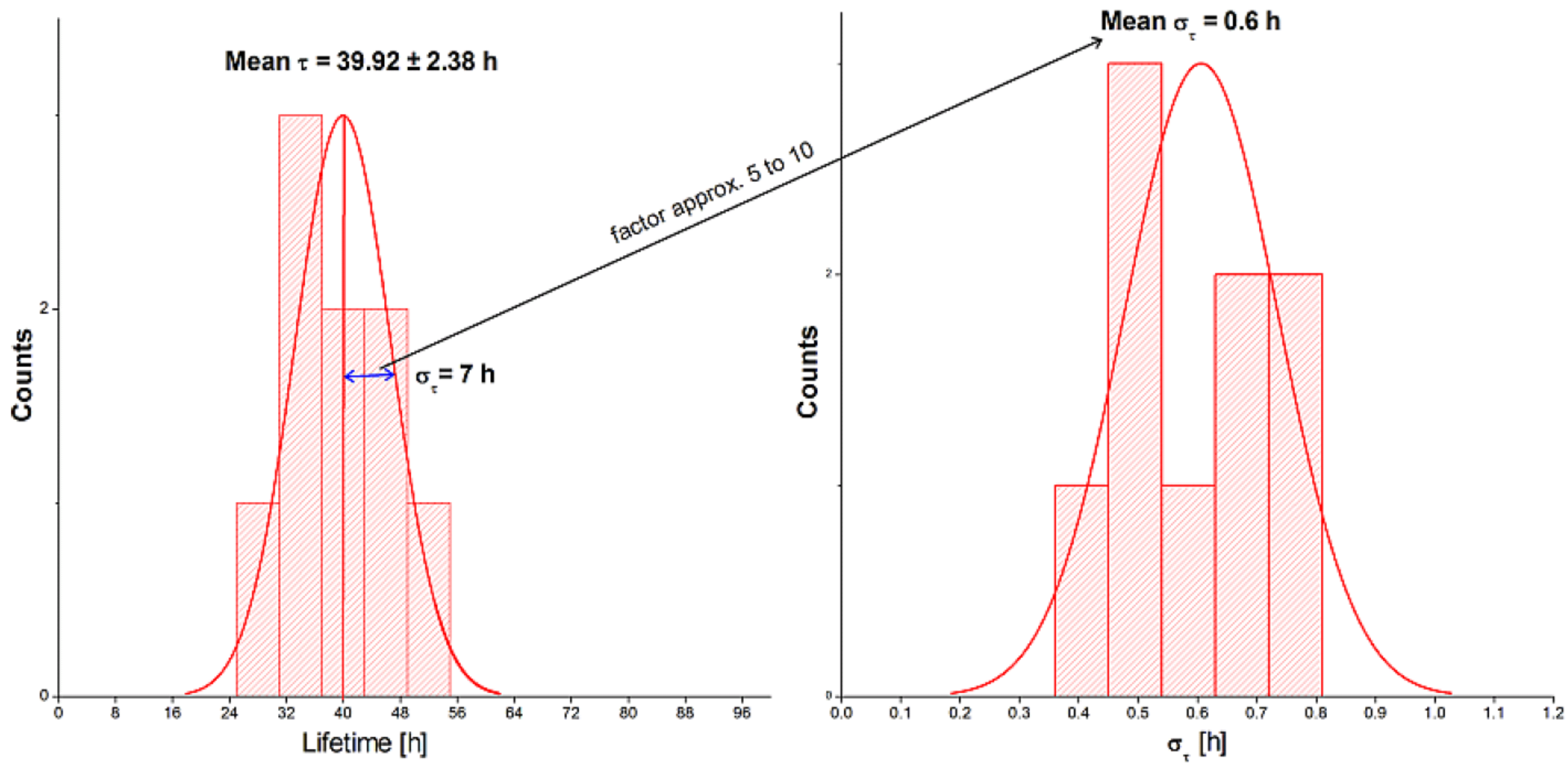
Lifetimes and their Standard Deviation



The standard deviation of the distribution of the measured lifetimes is by a factor 5 to 10 worse than the error of a single lifetime measurement.

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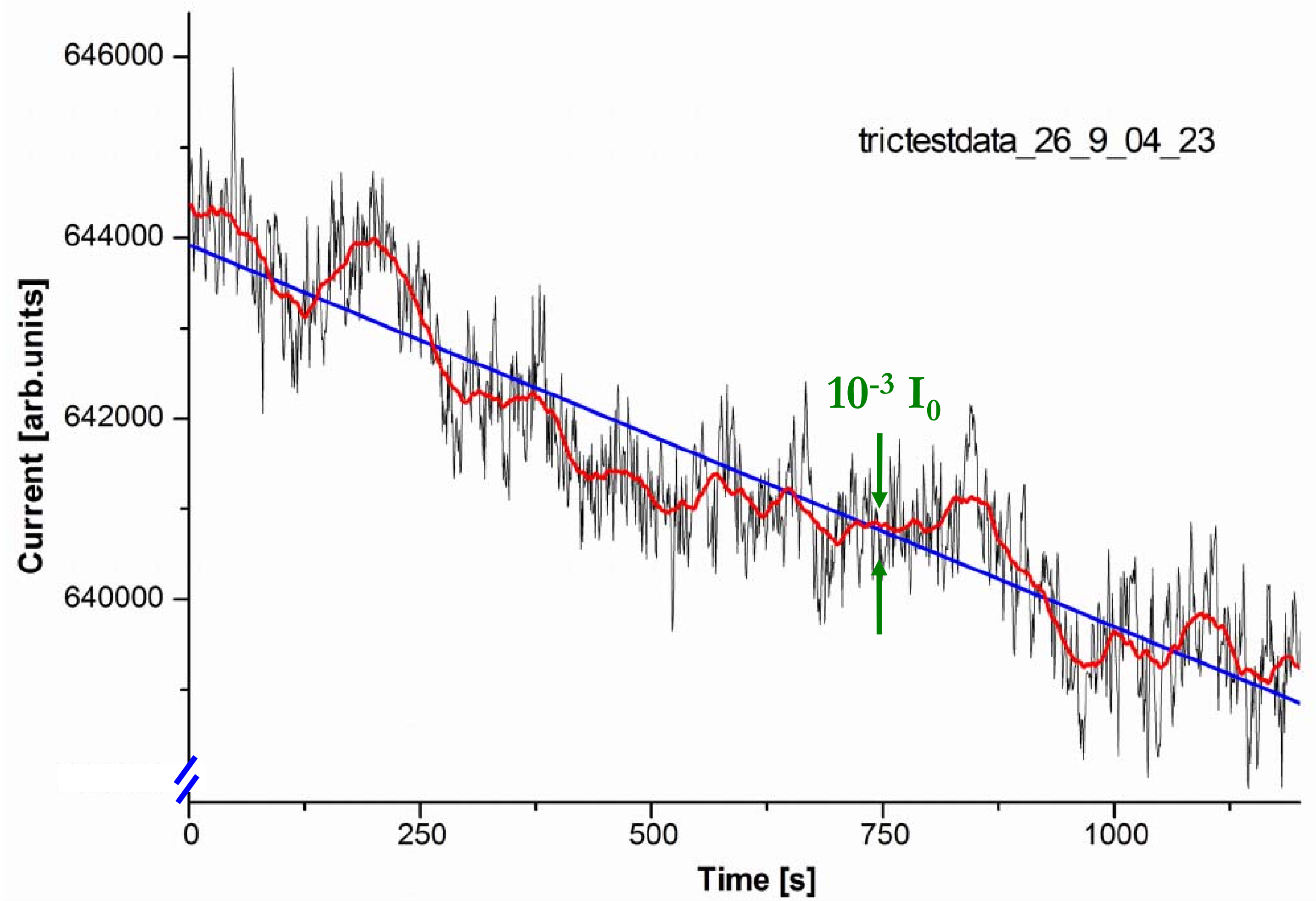
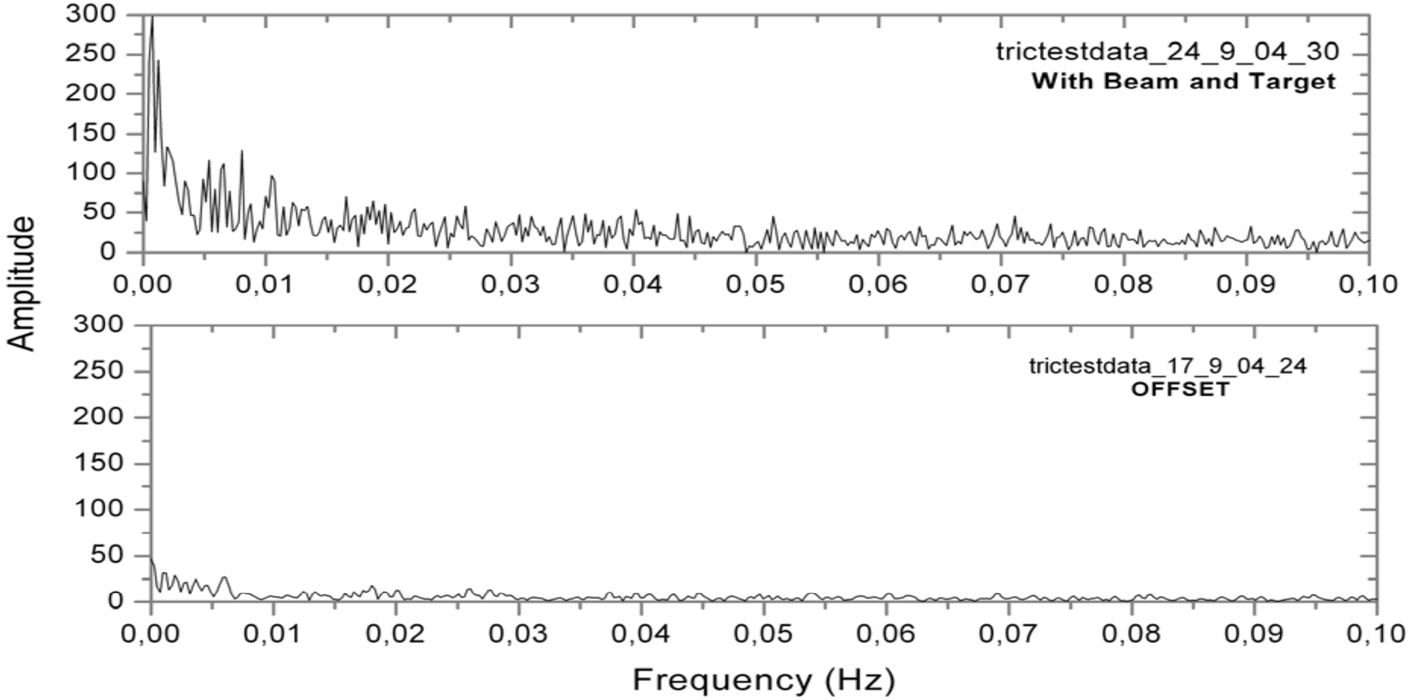
Slow Fluctuations



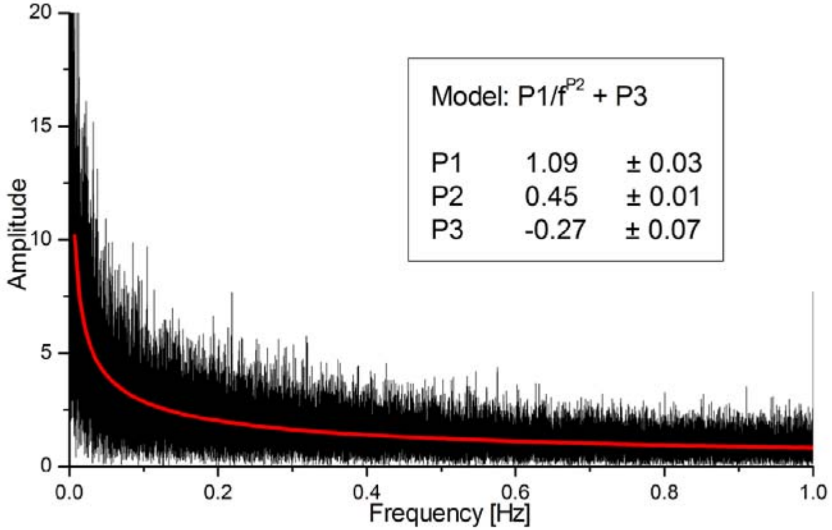
FFT of the BCT Signal



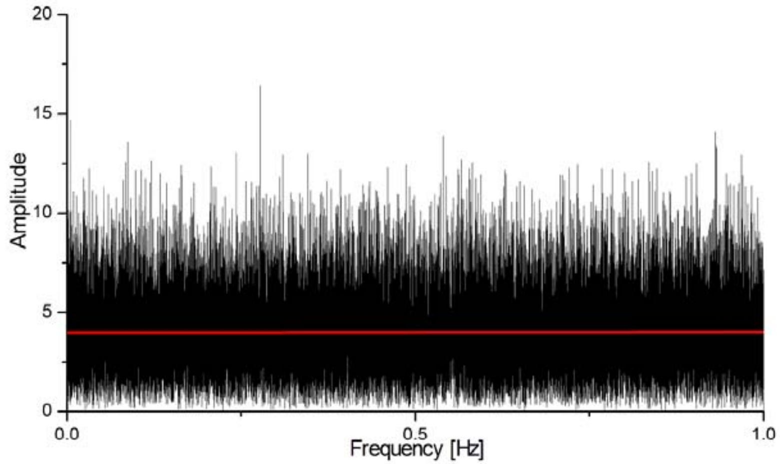
Noise in the offset substantially smaller than in the signal

The Feasiblity of the TRIC Experiment at COSY

1/f Noise of the BCT Signal and White Noise Simulation



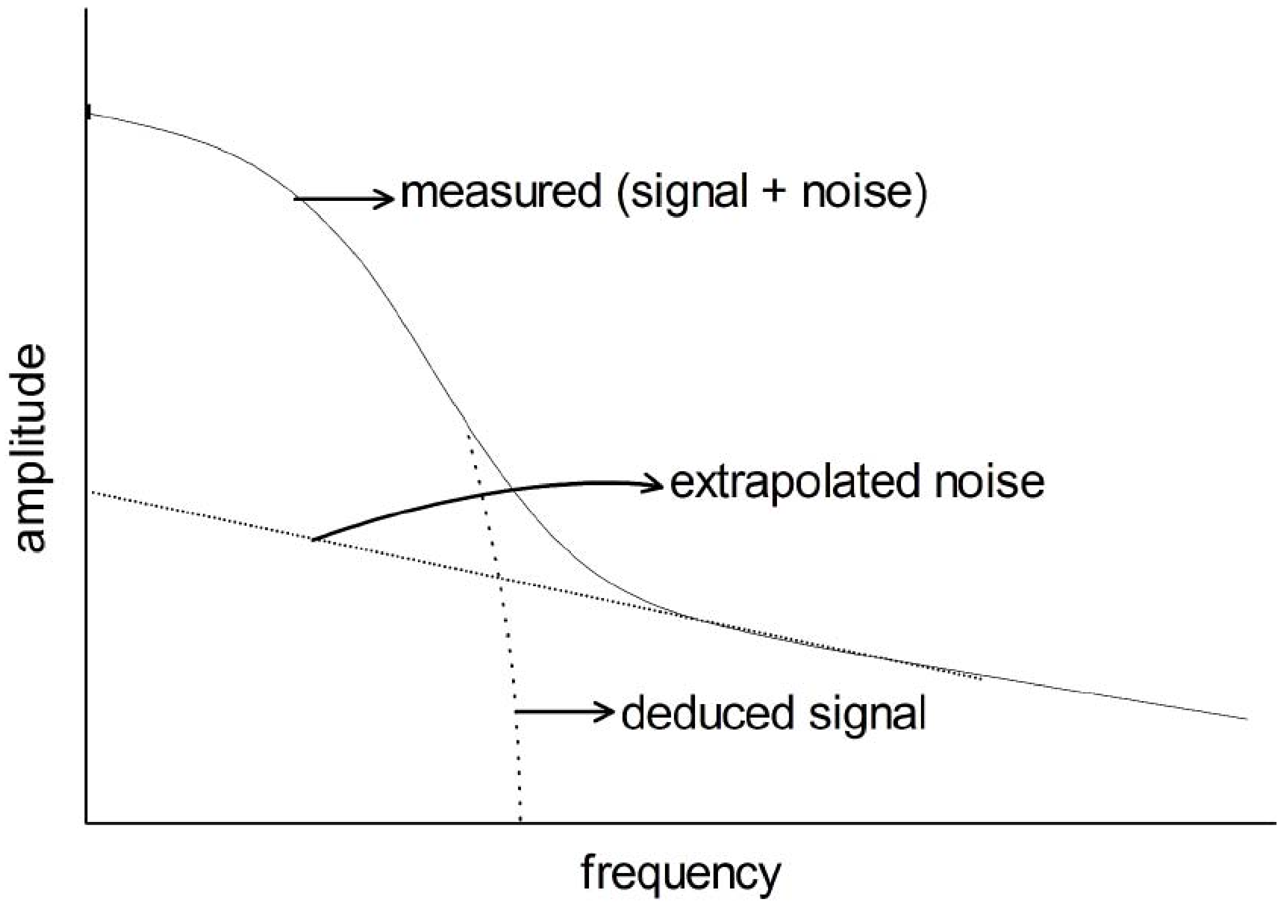
Fit to FFT of 1mA Data



White Noise Simulation at 0.05 Hz

The Feasiblity of the TRIC Experiment at COSY

Wiener-Khinchin Noise Reduction

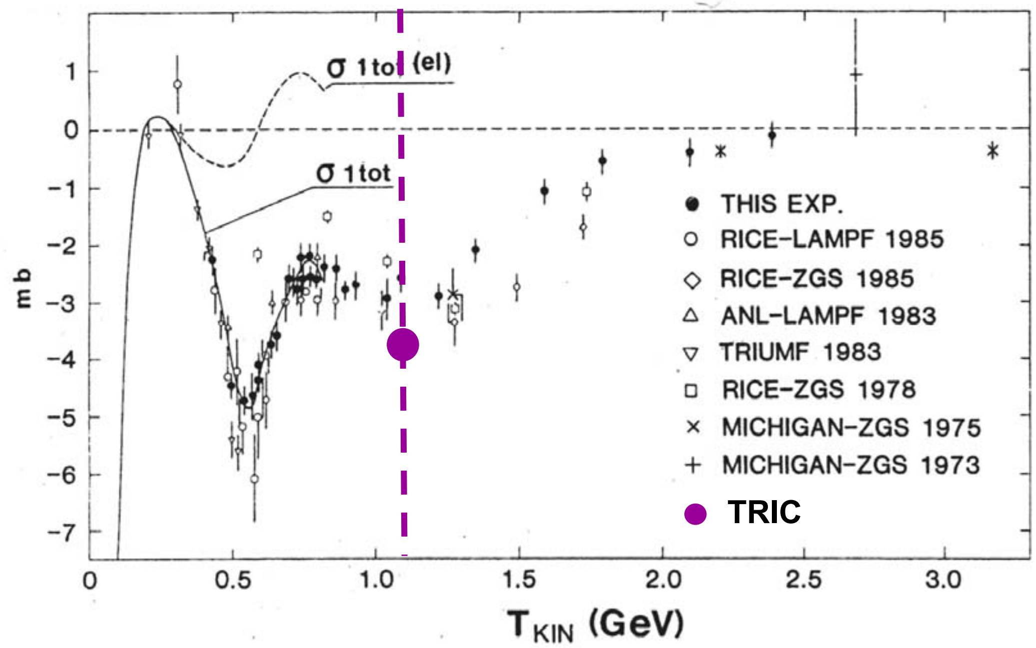


The Feasiblity of the TRIC Experiment at COSY

First Test of a Novel Measuring Method for Total Cross-Sections

TRIC

Ay,y
in p-p scattering



Result:

$\sigma_{1tot} = A_{y,y}\,\sigma_{tot}$

=$3.2 ± 9.6 mb

BUT: $ Beam intensity was low by a factor 10

$ A target cell will increase the density by a factor 40

$ A better BCT can decrease the noise up to an factor 3

Error reduces by a factor $\sqrt{10\cdot 40\cdot 3}$ □ 35

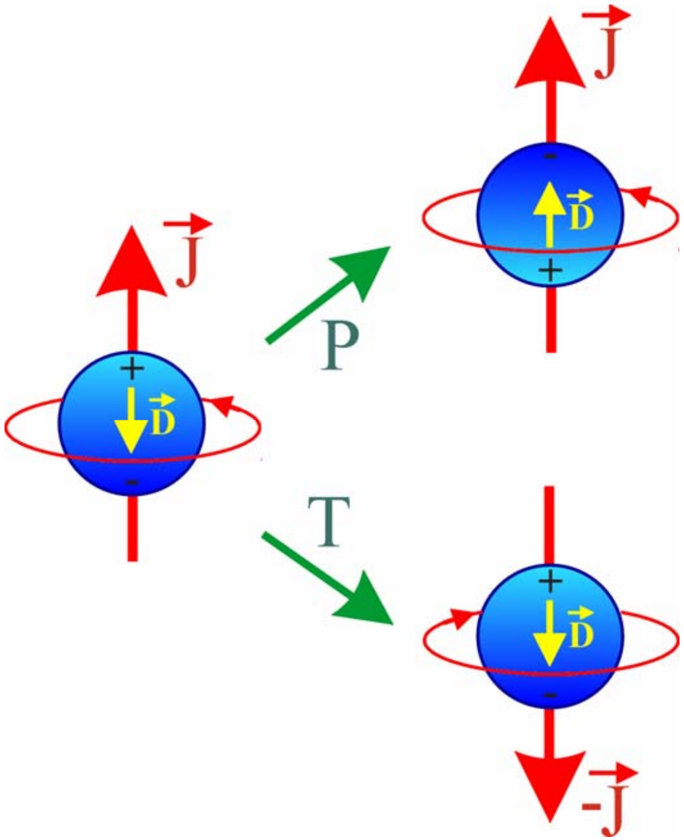
The Feasiblity of the TRIC Experiment at COSY

Summary

- The TRIC experiment is a true Null-Test of TRI.
- For this experiment COSY serves as accelerator, forward spectrometer, and detector.
- The novel measurement technique works, **BUT :**
- Excellent beam cooling is essential for the experiment.
- Low frequency noise from the BCT on the measured beam intensity impairs the precision of the experiment by a factor 3.

BCTs are needed with better or even no ferrite-core.

Thank You



EDM violates:

- Parity
- Time reversal
- CP- conservation

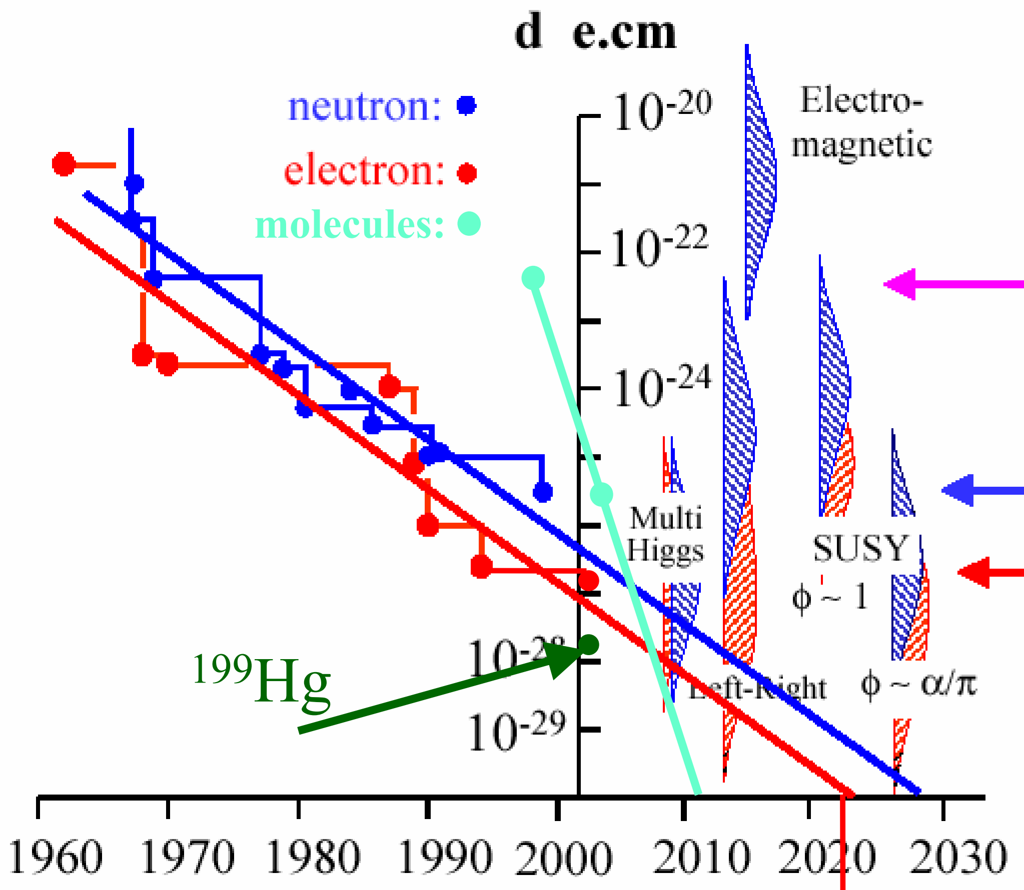
(if CPT conservation assumed)

Standard Model values are tiny, hence:

An observed EDM would be
Sign of New Physics
beyond
Standard Theory

The Feasiblity of the TRIC Experiment at COSY

Some Introductory Remarks



d(proton) < 6×10^{-23}

d(neutron) < 6×10^{-26}

d(electron) < 1.6×10^{-27}

d_e (SM) < 10^{-37}

after E.Hinds

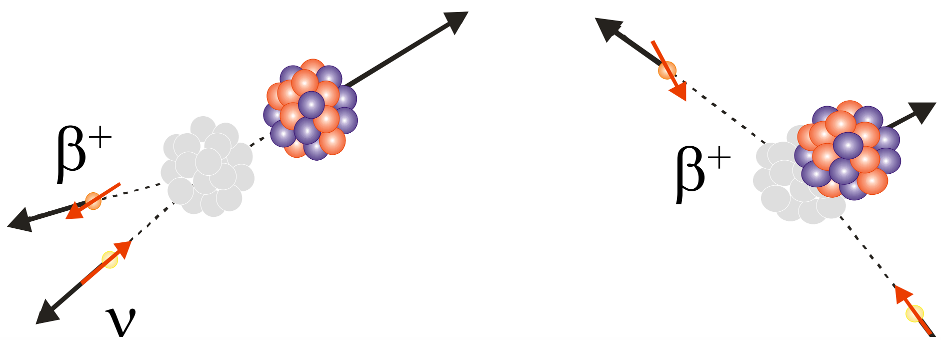
The Feasiblity of the TRIC Experiment at COSY

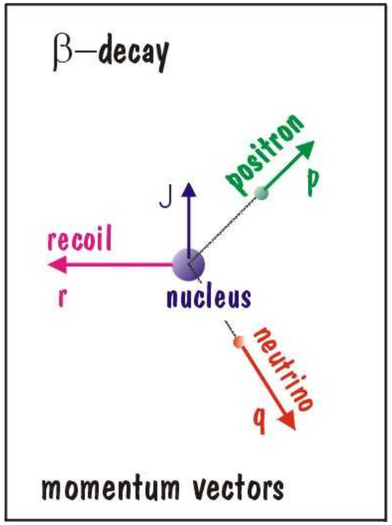
Some Introductory Remarks

In Standard Model:
Weak Interaction is
V-A

In general β-decay
could be also
S , P, T

Vector [Tensor] **Scalar [Axial vector]**





$$\frac{d^2W}{d\Omega_e d\Omega_\nu} \sim 1 + a\,\frac{\boldsymbol{p}\cdot\hat{\boldsymbol{q}}}{E} + b\,\Gamma\,\frac{m_e}{E}$$
$$+ \langle \boldsymbol{J}\rangle\cdot\left[A\,\frac{\boldsymbol{p}}{E} + B\,\hat{\boldsymbol{q}} + D\,\frac{\boldsymbol{p}\times\hat{\boldsymbol{q}}}{E}\right]$$
$$+ \langle \boldsymbol{\sigma}\rangle\cdot\left[G\,\frac{\boldsymbol{p}}{E} + Q\,\langle \boldsymbol{J}\rangle + R\,\langle \boldsymbol{J}\rangle\times\frac{\boldsymbol{p}}{E}\right]$$

⇒ nuclear β-decays, Experiments in Traps
⇒ muon decays, Michel parameters

The Feasiblity of the TRIC Experiment at COSY

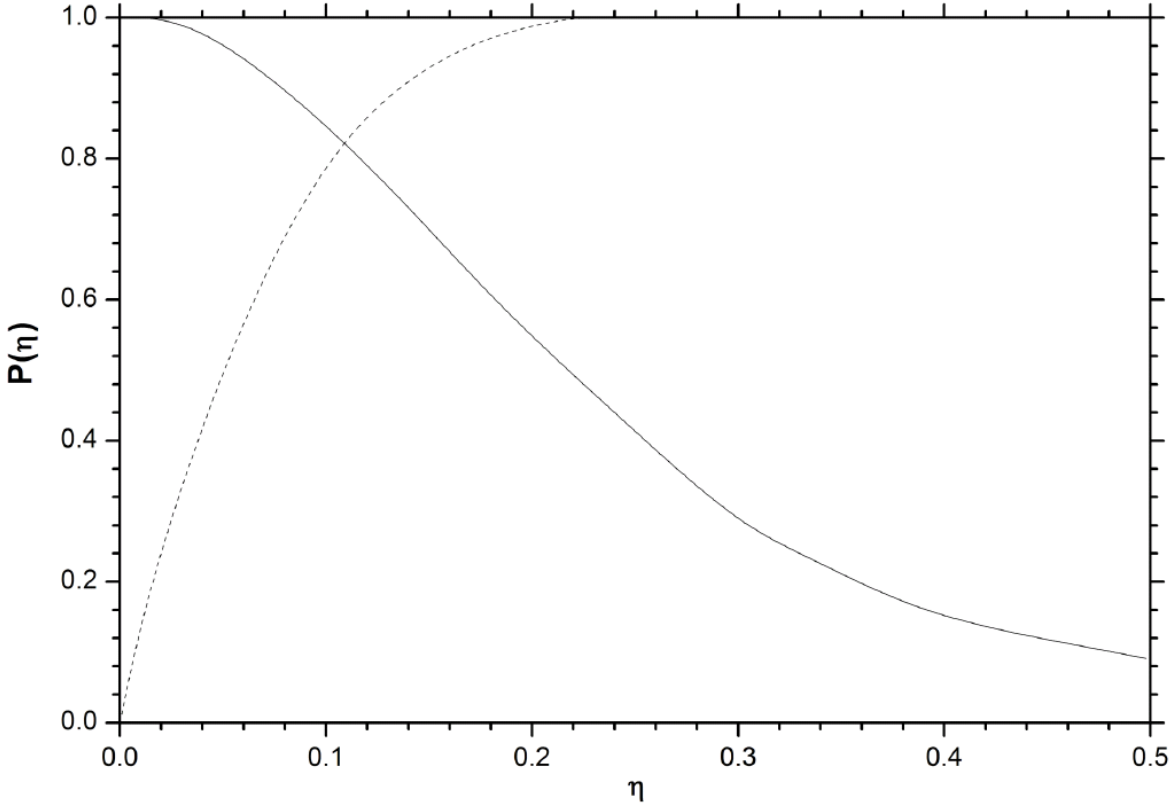


Figure 5.6: The Survival probability (full curve) and the emittance growth function (dashed curve). The dimensionless variable η increases linearly with turn number.

EDM of an elementary particle :

needed: i) Quantization axis (Spin $\vec{\sigma}$)
ii) Electric field $\vec{E}$

Quantity	T	P
$\vec{p}$	$-\vec{p}$	$-\vec{p}$
$\vec{\sigma}$	$-\vec{\sigma}$	$\vec{\sigma}$
$\vec{E}$	$\vec{E}$	$-\vec{E}$
$\vec{B}$	$-\vec{B}$	$\vec{B}$

Observable : $\vec{\sigma} \cdot \vec{E}$

$\frown$ **P-odd/T-odd** experiment

Upper limit : $\approx 6 \cdot 10^{-26}\, e \cdot cm$ (n-EDM)

↓

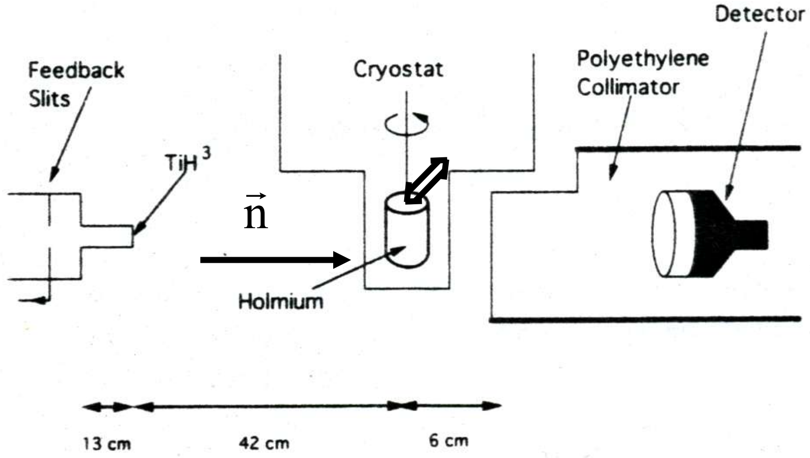
Deduced Strength for **P-even/T-odd** : $g_{\rho T}$ **: ~1.5 • 10^{-3}**

The Quantity of Interest for a True P-even/T-odd Null-Test

5.9 MeV Neutron Transmission Experiment through ^{165}Ho

Observable : $\vec{p}\cdot(\vec{\sigma}_1 \times \vec{\sigma}_2)(\vec{p}\cdot\vec{\sigma}_2)$

Result : $g_{\rho T}$: ☝ 2,3 • 10^{-2}

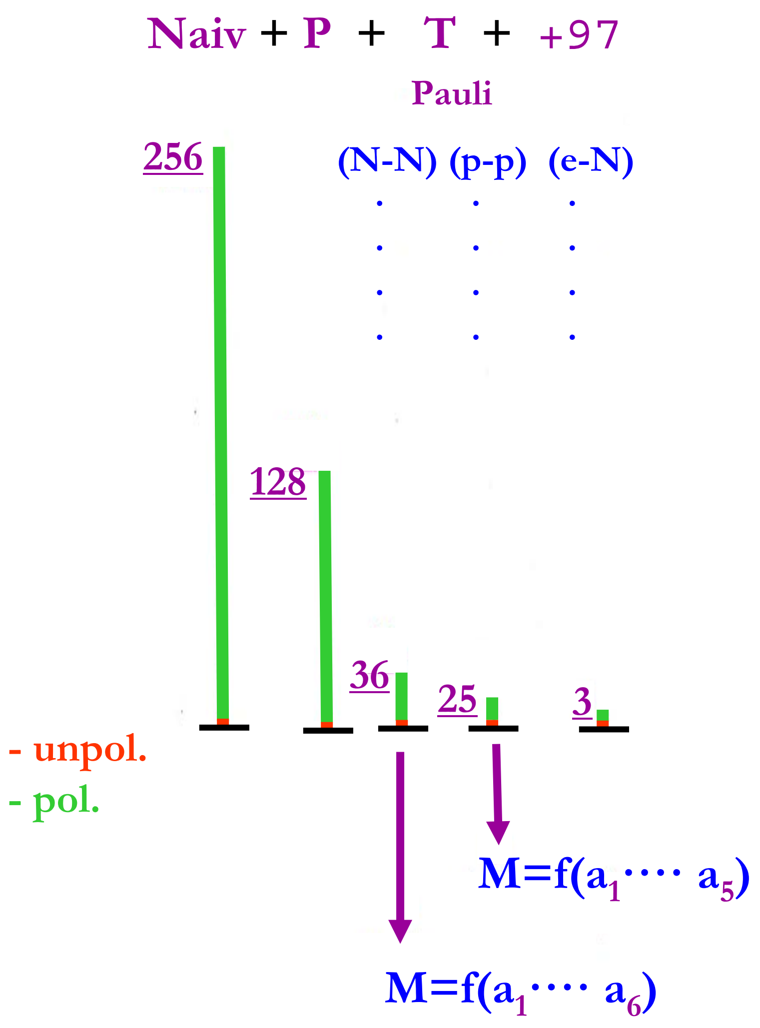


*J.E.Koster et al., Phys. Rev. C **49** (1994) 710*

- Since the tensor polarization in ^{165}Ho is generated by one valence nucleon, the effect is diluted by the other 164 nucleons
- Therefore:
  Restrict experiment to most simple Spin1-Spin½ system, i.e. $\vec{p}$ - $\vec{d}$ scattering at COSY (as an internal experiment)

The Quantity of Interest for a True P-even/T-odd Null-Test

Number of Spin ½+Spin ½ Observables



Example:

$$\sigma_0 = \sum_i a_i a_i^*$$

$$\sigma_{pol} = \sum_{i,j} \pm a_i a_j^*$$

The Feasiblity of the TRIC Experiment at COSY

The Quantity of Interest for a True P-even/T-odd Null-Test

TRIC

25 Observables for Identical Particles (Spin 1/2 + Spin 1/2)

$$\sigma \equiv I_{0000} = \sigma C_{nnnn} = \frac{1}{2}\{ |a|^2 + |b|^2 + |c|^2 + |d|^2 + |e|^2 \}$$

$$\sigma C_{nn00} = \sigma A_{00nn} = \frac{1}{2}\{ |a|^2 - |b|^2 - |c|^2 + |d|^2 + |e|^2 \}$$

$$\sigma D_{n0n0} = \sigma D_{0n0n} = \frac{1}{2}\{ |a|^2 + |b|^2 - |c|^2 - |d|^2 + |e|^2 \}$$

$$\sigma K_{0nn0} = \sigma K_{n00n} = \frac{1}{2}\{ |a|^2 - |b|^2 + |c|^2 - |d|^2 + |e|^2 \}$$

$$\sigma C_{llll} = \sigma C_{mmmm} = \frac{1}{2}\{ |a|^2 + |b|^2 + |c|^2 + |d|^2 - |e|^2 \}$$

$$\sigma P \equiv \sigma P_{n000} = \sigma P_{0n00} = \sigma A_{00n0} = \sigma A_{000n} = \sigma C_{nnn0} = \sigma C_{nn0n} = \sigma M_{n0nn} = \sigma N_{0nnn} = \mathrm{Re}\, a^* e$$

$$\sigma C_{lllm} = \sigma C_{llml} = -\sigma C_{lmll} = -\sigma C_{mlll} = \sigma C_{lmmm} = \sigma C_{mlmm} = -\sigma C_{mmlm} = -\sigma C_{mmml} = \mathrm{Im}\, a^* e$$

$$\sigma C_{lnl0} = \sigma C_{mnm0} = \sigma C_{nl0l} = \sigma C_{nm0m} = \sigma M_{l0ln} = \sigma M_{m0mn} = \sigma N_{0lnl} = \sigma N_{0mnm} = \mathrm{Re}\, b^* e$$

$$\sigma D_{l0m0} = \sigma D_{0l0m} = -\sigma D_{m0l0} = -\sigma D_{0m0l} = \sigma C_{nlnm} = \sigma C_{lnmn} = -\sigma C_{mnln} = -\sigma C_{nmnl} = \mathrm{Im}\, b^* e$$

$$\sigma C_{nll0} = \sigma C_{nmm0} = \sigma C_{ln0l} = \sigma C_{mn0m} = \sigma M_{l0nl} = \sigma M_{m0nm} = \sigma N_{0lln} = \sigma N_{0mmn} = \mathrm{Re}\, c^* e$$

$$\sigma K_{0lm0} = \sigma K_{l00m} = -\sigma K_{m00l} = -\sigma K_{0ml0} = \sigma C_{nlmn} = \sigma C_{lnnm} = -\sigma C_{mnnl} = -\sigma C_{nmln} = \mathrm{Im}\, c^* e$$

$$\sigma C_{lln0} = -\sigma C_{mmn0} = \sigma C_{ll0n} = -\sigma C_{mm0n} = \sigma M_{n0ll} = -\sigma M_{n0mm} = \sigma N_{0nll} = -\sigma N_{0nmm} = -\mathrm{Re}\, d^* e$$

$$\sigma C_{lm00} = \sigma C_{ml00} = -\sigma A_{00lm} = -\sigma A_{00ml} = -\sigma C_{nnml} = -\sigma C_{nnlm} = \sigma C_{mlnn} = \sigma C_{lmnn} = \mathrm{Im}\, d^* e$$

$$\sigma D_{m0m0} = \sigma D_{0m0m} = \sigma C_{nlnl} = \sigma C_{lnln} = \mathrm{Re}\,(a^* b + c^* d)$$

$$\sigma C_{mnl0} = \sigma C_{nm0l} = -\sigma M_{l0mn} = -\sigma N_{0lnm} = \mathrm{Im}\,(a^* b + c^* d)$$

$$\sigma D_{l0l0} = \sigma D_{0l0l} = \sigma C_{nmnm} = \sigma C_{mnmn} = \mathrm{Re}\,(a^* b - c^* d)$$

$$\sigma C_{lnm0} = \sigma C_{nl0m} = -\sigma M_{m0ln} = -\sigma N_{0mnl} = -\mathrm{Im}\,(a^* b - c^* d)$$

$$\sigma K_{0mm0} = \sigma K_{m00m} = \sigma C_{nlln} = \sigma C_{lnnl} = \mathrm{Re}\,(a^* c + b^* d)$$

$$\sigma C_{nml0} = \sigma C_{mn0l} = -\sigma M_{l0nm} = -\sigma N_{0lmn} = \mathrm{Im}\,(a^* c + b^* d)$$

$$\sigma K_{0ll0} = \sigma K_{l00l} = \sigma C_{mnnm} = \sigma C_{nmmn} = \mathrm{Re}\,(a^* c - b^* d)$$

$$\sigma C_{nlm0} = \sigma C_{ln0m} = -\sigma M_{m0nl} = -\sigma N_{0mln} = -\mathrm{Im}\,(a^* c - b^* d)$$

$$\sigma C_{mm00} = \sigma A_{00mm} = -\sigma C_{nnll} = -\sigma C_{llnn} = \mathrm{Re}\,(a^* d + b^* c)$$

$$\sigma C_{lmn0} = \sigma C_{ml0n} = -\sigma M_{n0lm} = -\sigma N_{0nml} = -\mathrm{Im}\,(a^* d + b^* c)$$

$$\sigma C_{ll00} = \sigma A_{00ll} = -\sigma C_{mmnn} = -\sigma C_{nnmm} = -\mathrm{Re}\,(a^* d - b^* c)$$

$$\sigma C_{mln0} = \sigma C_{lm0n} = -\sigma M_{n0ml} = -\sigma N_{0nlm} = -\mathrm{Im}\,(a^* d - b^* c)$$

$$C_{lmlm} = C_{mlml} = -1 + D_{n0n0} + C_{llll}$$

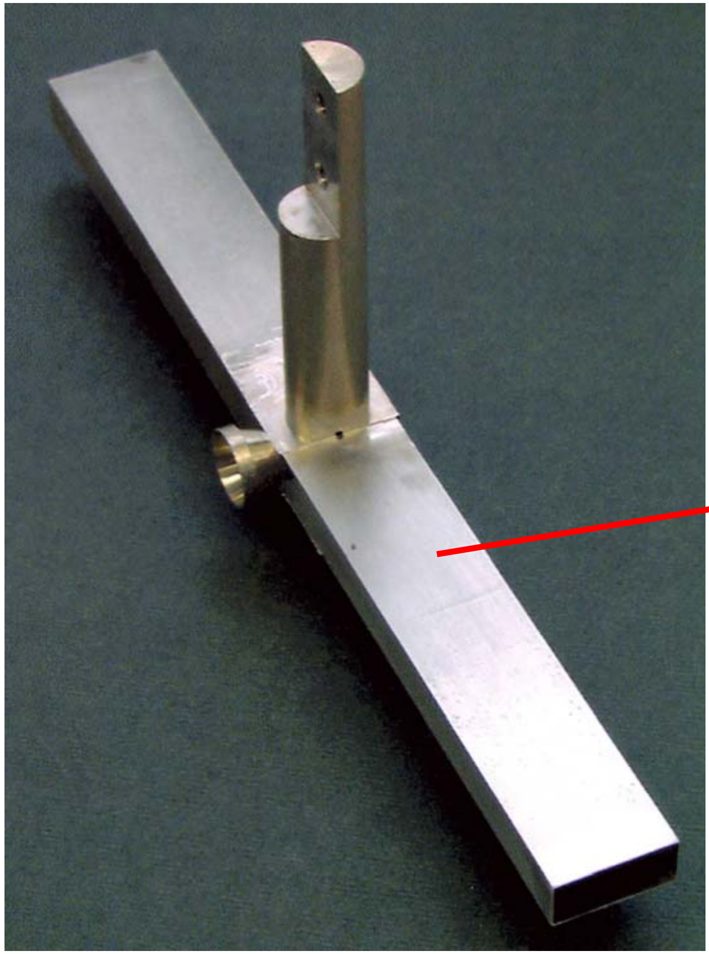
$$C_{llmm} = C_{mmll} = 1 - A_{00nn} - C_{llll}$$

$$C_{lmml} = C_{mllm} = -1 + K_{0nn0} + C_{llll}\,.$$

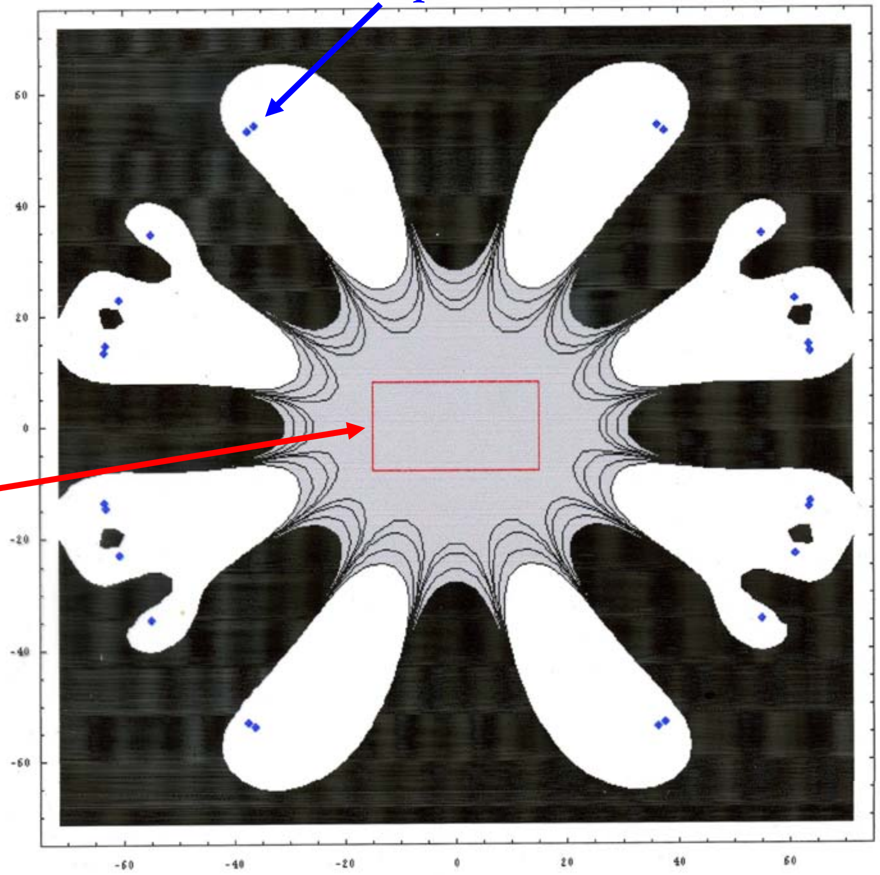
[Bistricky et al, J. de Phys. 39]

The Feasiblity of the TRIC Experiment at COSY

Some Experimental Details

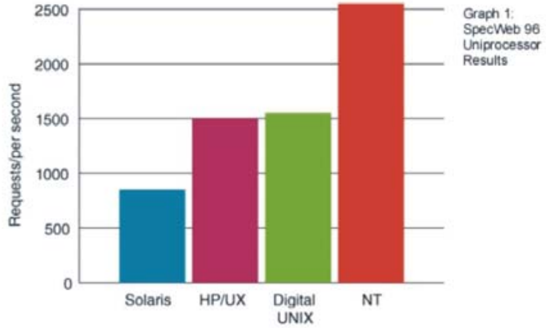


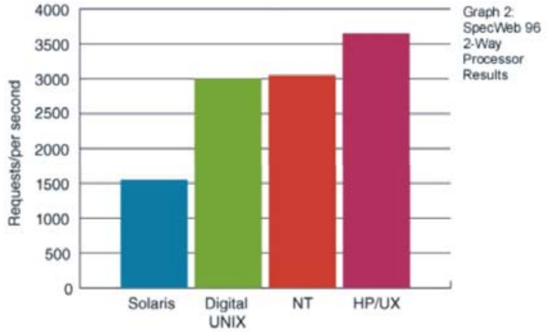
24 parallele Stromleiter

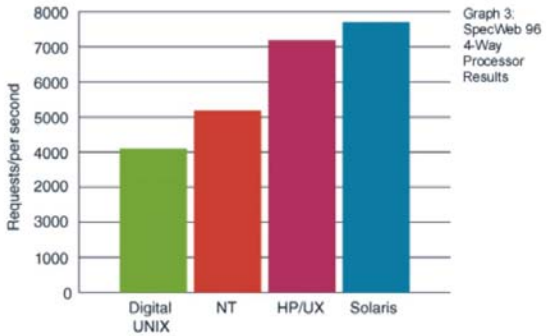


Schnitt in der xy - Ebene bei z = 0 mm. Berechnete Abweichung vom B_y-Feld im Mittelpunkt. Höhenlinien bei ± (0.1; 0.2; 0.5; 1) Promill.

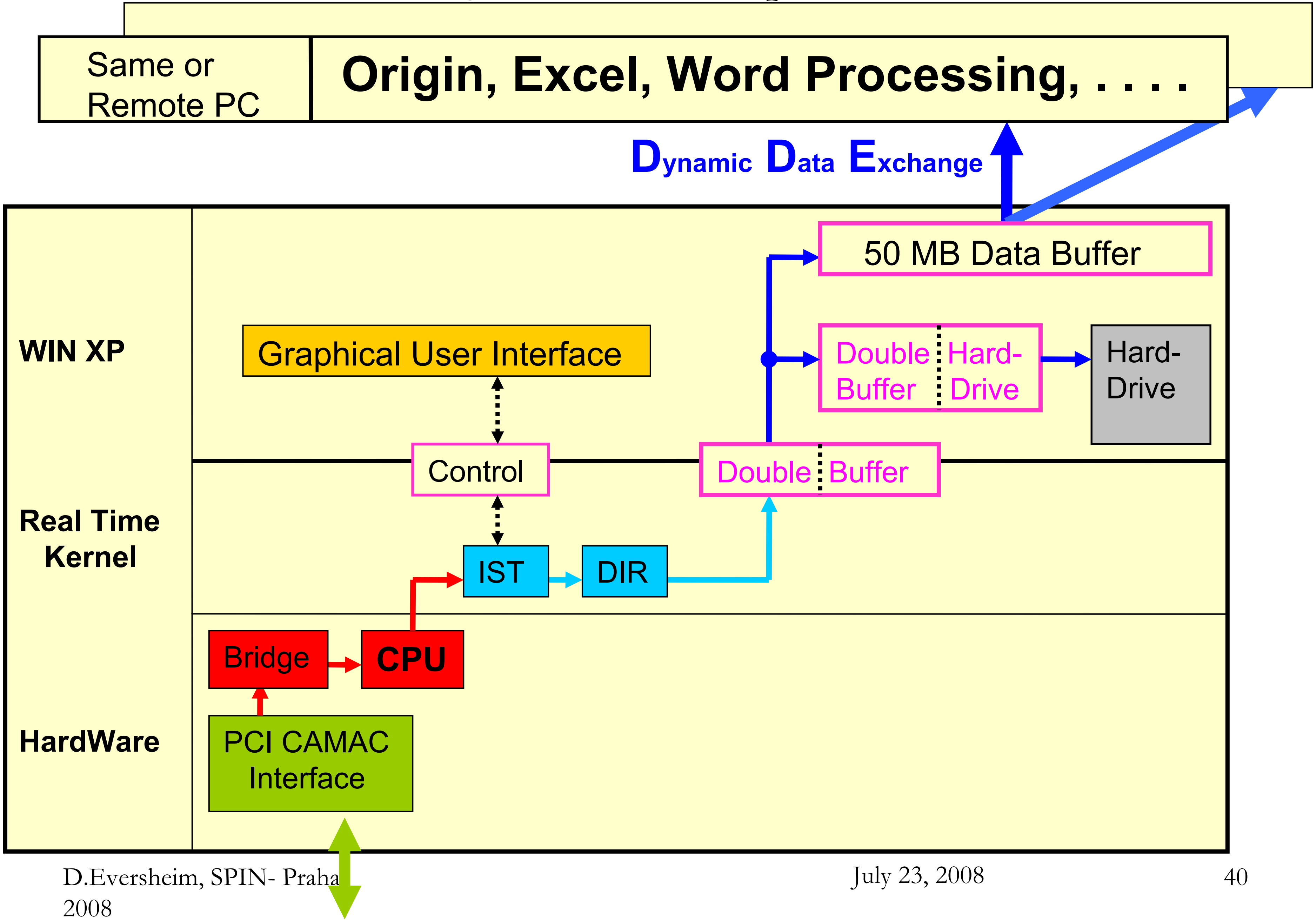
The Feasiblity of the TRIC Experiment at COSY
Operating System Performance



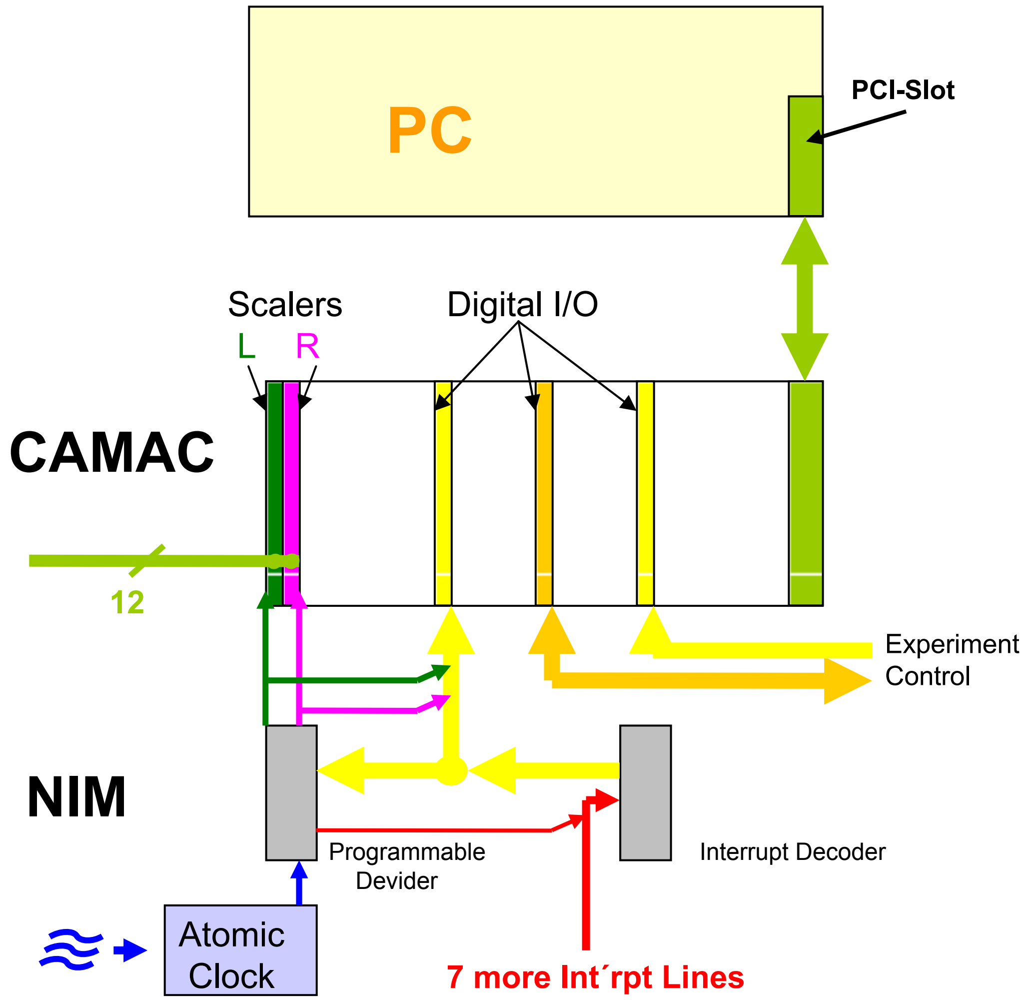




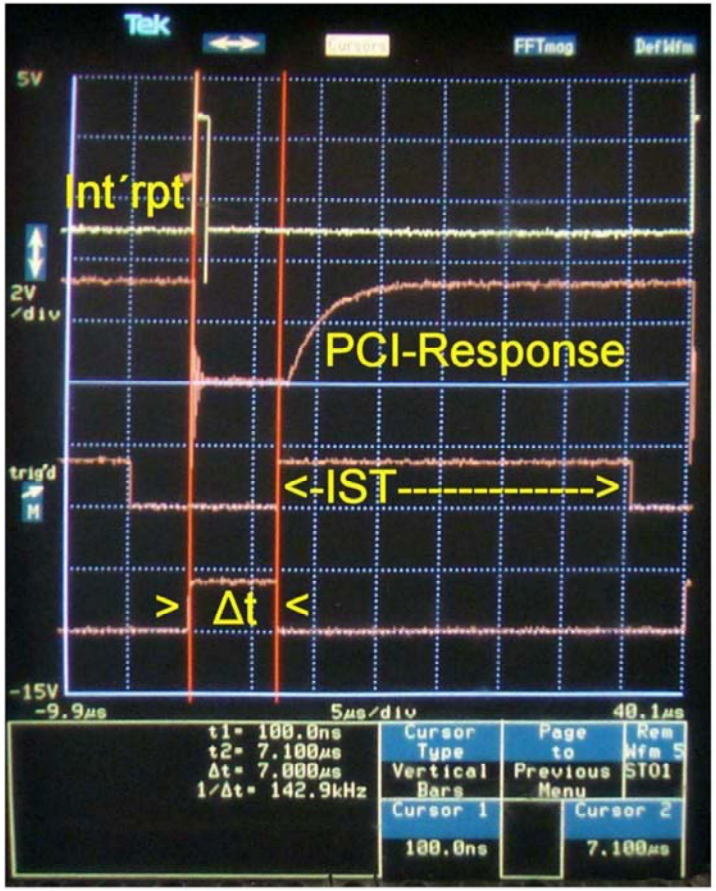
The Feasiblity of the TRIC Experiment at COSY



Principle of „Dead-Time Less“ Data Acquisition



The Feasiblity of the TRIC Experiment at COSY
Interrupt Response

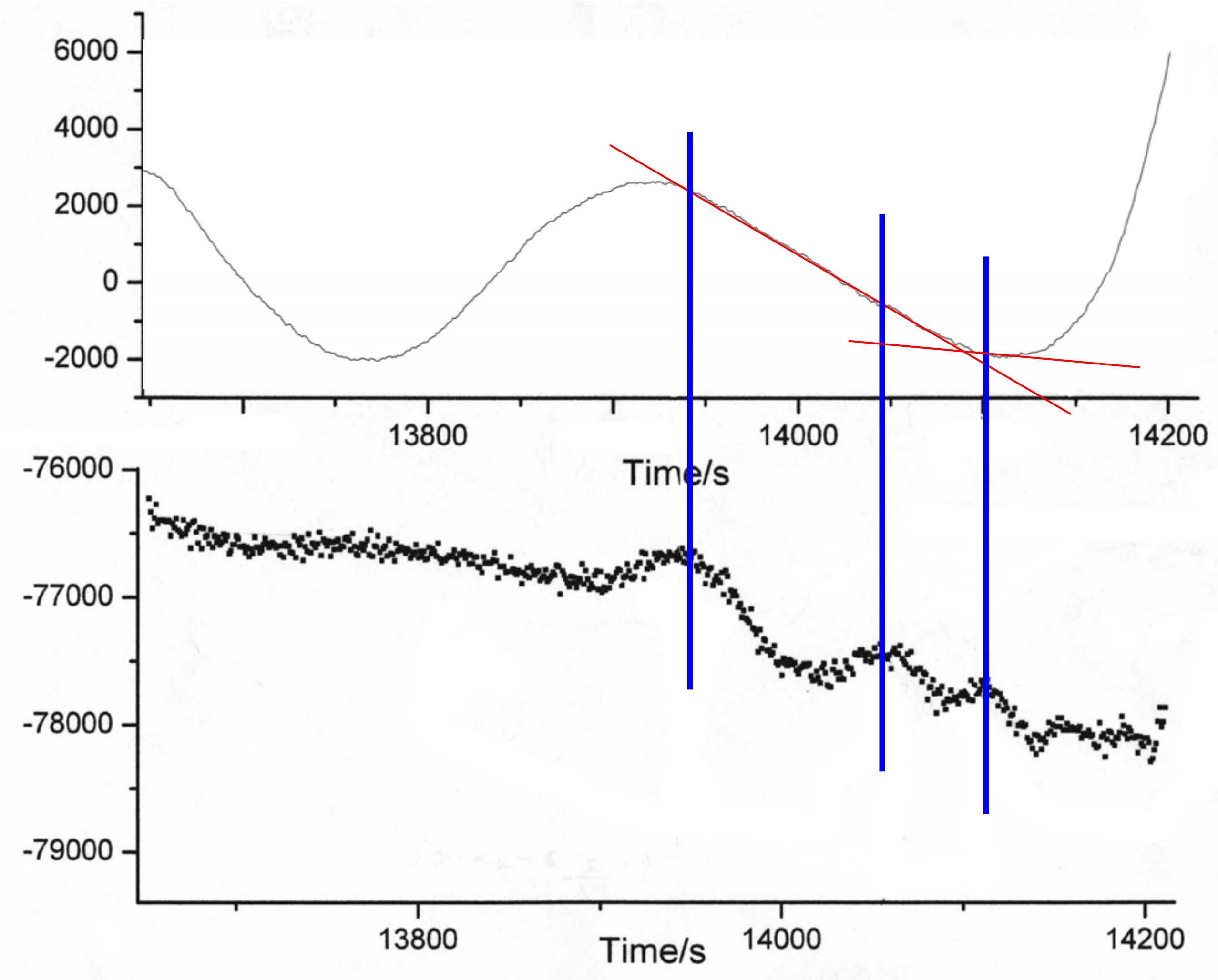


The Feasiblity of the TRIC Experiment at COSY

The Gain Riddle

Residue

Gain



The Feasiblity of the TRIC Experiment at COSY

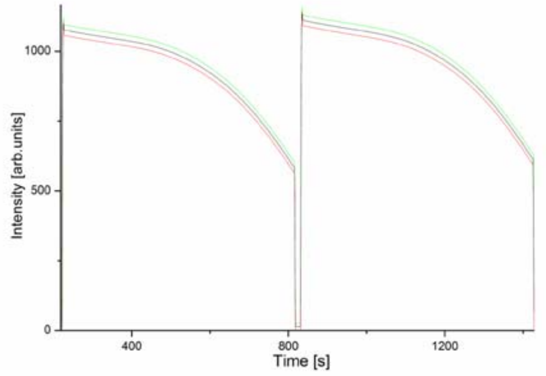


Figure 5.10: The red (lower) and green (upper) lines are due to the addition of a modulated current ($\pm\delta I$) to the beam current. The black (middle) curve is the average of the upper and the lower curves.

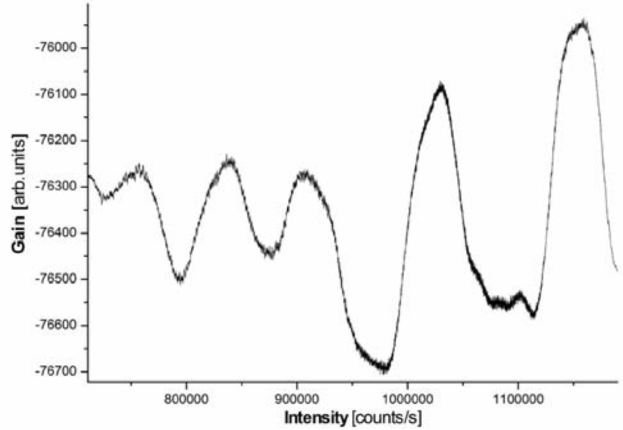


Figure 5.12: The universal gain curve constructed from all available data.

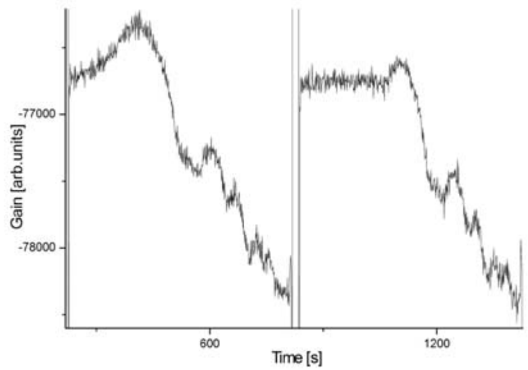


Figure 5.11: The difference between two neighboring data points. Non-linearities are revealed in this plot.

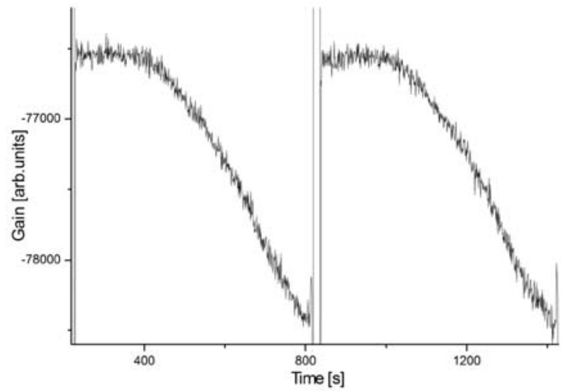
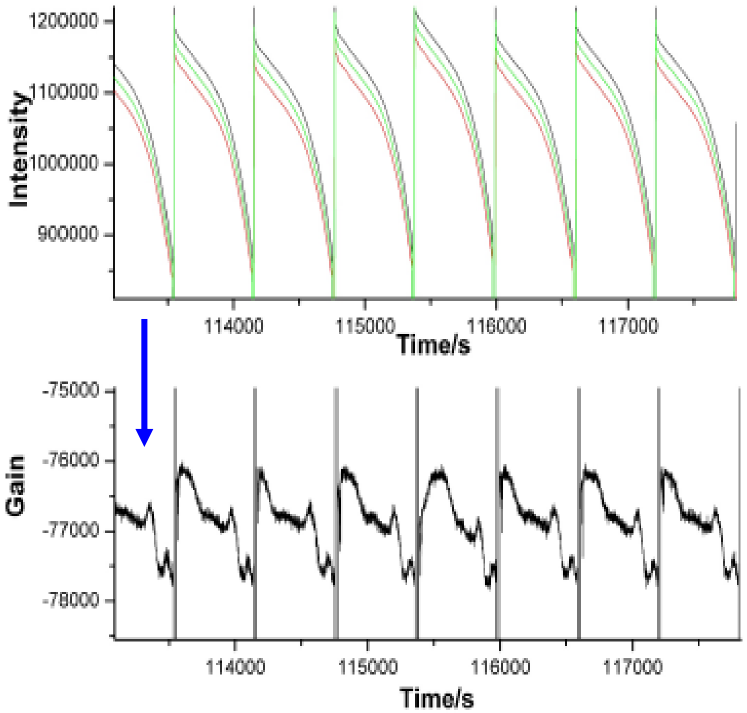


Figure 5.13: The corrected gain curve of figure 5.11 using the universal gain curve.

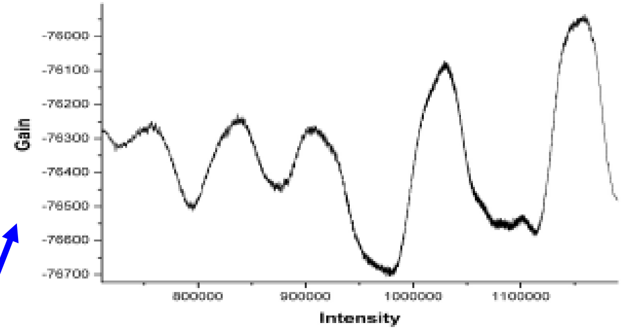
The Feasiblity of the TRIC Experiment at COSY
Gain Correction Scheme

TRIC

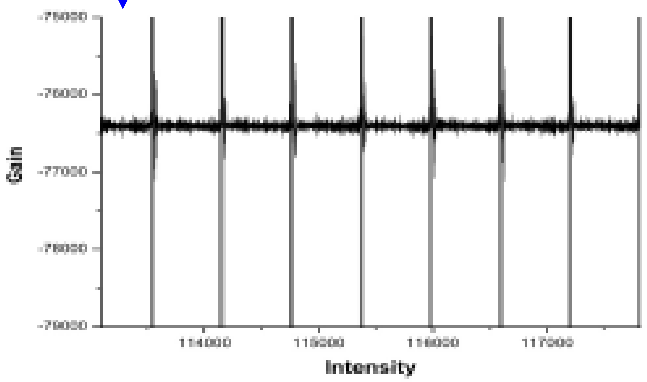
Intensity Modulations of ANKE Runs



Above: Data with modulated current input
Below: Gain derived from the above plot



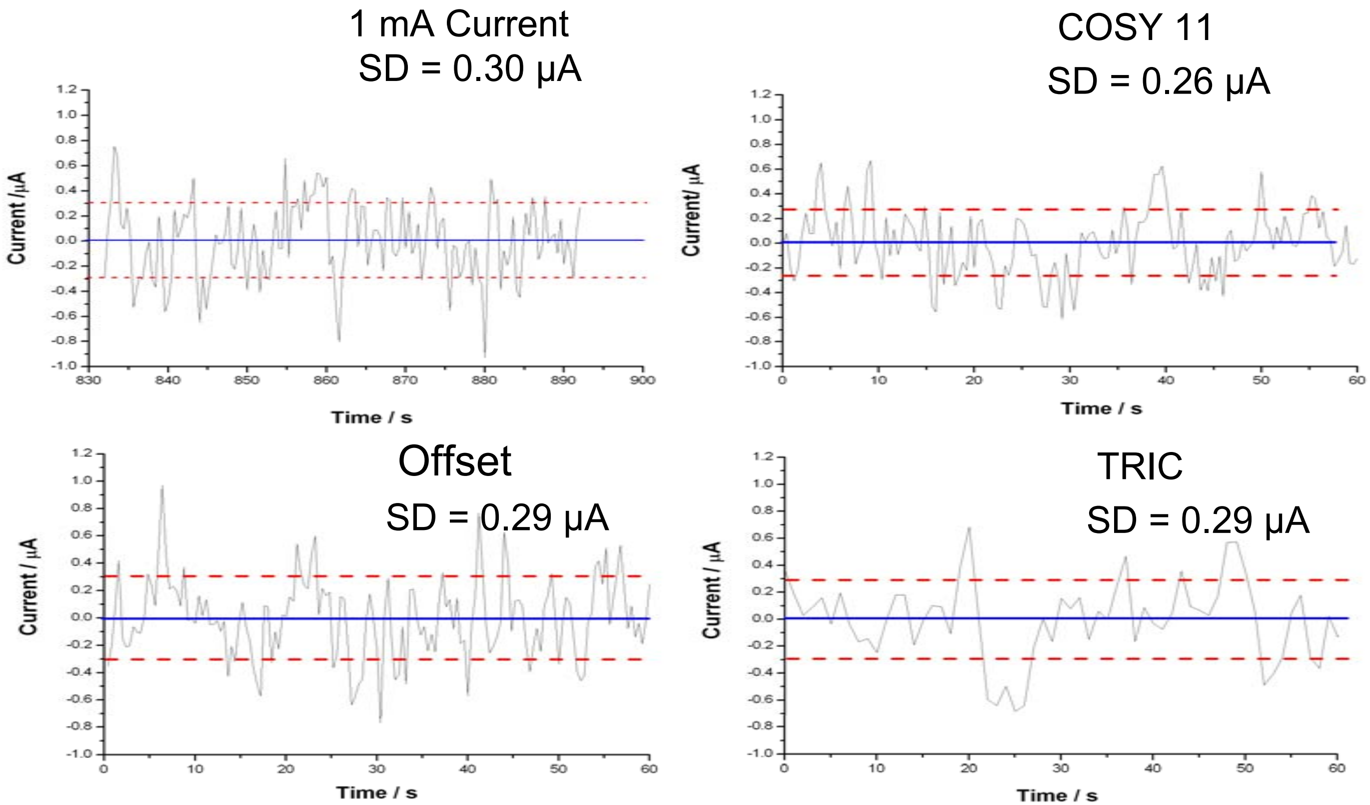
The universal gain vs. intensity plot



The completely corrected gain

The Feasiblity of the TRIC Experiment at COSY

Standard Deviations



The Standard deviations of residues compare and are well within the limits

The Feasiblity of the TRIC Experiment at COSY

Comparison with other Experiments

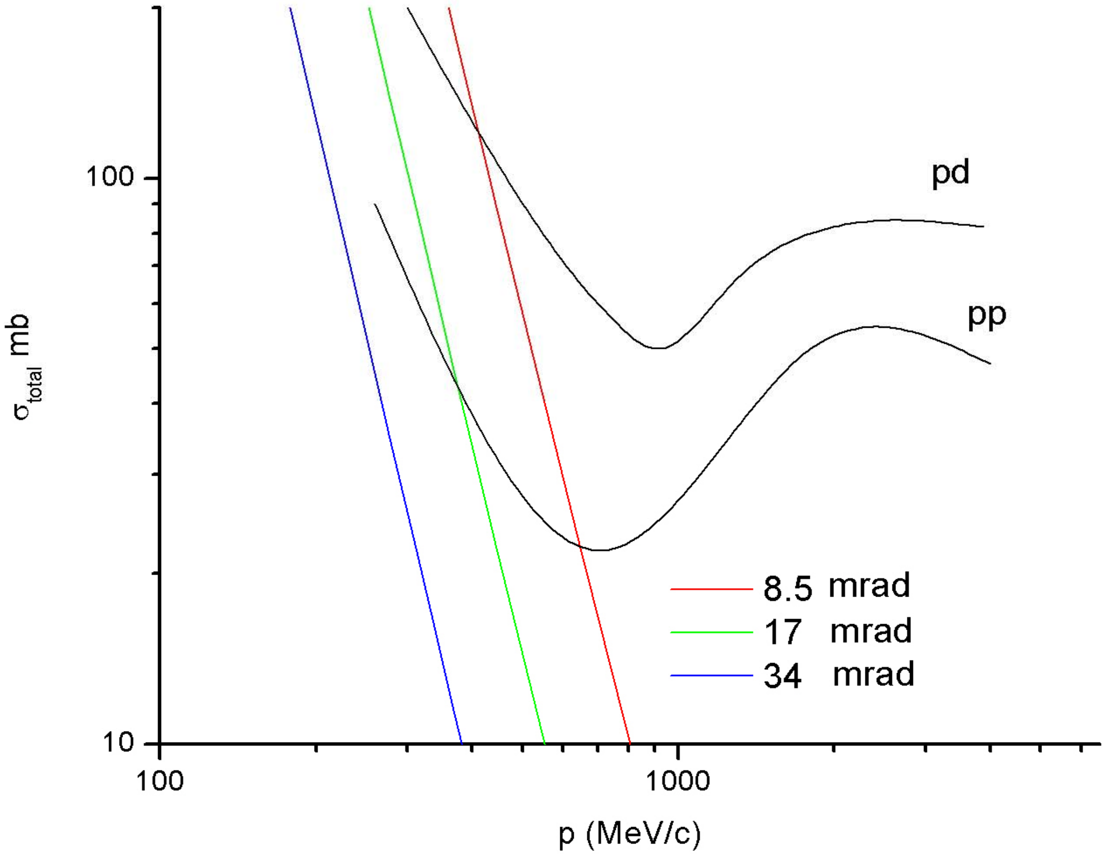
Experiment	Mean Slope [nA/s]	$\bar{\sigma}_{Residuals}$ [μA]	Expected $\bar{\sigma}^{Slope}$ [nA/s]	$\bar{\sigma}^{Slope}$ [nA/s]	$\sigma^{Slope}_{Distr.}$ [nA/s]	M [h]	$\bar{\sigma}^{\tau}$ [h]	$\sigma^{\tau}_{Distr.}$ [h]	$\frac{\sigma^{Slope}_{Distr.}}{\bar{\sigma}^{Slope}}$	$\frac{\sigma^{\tau}_{Distr.}}{\bar{\sigma}^{\tau}}$
TRIC	-2.86	0.36	0.1	0.1	1.22	47.8	2.86	13.2	12.5	4.76
COSY11	-72	0.37	1.7	0.8	11.9	8.3	0.09	0.9	16.7	10
ANKE	-2916	0.52	3.7	3.57	149	1.29	0.001	0.04	50	50

The Feasiblity of the TRIC Experiment at COSY

Comparison with other Data

Experiment	Mean Slope [nA/s]	$\bar{\sigma}_{Residuals}$ [μA]	Expected $\bar{\sigma}^{Slope}$ [nA/s]	$\bar{\sigma}^{Slope}$ [nA/s]	$\sigma^{Slope}_{Distr.}$ [nA/s]	M [h]	$\bar{\sigma}^{\tau}$ [h]	$\sigma^{\tau}_{Distr.}$ [h]	$\frac{\sigma^{Slope}_{Distr.}}{\bar{\sigma}^{Slope}}$	$\frac{\sigma^{\tau}_{Distr.}}{\bar{\sigma}^{\tau}}$
TRIC	-2.86	0.36	0.1	0.1	1.22	47.8	2.86	13.2	12.5	4.76
COSY11	-72	0.37	1.7	0.8	11.9	8.3	0.09	0.9	16.7	10
ANKE	-2916	0.52	3.7	3.57	149	1.29	0.001	0.04	50	50
10mA \$100pts	-0.2	0.33	1.7	1.1	5.3				4.8	
\$1000pts	-0.09	0.39	0.05	0.04	0.5				12.5	
Model Spectrum \$100pts	-2.09	0.35		1.23	1.16				0.94	
\$1000pts	-2.17	0.35		0.04	0.04				1	

The Feasiblity of the TRIC Experiment at COSY
pp-, pd- and Coulomb- Cross Section



The Feasiblity of the TRIC Experiment at COSY
Present precision

Starting from : $\delta(\Delta T) = |-S| \cdot \delta A_{y,xz} \cong \frac{1}{\sqrt{2}} \cdot \frac{\delta I}{I}$

with:
$\sigma_0 = 80\text{mb}$
$\rho d = 3 \cdot 10^{11}\,\text{Protons}/\text{cm}^2$
$P_x, P_{yz} = 1$
$N = 1200\text{s} \cdot 10^6\,\text{Hz} = 1.2 \cdot 10^9\,\text{turns}$
$I_0 = 32\text{mA}$ (Space charge limit $2 \cdot 10^{11}$)

giving for a 20 min. measurement: $S = \sigma_0 \cdot \rho d \cdot P_y P_{xz} \cdot N = 2.9 \cdot 10^{-5}$

The BCT resolution is 0.5μA for 1s measurement:

$$\delta I / I(@20\,\text{min}) = \frac{0,5\mu A}{32\text{mA}} \cdot \frac{1}{\sqrt{1200}} = 4.5 \cdot 10^{-7}$$

This results in: $\delta A_{y,xz} \cong \frac{1}{\sqrt{2}} \cdot \frac{\delta I}{I} \cdot \frac{1}{S} = 0,011$

Use of a targetcell (, 180) and measuring for 10 days ($\div\sqrt{720} \rightarrow \delta A_{y,xz} \square\, 2.2 \cdot 10^{-6}$)

Combining data at present is worse by a factor 4: $\rightarrow \boldsymbol{\delta A_{y,xz} = 8.8 \cdot 10^{-6}}$

Preparation of “pure“ $\vec{J}$ state	→	Interaction with $\vec{E}$ - field	→	Analysis of state
Polarization		Spin Rotation		Determination of Ensemble Spin average

electric dipole moment: $\vec{D} = \eta\, \mu_x\, c^{-1}\, \vec{J}$

Spin precession : $\vec{\omega}_e = \dfrac{\vec{D} \bullet \vec{E}}{\hbar} \dfrac{\vec{E} \times \vec{J}}{|\vec{E} \times \vec{J}|}$

Example: $D=10^{-24}$ e cm, E=100 kV/cm, J=1/2
ω_e = **15.2 mHz**

The Feasiblity of the TRIC Experiment at COSY
Some Introductory Remarks

TRIC

particle	limit on edm $\|d\|$ [e cm] (95% C.L.)	system	improvement factor	new physics limits [e cm]
e	1.9×10^{-27}	^{205}Tl	> 1	10^{-27}
μ	1.05×10^{-19}	rest frame E	10^3	10^{-22}
τ	3.1×10^{-16}	$(e^+e^- \rightarrow \tau^+\tau^-\gamma)$	10^4	10^{-20}
p	6.5×10^{-23}	^{205}Tl-F	10^4	5×10^{-26}
n	7.5×10^{-26}	ultracold neutrons	> 1	5×10^{-26}
Λ	1.5×10^{-16}	rest frame E	10^7	10^{-23}
^{199}Hg	2.1×10^{-28}	^{199}Hg	> 1	10^{-28}
Ξ^0	?	as Λ	?	10^{-23}

Table 1: Current limits on edm's, converted to a common 95% confidence limit. The improvement factor indicates how much the measurement needs to be improved to yield new physics limits. No data in the charmed sector

Precession frequency ω due to a particle with anomalous magnetic moment $a = g/2 - 1$ and edm d

$$\omega = -\frac{e}{m}\left[a\mathbf{B} - a\frac{\gamma}{\gamma+1}\mathbf{v}(\mathbf{v}\cdot\mathbf{B}) - \left(a - \frac{1}{\gamma^2-1}\right)\mathbf{v}\times\mathbf{E}\right] - \frac{d}{2}\left[\mathbf{E} - \frac{\gamma}{\gamma+1}\mathbf{v}(\mathbf{v}\cdot\mathbf{E}) + \mathbf{v}\times\mathbf{B}\right]$$

^{205}Tl: $d = -585\, d_e$

^{199}Hg:
$d \propto$ nucl$\times$atom

Theoretical input needed

EDM Limits as of June 2004

Particle	Limit/Measurement (e-cm)	Method
e	$< 1.6 \times 10^{-27}$	Thallium beam [1]
μ	$< 1.05 \times 10^{-18}$	Tilt of precession plane in magnetic moment experiment [2]
τ	$(-2.2 < d_\tau < 4.5) \times 10^{-17}$	BELLE $e^+e^- \to \tau\tau$ events [3]
n	$< 6.3 \times 10^{-26}$	Ultra-cold neutrons [4]
p	$(-3.7 \pm 6.3) \times 10^{-23}$	120kHz thallium spin resonance [5]
Λ	$(-3.0 \pm 7.4) \times 10^{-17}$	Tilt of precession plane in magnetic moment experiment [6]
$\nu_{e,\mu}$	$< 2 \times 10^{-21}$	Inferred from magnetic moment limits [7]
ν_τ	$< 5.2 \times 10^{-17}$	Z decay width [8]

The Feasiblity of the TRIC Experiment at COSY

Some Introductory Remarks

- **Large number of Possibilities to**
  - **Find Physics Beyond Standard Theory**
  - **Determine Standard Model important Parameters**

Urgent issues to be solved in Theory and Experiment

In the area of Fundamental Symmetries and Interactions there is large overlap between Astro-, Particle-, and Nuclear- Physics

⇒ **Fields merge**

⇒ **Low energy Precision and High Energy Direct approaches are complementary**

Enourmous benefit from a High Power Proton machine expected

The Feasiblity of the TRIC Experiment at COSY

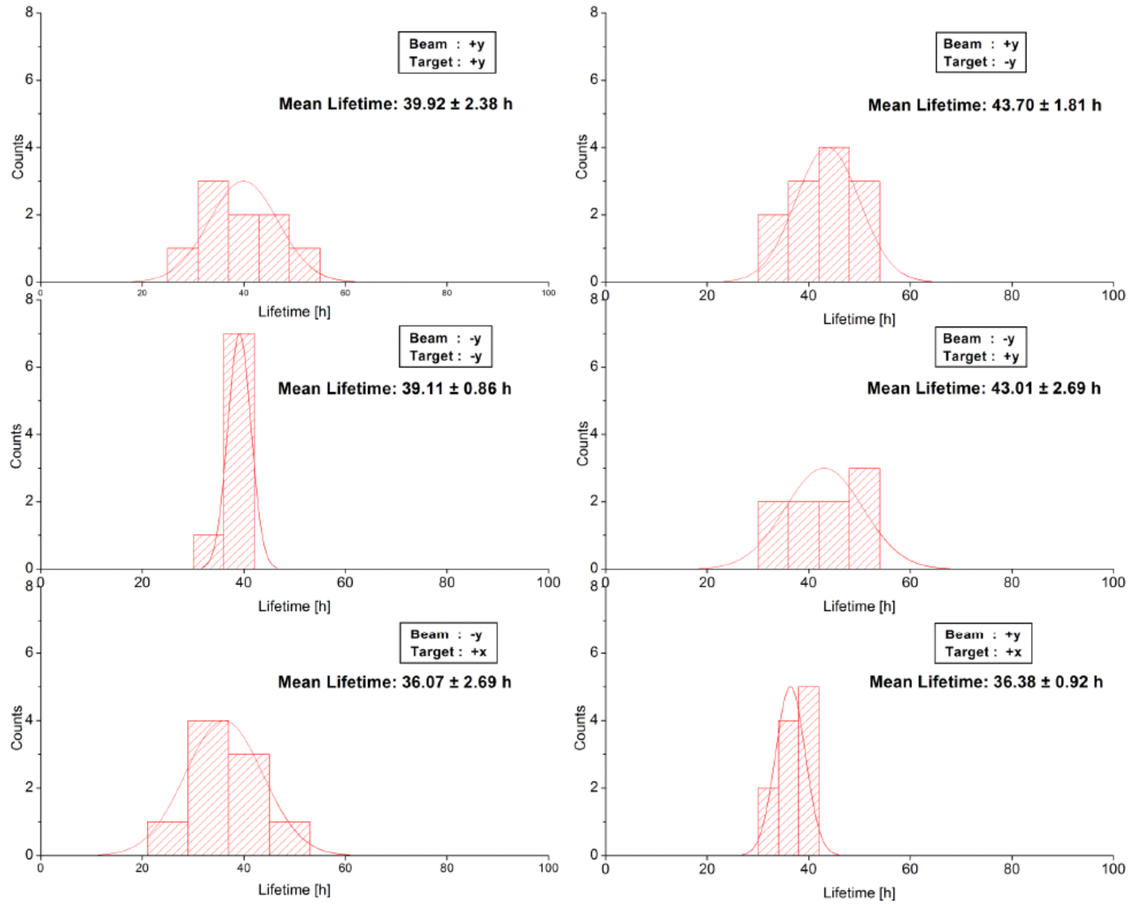
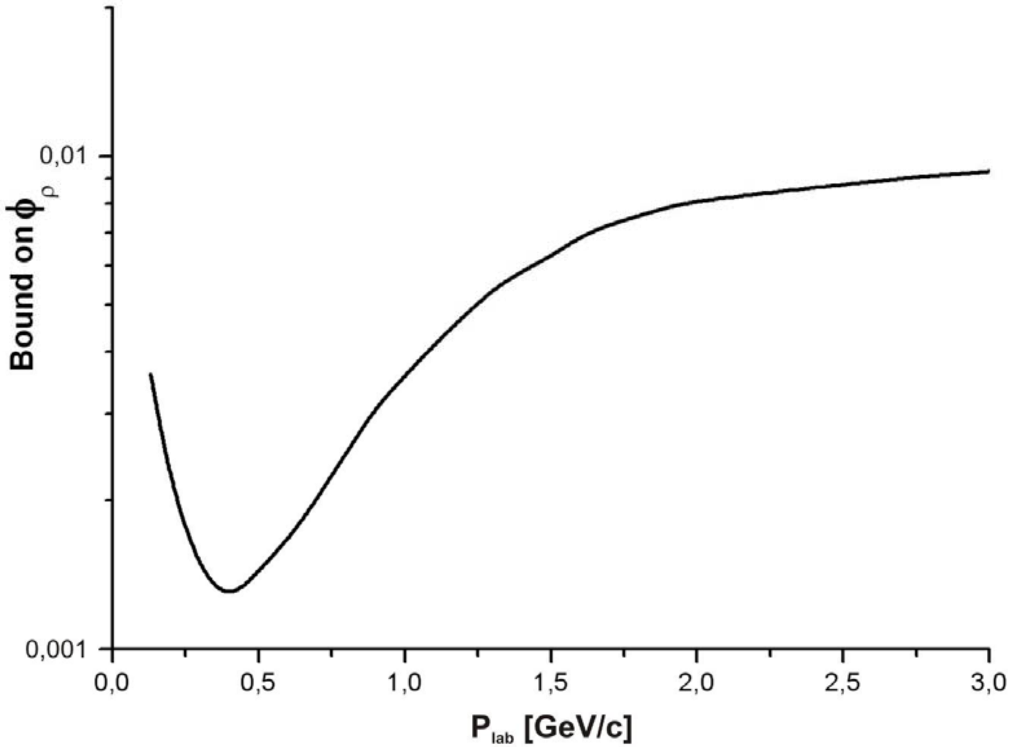


Figure 5.2: The distribution of the unweighted lifetimes of all the polarization setups.

The Feasiblity of the TRIC Experiment at COSY
Some Experimental Details

Theoretical bound on TRV by rho exchange

M. Beyer, Nucl. Phys. ***A560 (1993) 895***



Beam/Target	Without parabolic subtraction	With parabolic subtraction
- y/ + y	41.29 ± 0.59	41.98 ± 0.54
+ y/ - y	41.54 ± 0.64	45.13 ± 0.75
Mean	41.41 ± 0.43	43.56 ± 0.46
- y/ - y	41.87 ± 0.59	44.56 ± 0.67
+ y/ + y	41.38 ± 0.62	42.28 ± 0.65
Mean	41.62 ± 0.42	43.42 ± 0.46
- y/ +x	37.98 ± 0.48	41.52 ± 0.54
+ y/ +x	35.46 ± 0.44	40.12 ± 0.65
Mean	36.72 ± 0.33	40.82 ± 0.42

Table 5.7: The Lifetime values in hours obtained using the global fitting method.