Results from the *a*SPECT experiment

M. Beck

Institut für Physik, Johannes Gutenberg-Universität Mainz
und
Helmholtz-Institut Mainz

The *a*SPECT experiment
- Experimental principle
- Set-up

The beamtime 2013
- Detector saturation
- Electric potential
- Magnetic field ratio
- Background

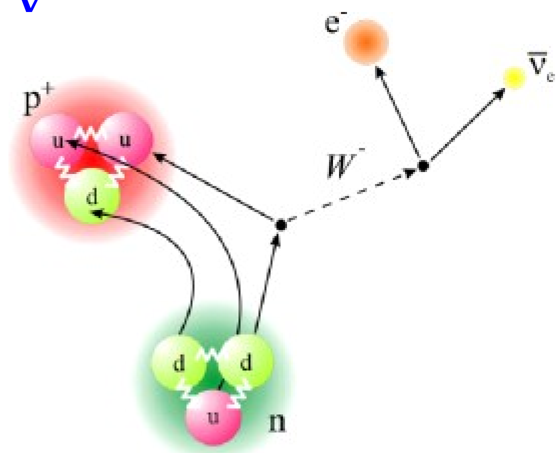
Status

The next steps

Decay of the free neutron

β–ν correlation in neutron decay n → p + e^- + $\overline{\nu}$

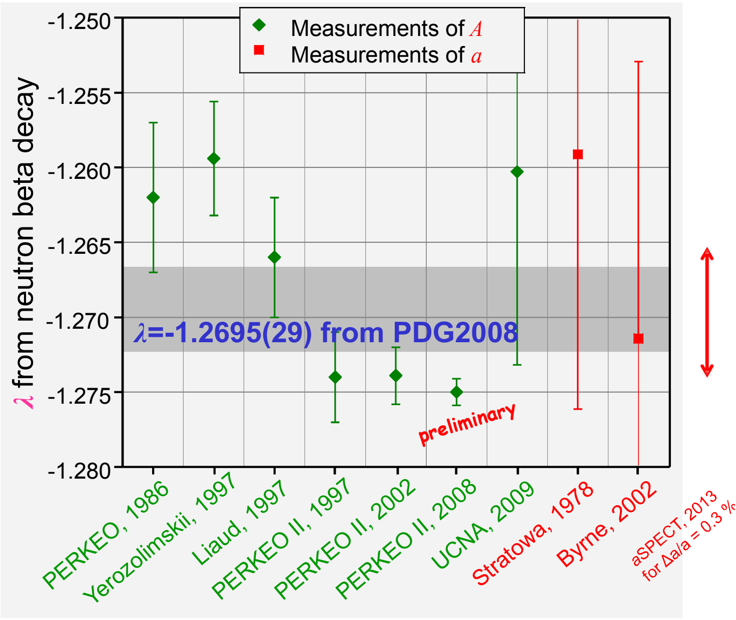
Mixed Fermi and Gamow Teller decay.



$$a = \frac{1 - |\lambda|^2}{1 + 3|\lambda|^2} \qquad A = -2\frac{|\lambda|^2 + |\lambda|\cos\phi}{1 + 3|\lambda|^2}$$

$$\lambda = |g_A / g_V| e^{i\phi}$$

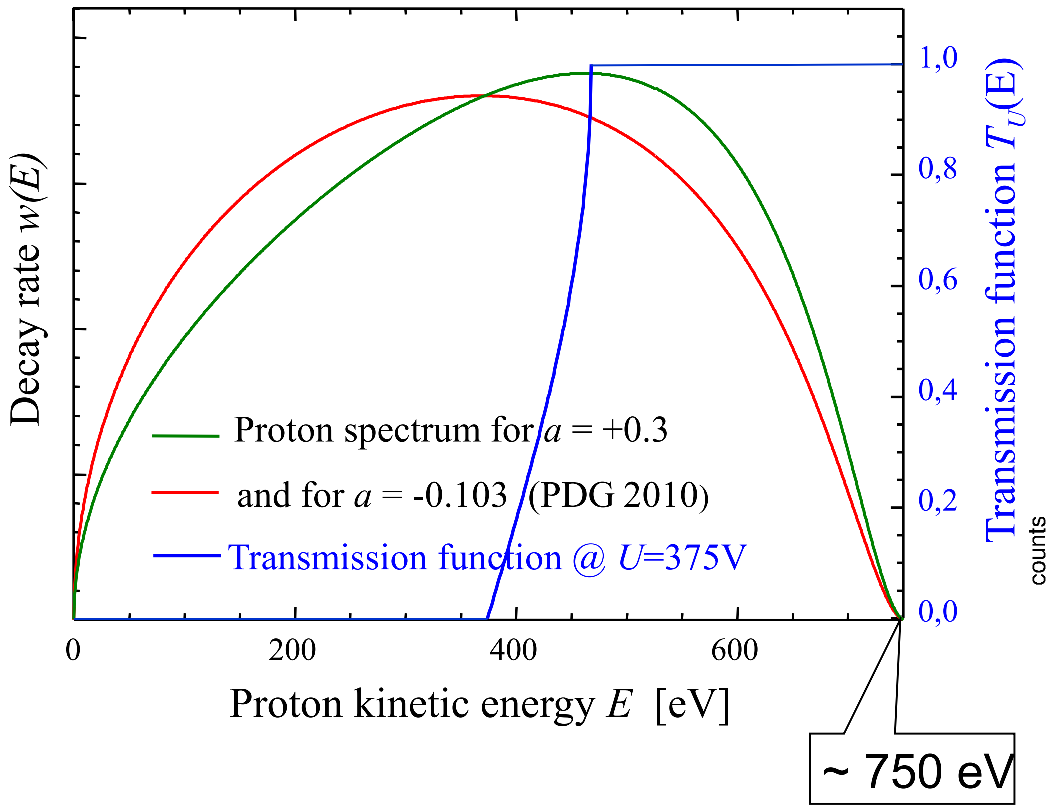
Accuracy of best previous experiments: $\Delta a / a \sim 5\%$
Our final aim: $\Delta a / a \sim 0.3\%$



For the physics see e.g. H. Abele, Prog. Part. Nucl. Phys. 60 (2008) 1

Experimental principle

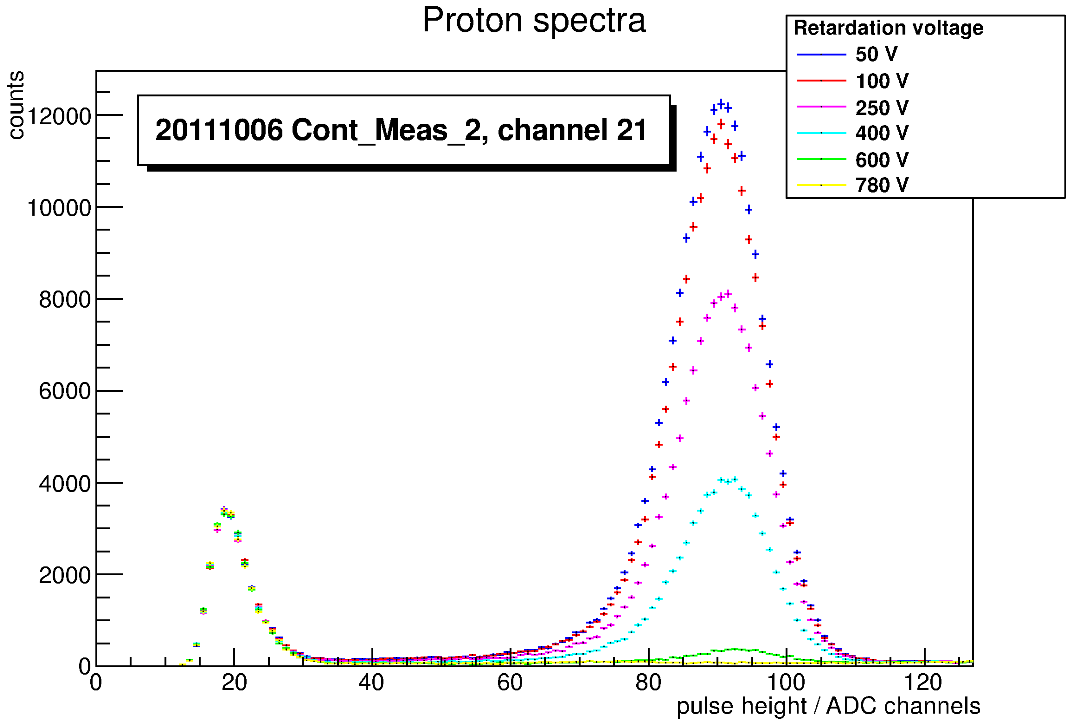
Measurement of the β–ν angular correlation
via the energy spectrum of the decay protons



Energy determination using
a retardation spectrometer (MAC-E filter).

Proton detection using
a silicon drift detector (SDD).

Measured proton spectra:

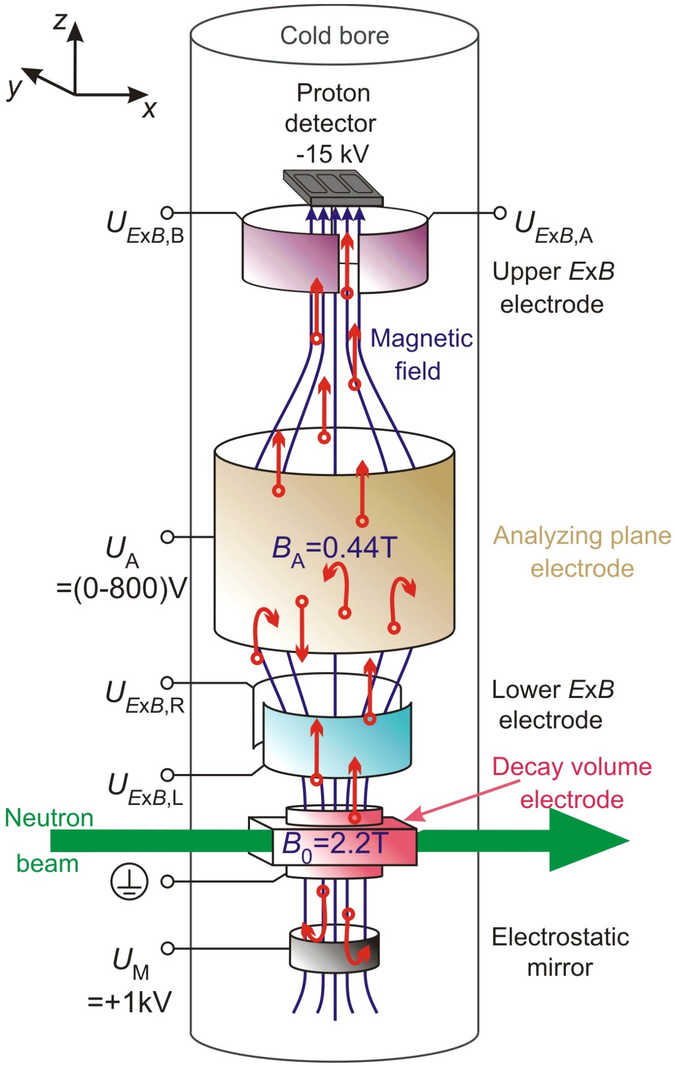


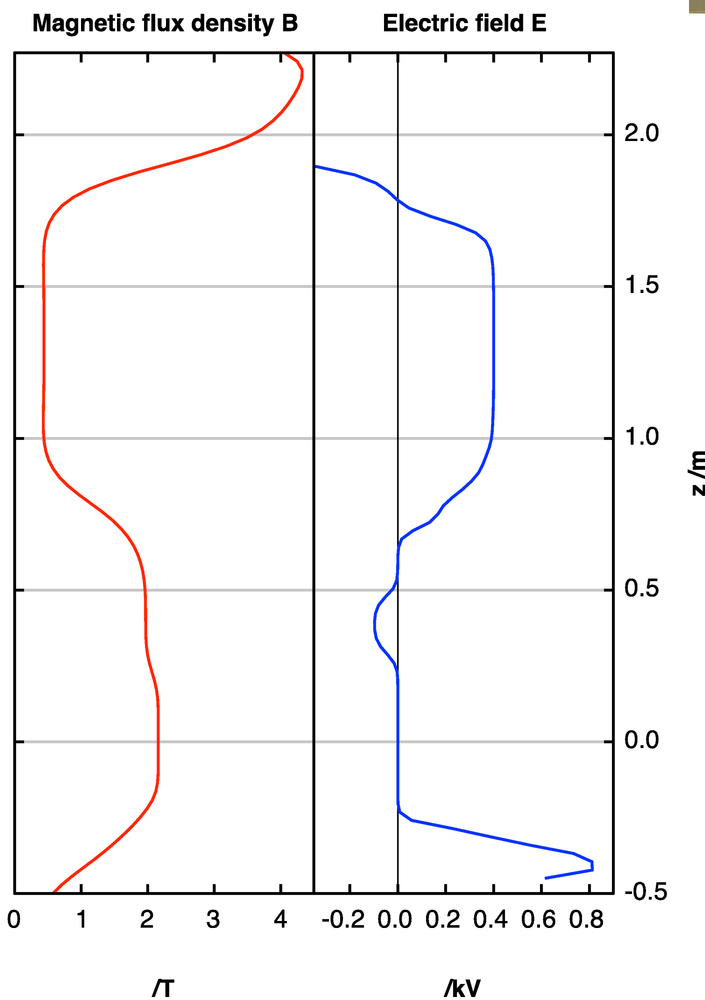
For details on *a*SPECT see

O. Zimmer et al., NIM A 440 (2000) 440
F. Glück et al., EPJ A 23 (2005) 135
S. Baeßler et al., EPJ A 38 (2008) 17
M. Simson et al., NIM A 611 (2009) 203
G. Konrad et al., Nucl. Phys. A 827 (2009) 529c

Overview *a*SPECT

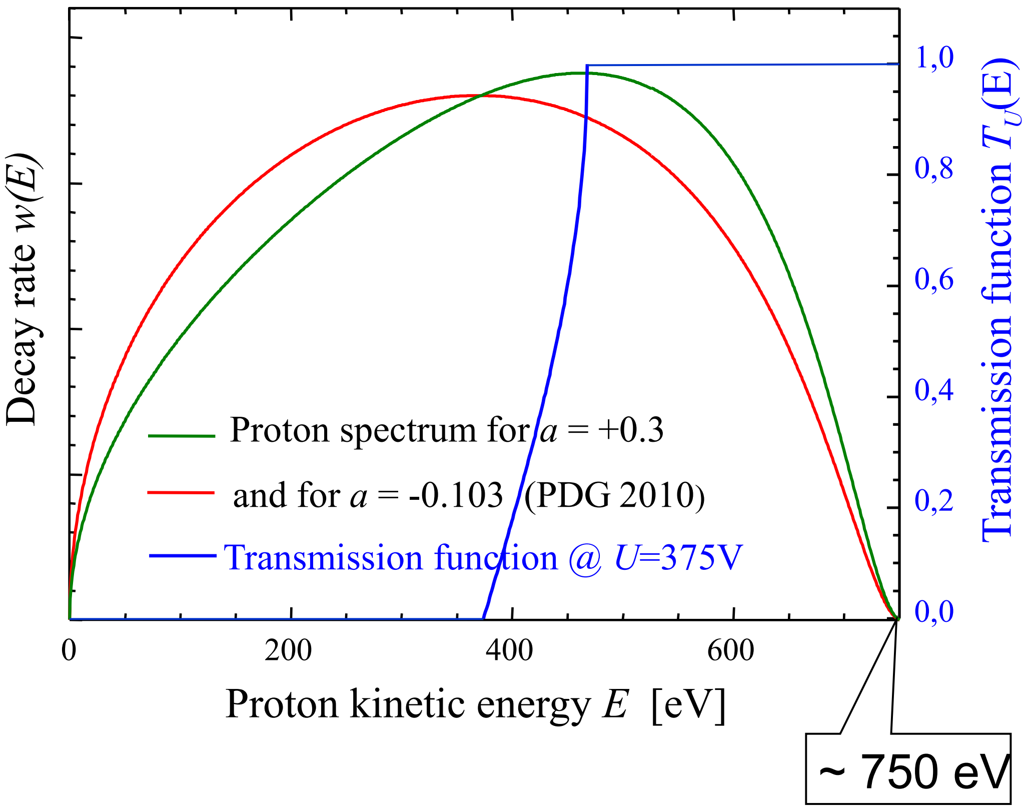
Schematic and set-up at PF1b at the Institut Laue Langevin

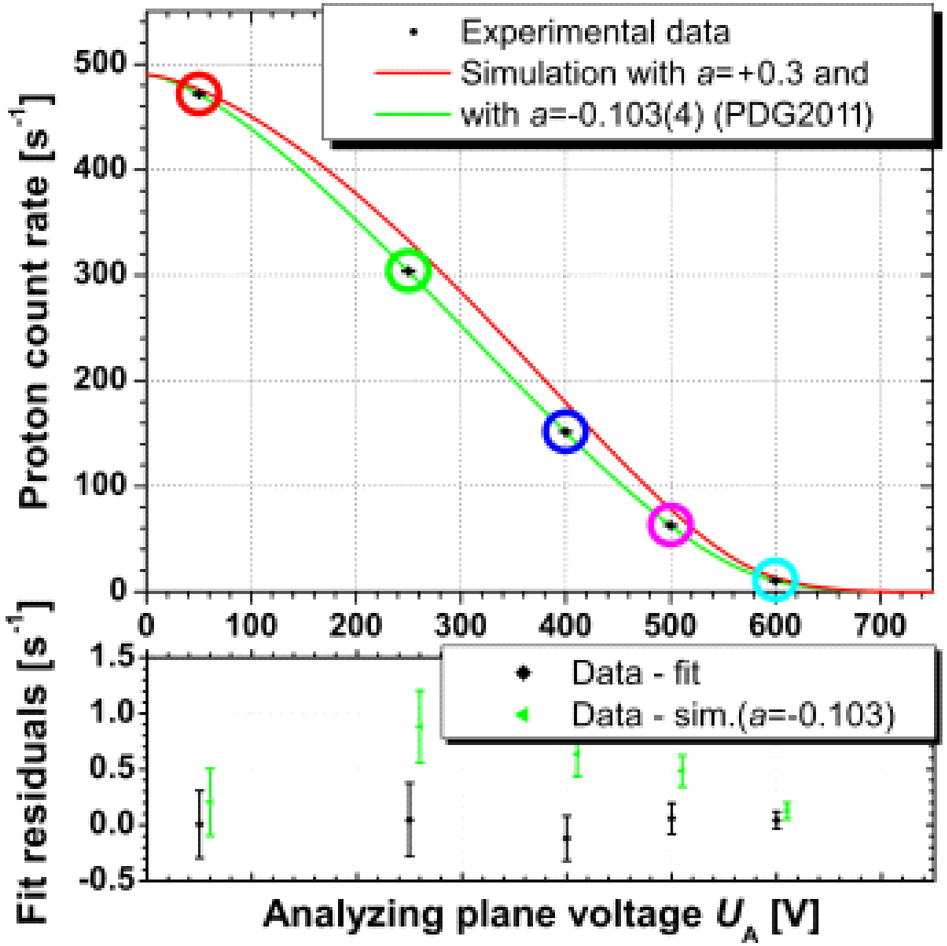




Recoil energy spectrum 2008

Measurement of the β–ν angular correlation via the energy spectrum of the decay protons



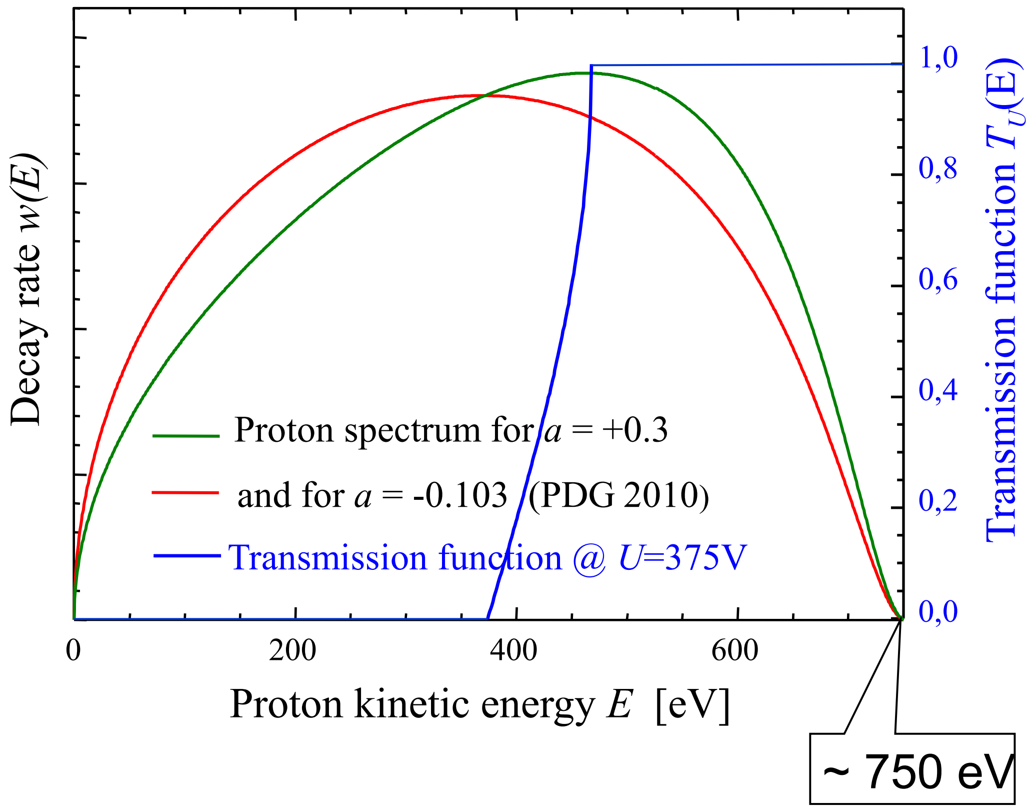


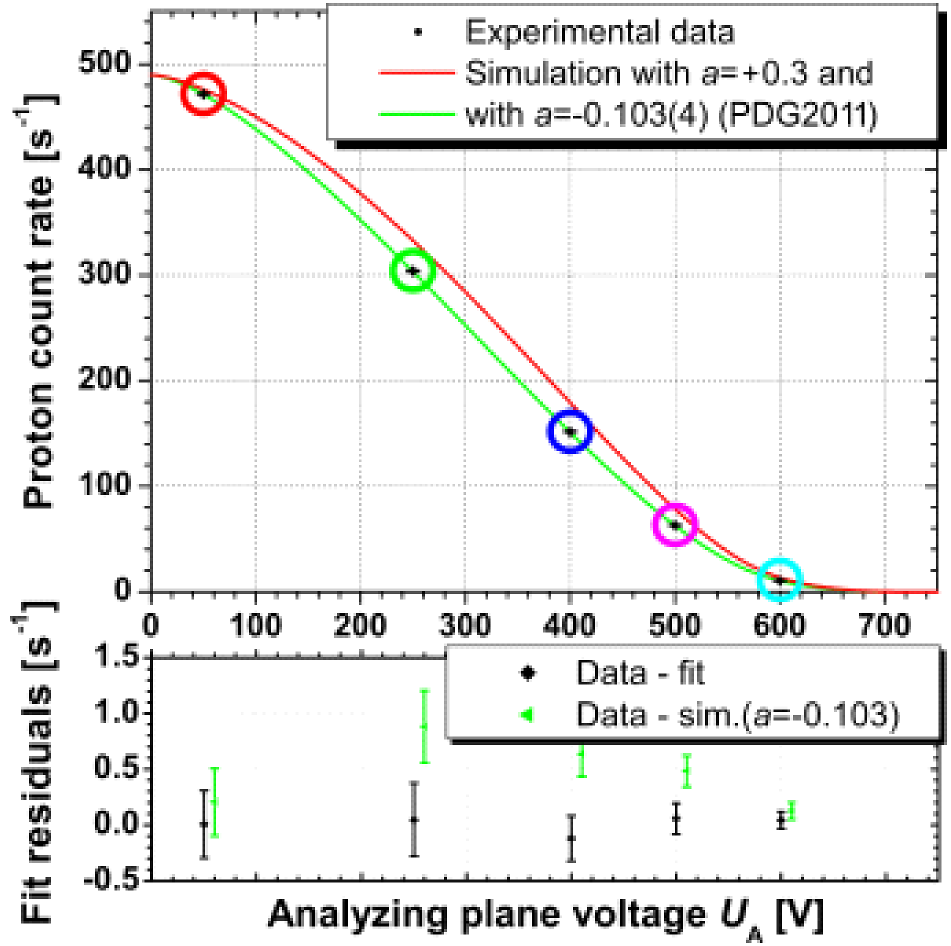
The systematic errors have to be understood.

M. Simson, PhD thesis, ILL 2010
M. Borg, PhD thesis, Mainz 2011
G. Konrad, PhD thesis, Mainz 2011
F. Ayala Guardia, PhD thesis, Mainz 2011

Recoil energy spectrum 2008

Measurement of the β–ν angular correlation via the energy spectrum of the decay protons





A new beamtime of ~100 days has been completed successfully at the cold neutron beam line PF1B at ILL in 2013!

The beam time 2013

Data taking for small a and for systematic investigations:

1 day of data ↔ $\Delta a/a \sim 1.3\%$, typical length of one data set 2-3 days

→ Systematic investigations for different conditions with the full statistics

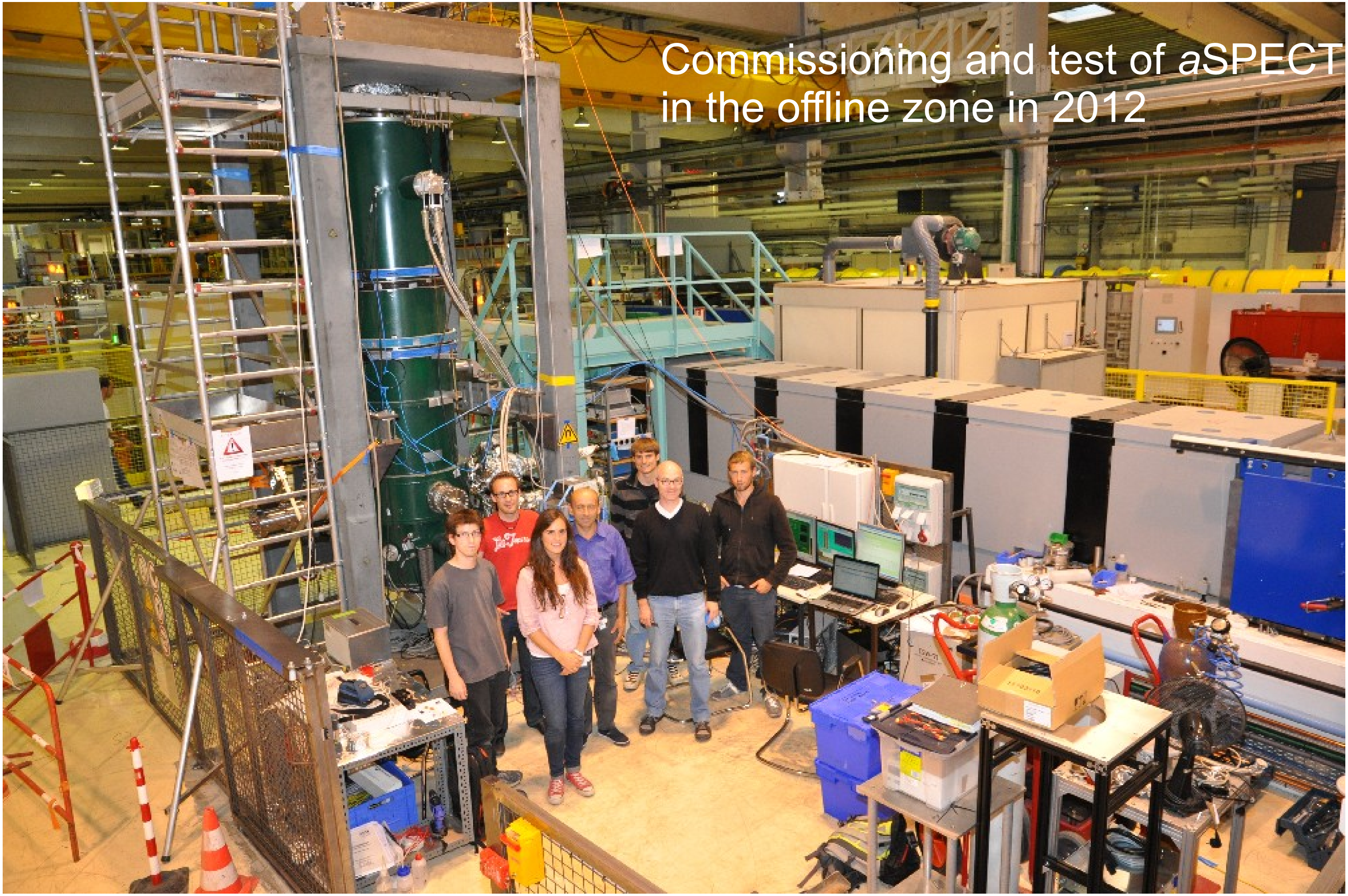
- 2 different detector electronics
- Different background conditions
  - E15 dipole on/off,different focussing on the detector
  - β-source in the DV
- 2 different beam profiles
- Measurement of the beam profile directly inside the DV
- Check of field leakage into the DV

Emphasis on the understanding of the background.
(variable components and retardation voltage dependence).

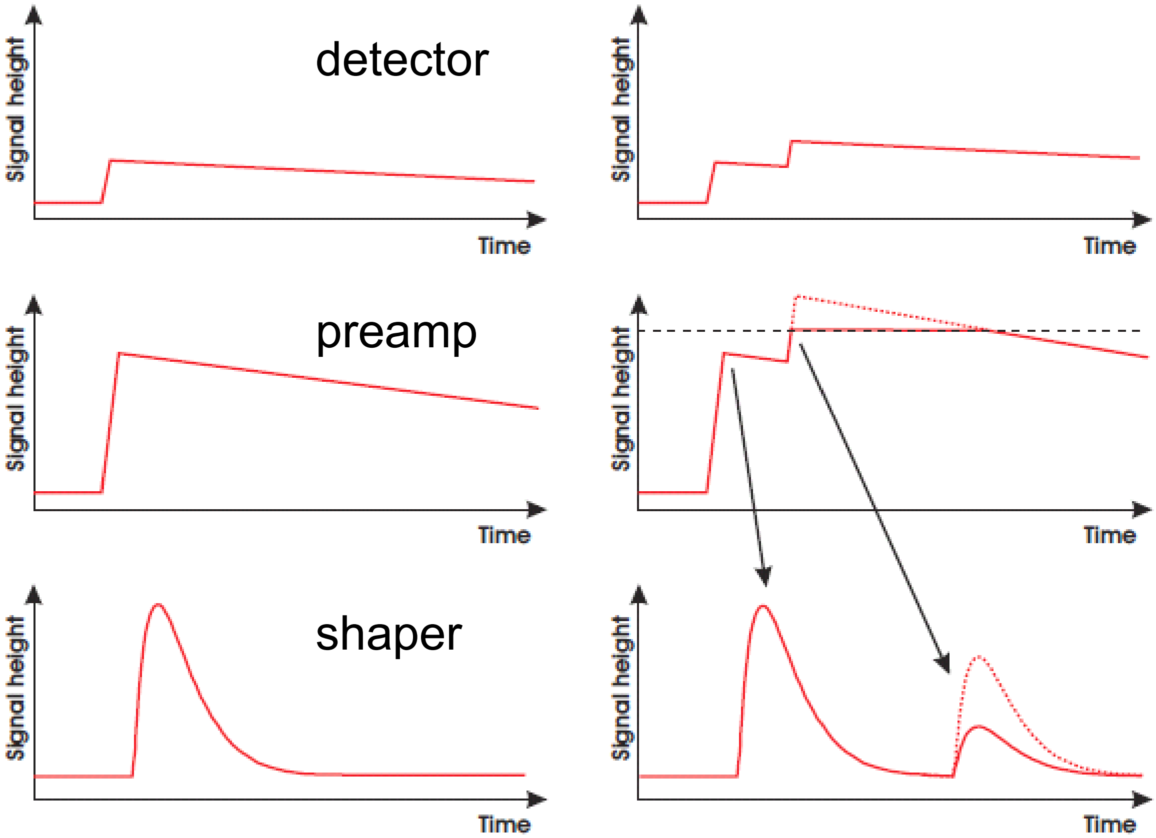
No catastrophic systematic effect observed. The data look good!

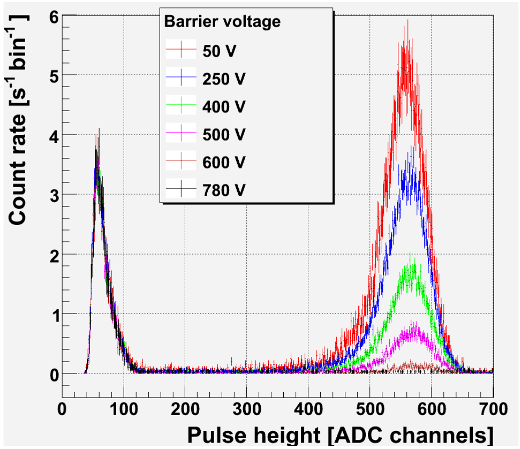
Goal of this beam time: $\Delta a/a \sim 1\text{-}2\%$

The Test Set-Up



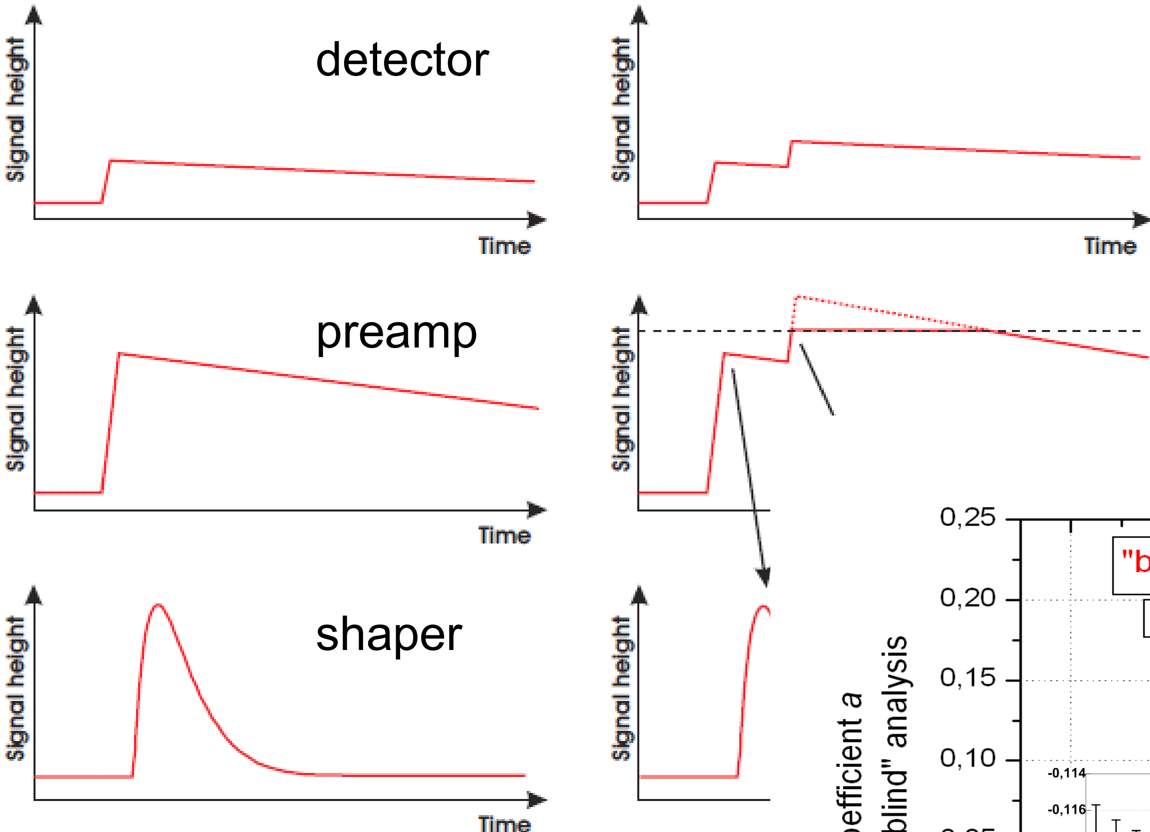
Detector saturation

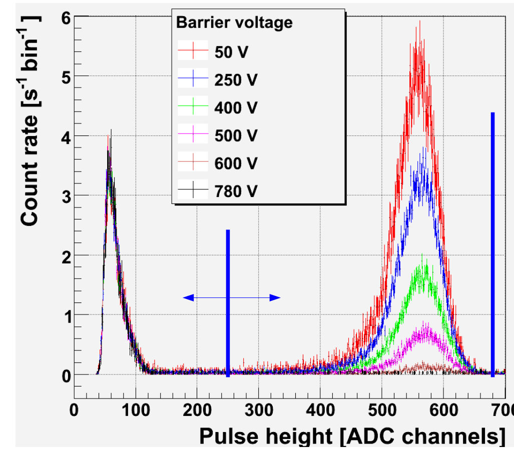


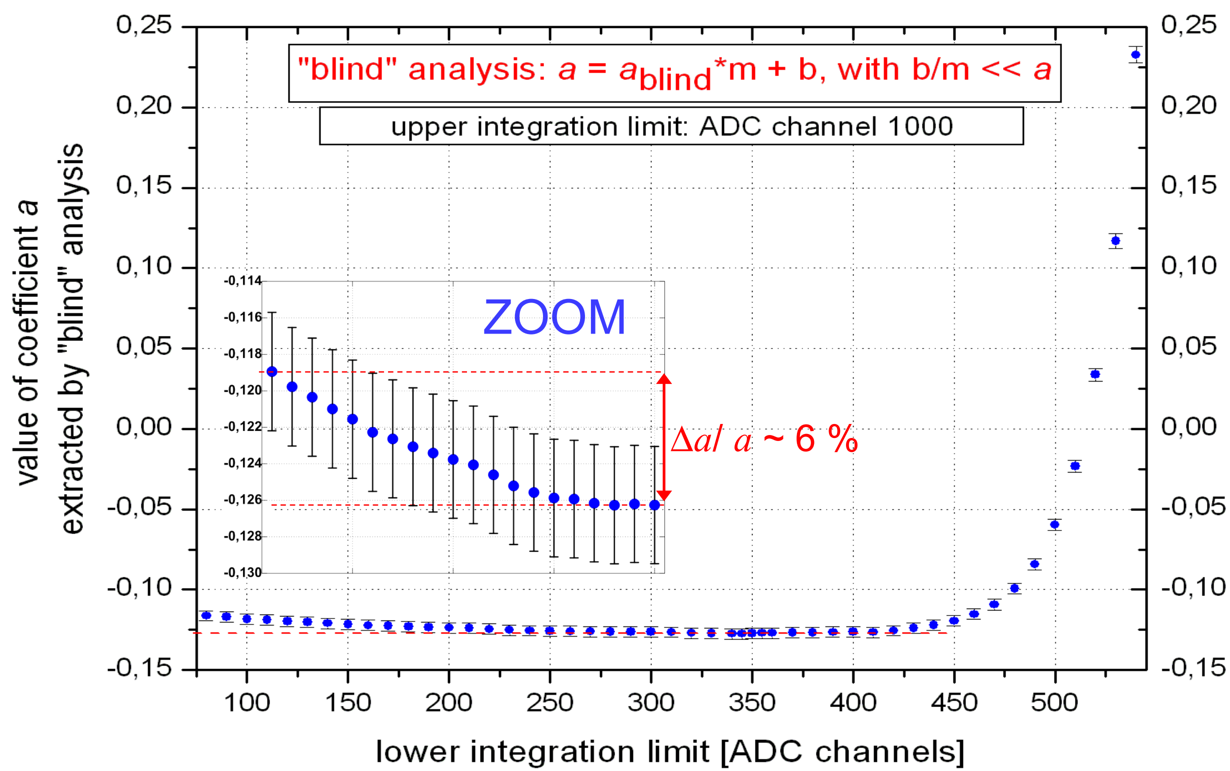


After e-event:
Preamplifier saturates
Shaper saturates
Shaper undershoots

Detector saturation







Previous detector electronics:

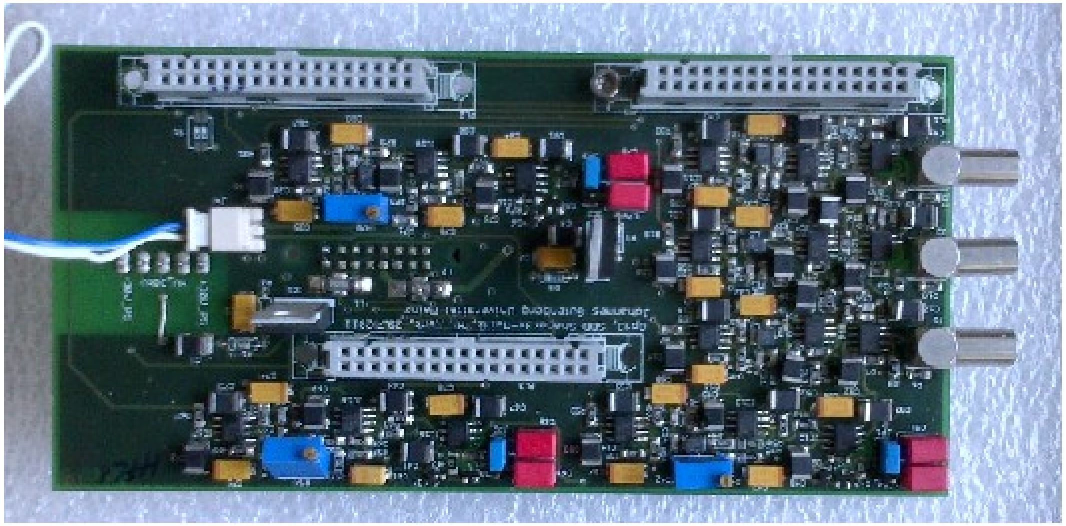
Systematic influence on small a by correlated e-p events

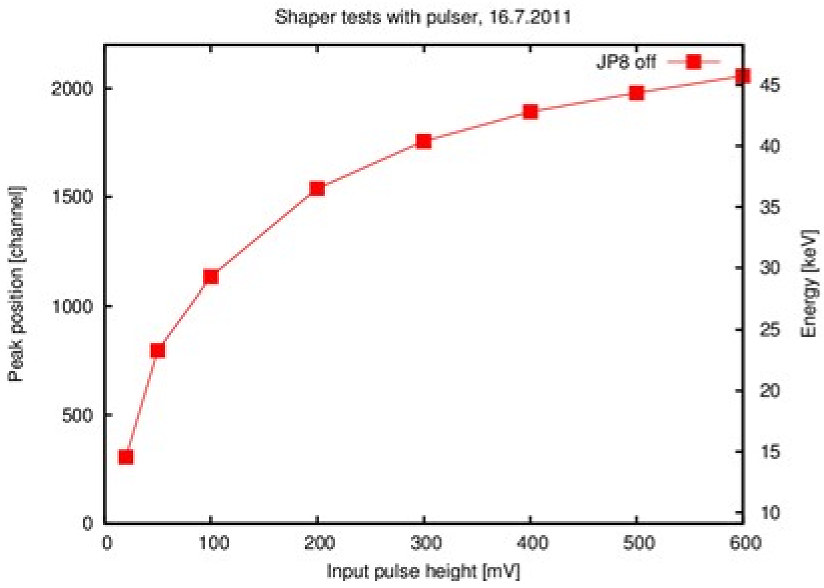
See M. Simson, PhD thesis 2010

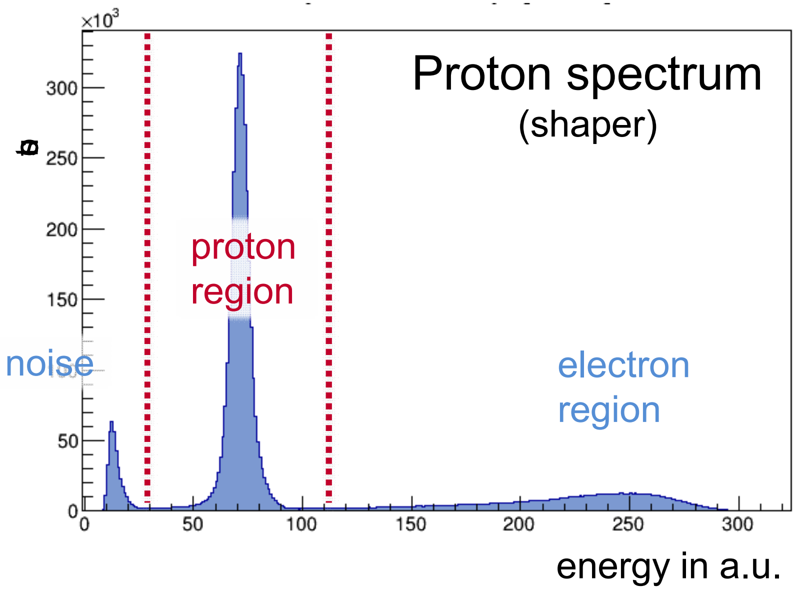
Detector saturation

Modified detector electronics

Preamplifier with reduced amplification
New shaper with
- log amplification for large signals
- proton-electron separation





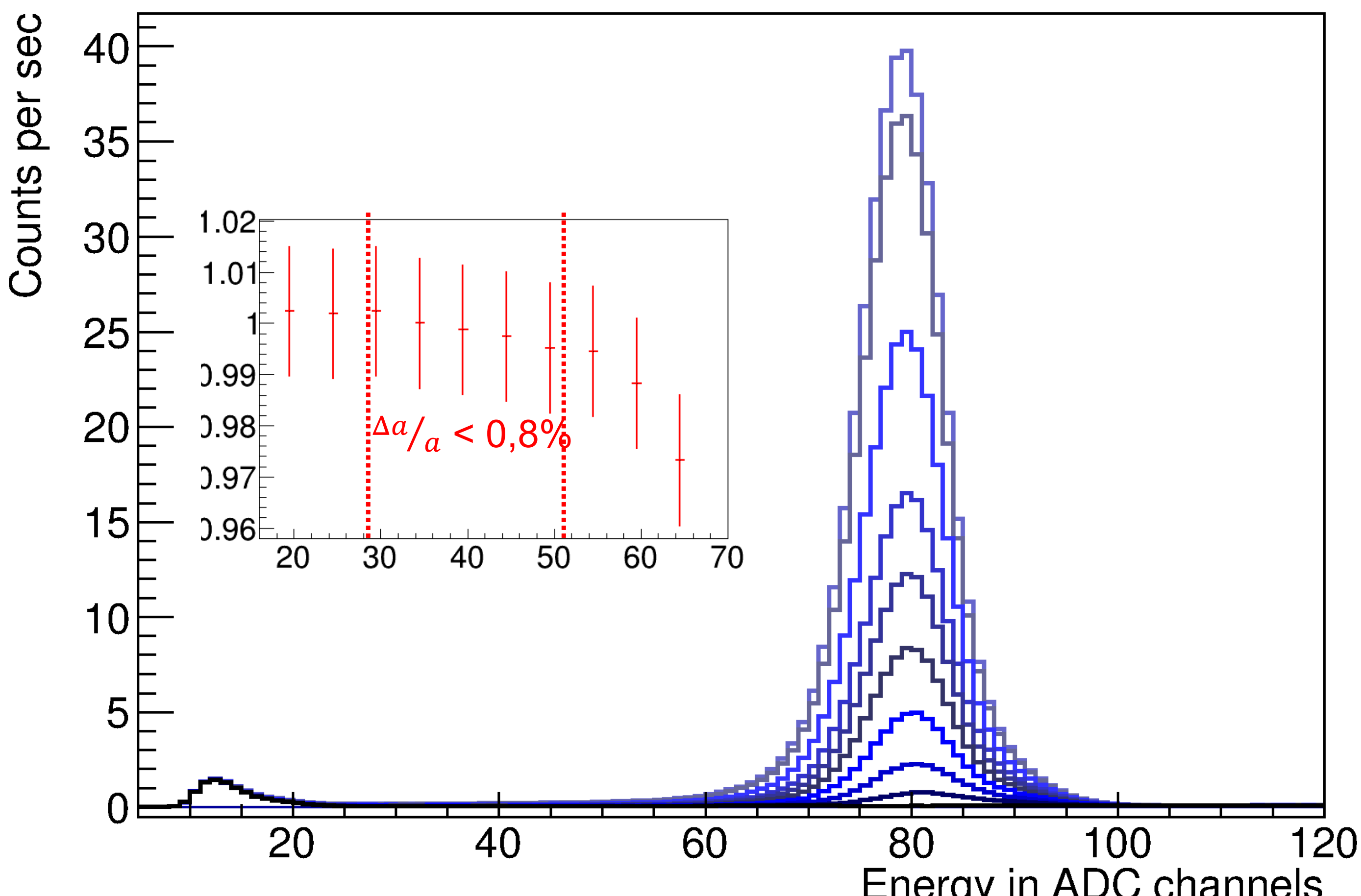


Detector saturation

Modified detector electronics

Check with neutrons:

Detector spectrum ch20



Problem solved!

Electric potential

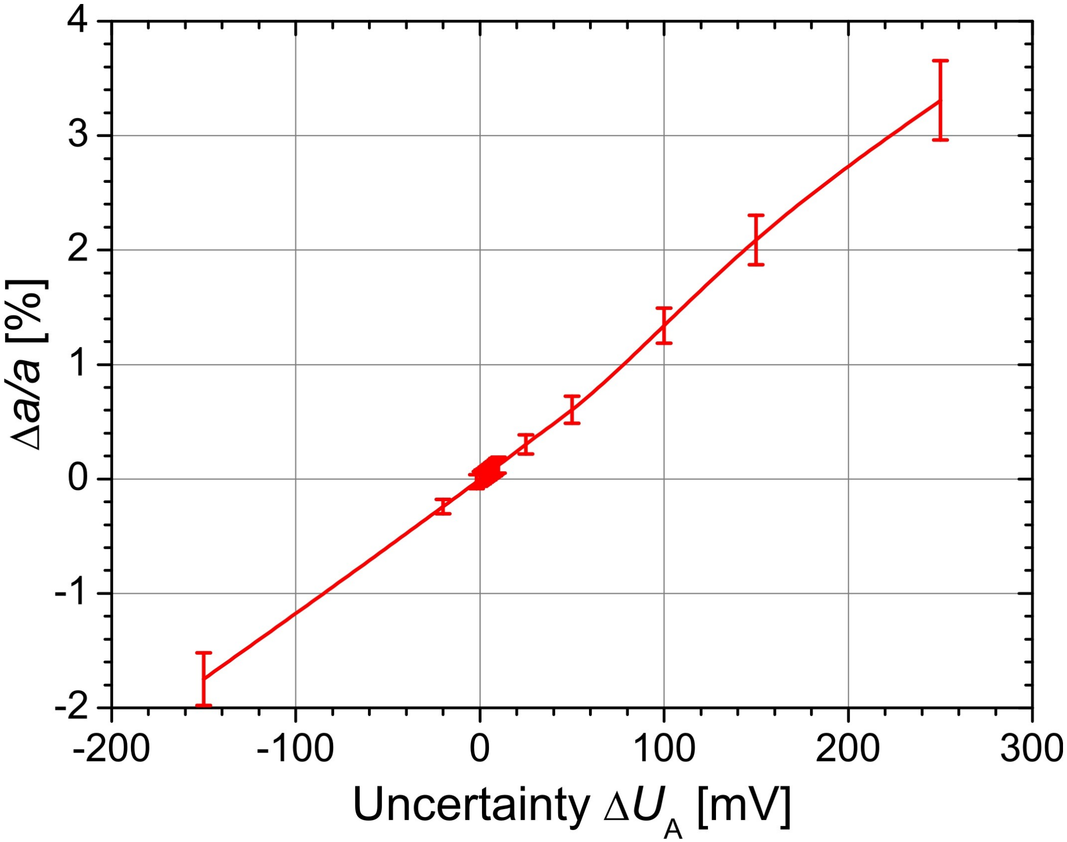
Small a is highly sensitive to the retardation potential U_A:

→ PhD thesis G. Konrad 2011

$\Delta a/a = 0.3\% \Leftrightarrow \Delta U_A \approx 10$ mV

$\Delta a/a = 1\% \Leftrightarrow \Delta U_A \approx 30$ mV

→ $\Delta U_A/U_A = 1 \cdot 10^{-5}$ necessary



Solutions:
- Precision power supply
- Measure the voltage applied between DV and AP with a precision DVM

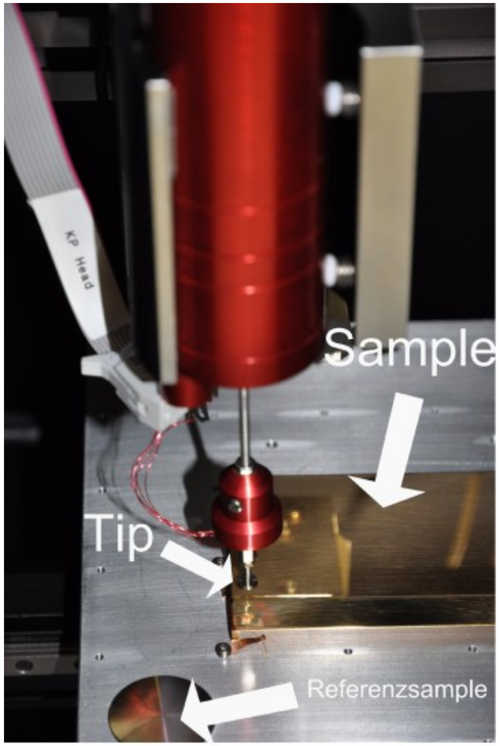
So, what is the problem?

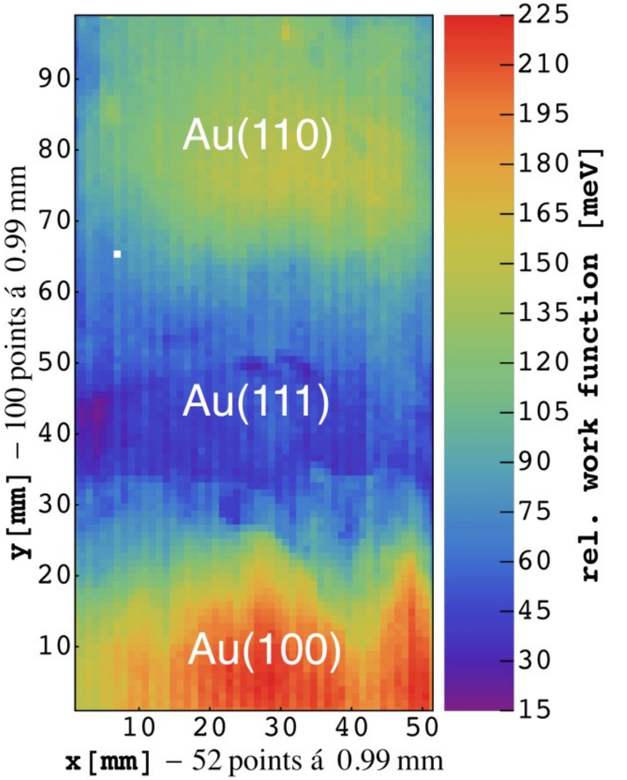
Electric potential

The applied potential is modified by the work function of the electrode(s)

Spatial variation across a surface
Au:
100   5.47eV
110   5.37eV
111   5.31eV
various 5-5.5eV

Measurement of the WF-fluctuations using a **Kelvin probe**.





Required precision for the retardatdion potential:

10 mV

Typical WF-fluctuations of our electrodes:

$\sigma_{RMS} = O(30\ \text{meV})$

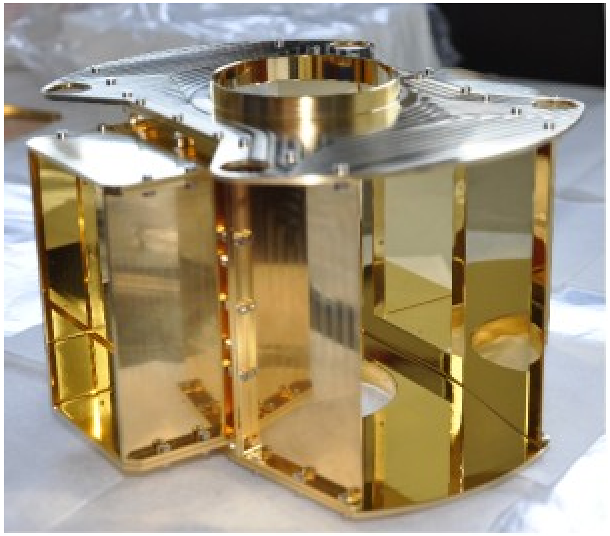
Electric potential

New decay volume and analyzing plane electrode

Goal: Well-defined WF

Decay volume

Main analysis plane electrode



Flat surfaces, 1 μm Au on 10 μm Ag on polished Cu surface

→ well defined surface properties
→ WF can be measured easily

Diploma thesis Ch. Schmidt, Mainz 2012

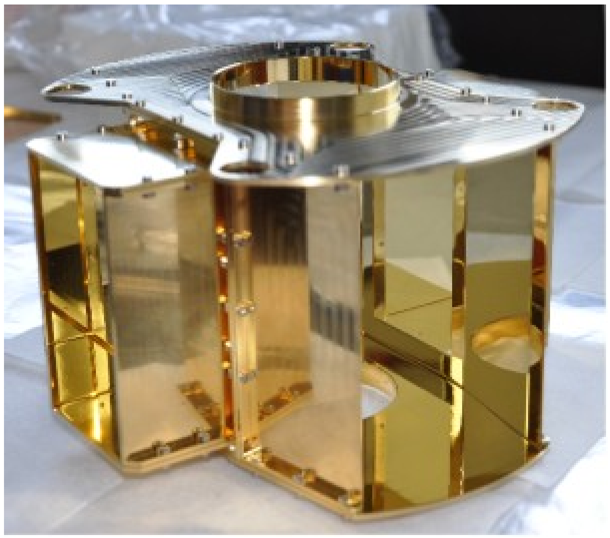
Preliminary results:

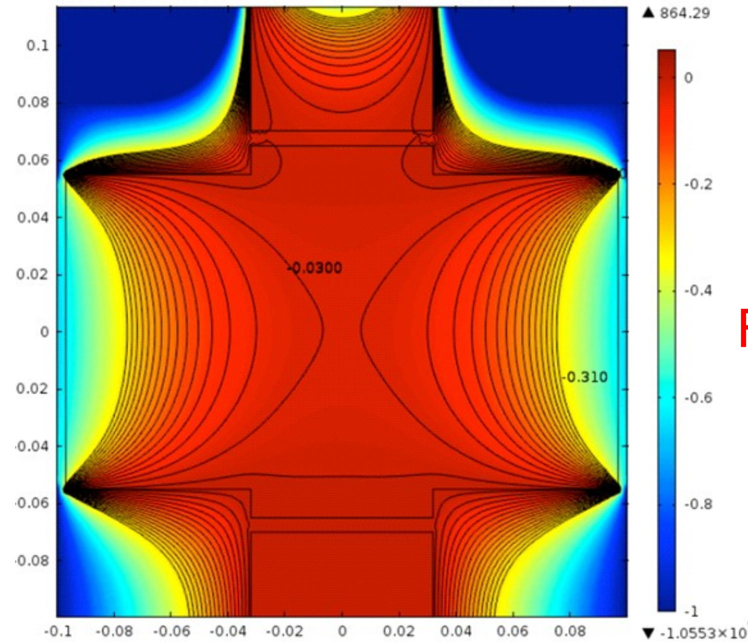
Average rms-fluctuation of WF of all electrodes 19 meV

Average rms-deviation of WF between electrodes 35 meV

Electric potential

Field leakage: Beam collimation



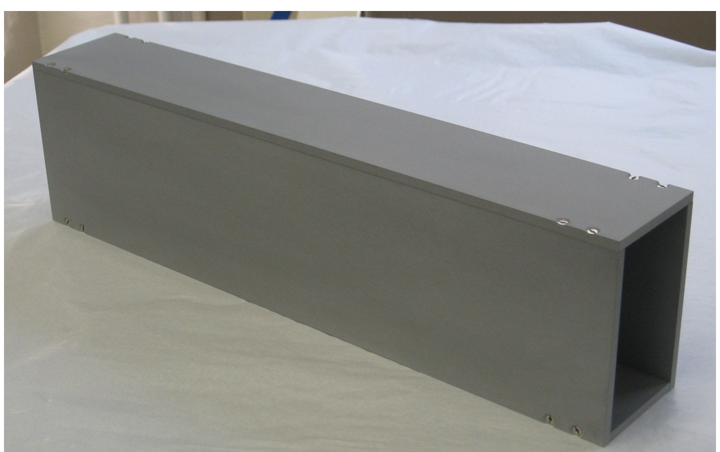


ΔWF = 1 eV

⇓

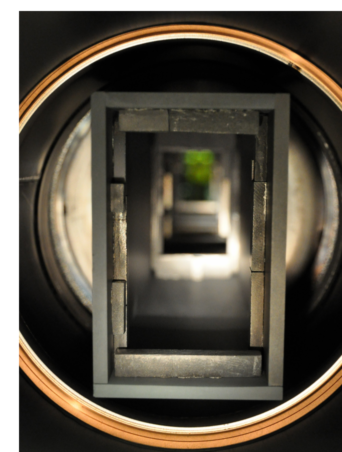
Field leakage into DV

30mV



Beam collimation support:
TiB_2 and BN (conductive)

Collimation:
LiF coated with Ti



B-field ration r_B

Precision determination of the magnetic field ratio $r_B = B_{AP}/B_{DV}$:

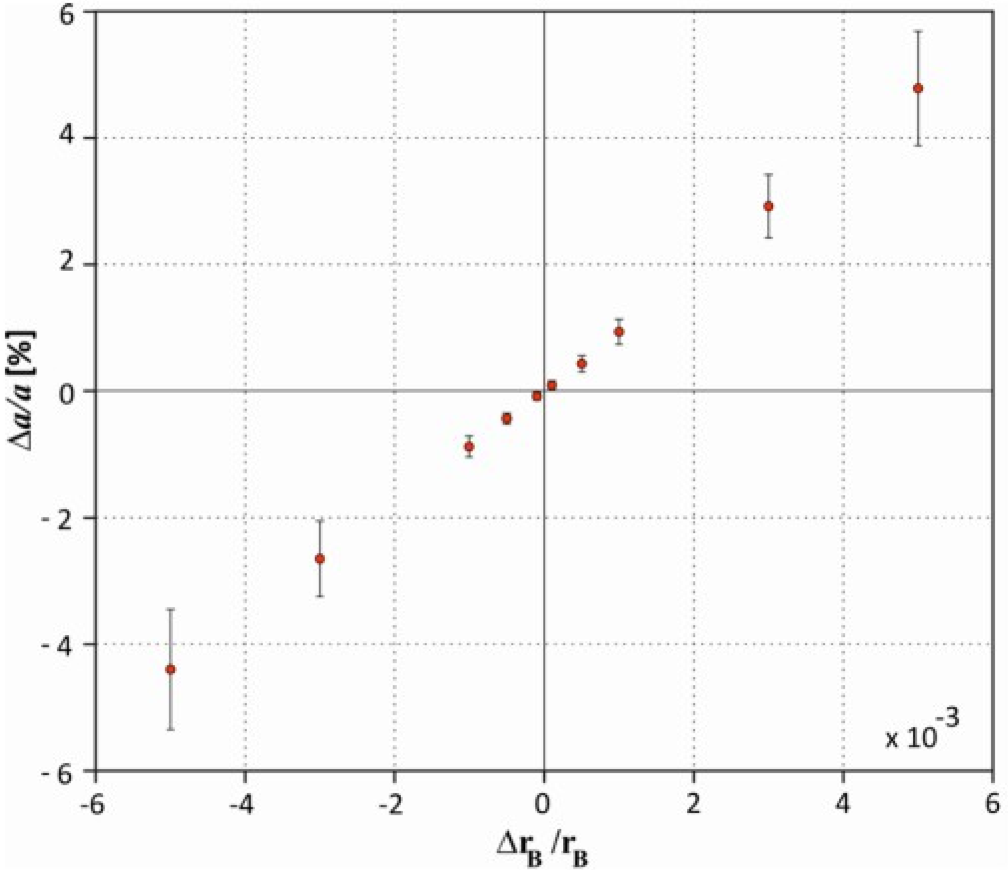
Small a is highly sensitive to r_B:

$\Delta a/a \approx 10\ \Delta r_B/r_B$

→ PhD thesis G. Konrad 2011

$\Delta a/a \approx 1\% \Leftrightarrow \Delta r_B/r_B \approx 1\cdot 10^{-3}$

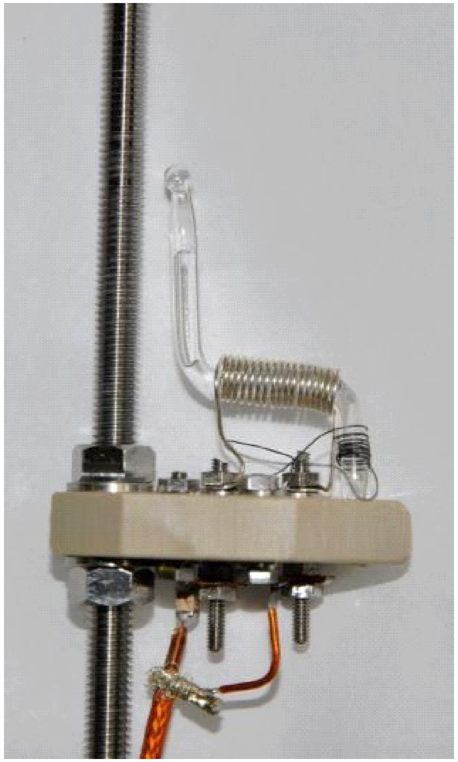
$\Rightarrow \Delta r_B/r_B \leq 10^{-4}$ to be neglegible

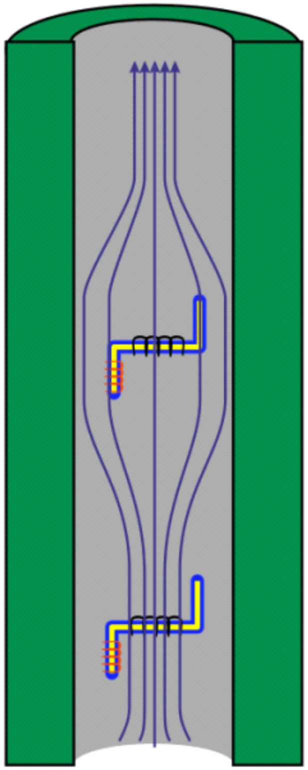


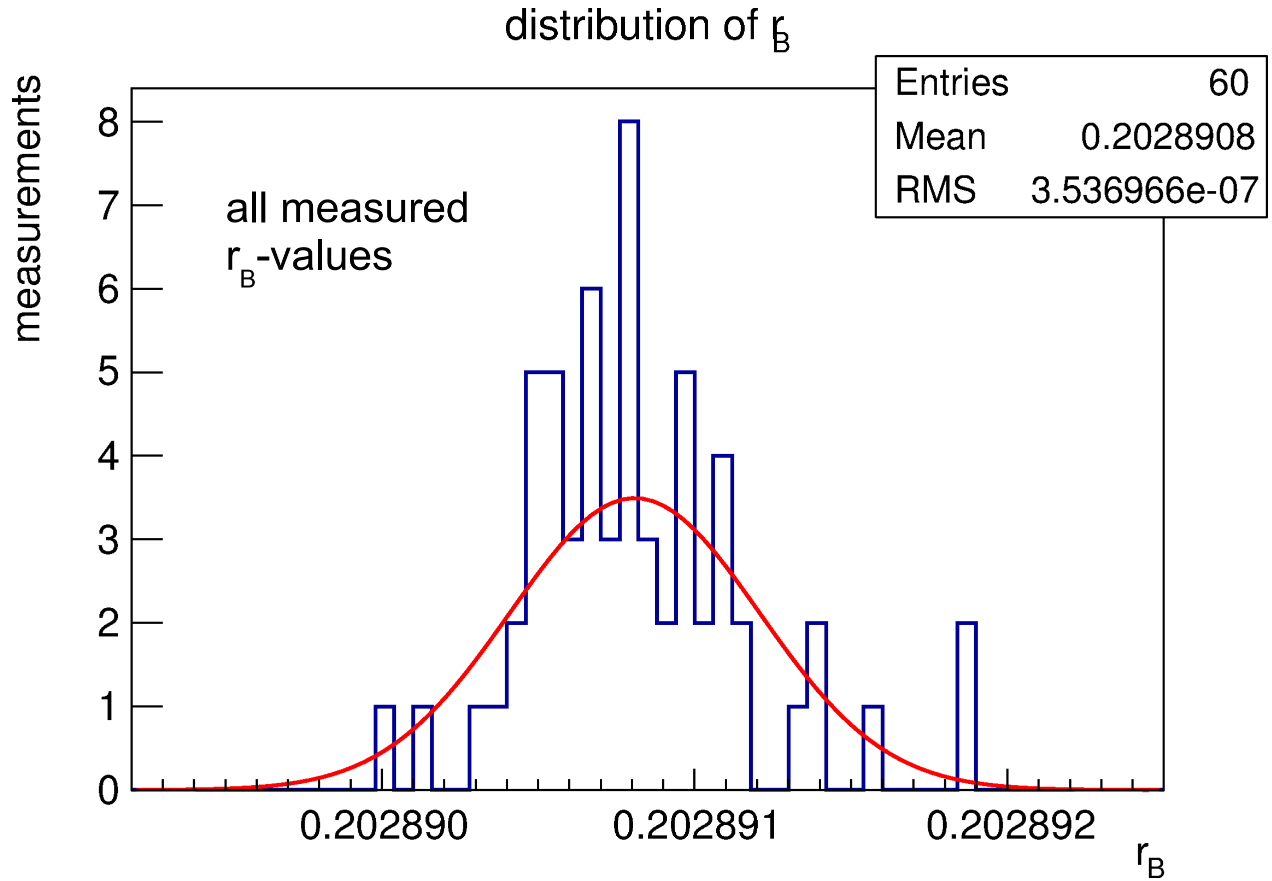
Solution: A new compact NMR-system!

B-field ration r_B

Nuclear Magnetic Resonance measurement







rms-fluctuation of r_B

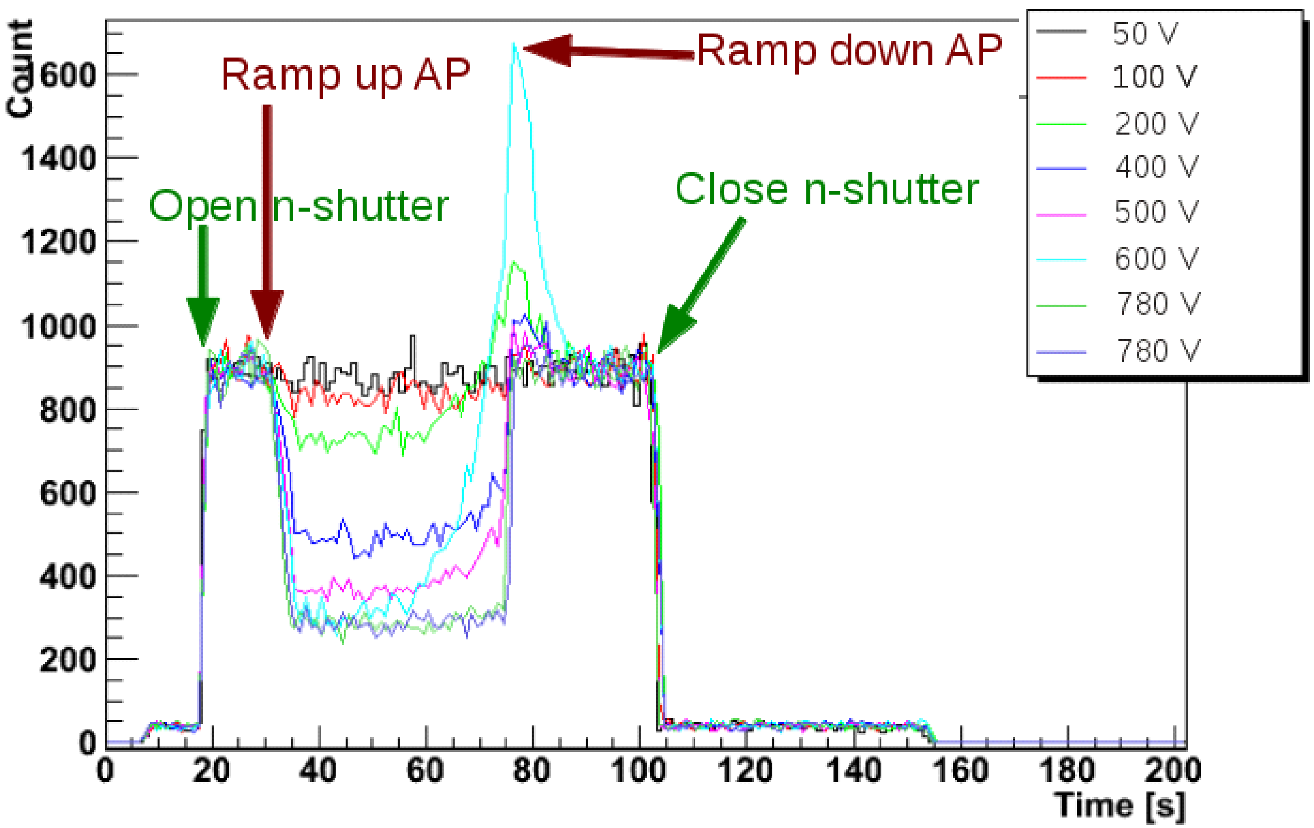
$\Delta r_B / r_B \approx 2 \cdot 10^{-6}$

→ All right!

Background and Discharges

Discharges can be catastrophic
Small discharges can cause background
Ret.-voltage dependent background has to be avoided and quantified
< 0.1 1/s necessary

The situation 2011:



Measures undertaken:

- Improved vacuum
- Improved the cleaning
- New eletrodes
- Smoothed edges of electrodes
- Recoated electrodes
- New internal collimation
- New dipole electrode above AP to remove stored partilces

→ No more obvious discharges

Background and Discharges

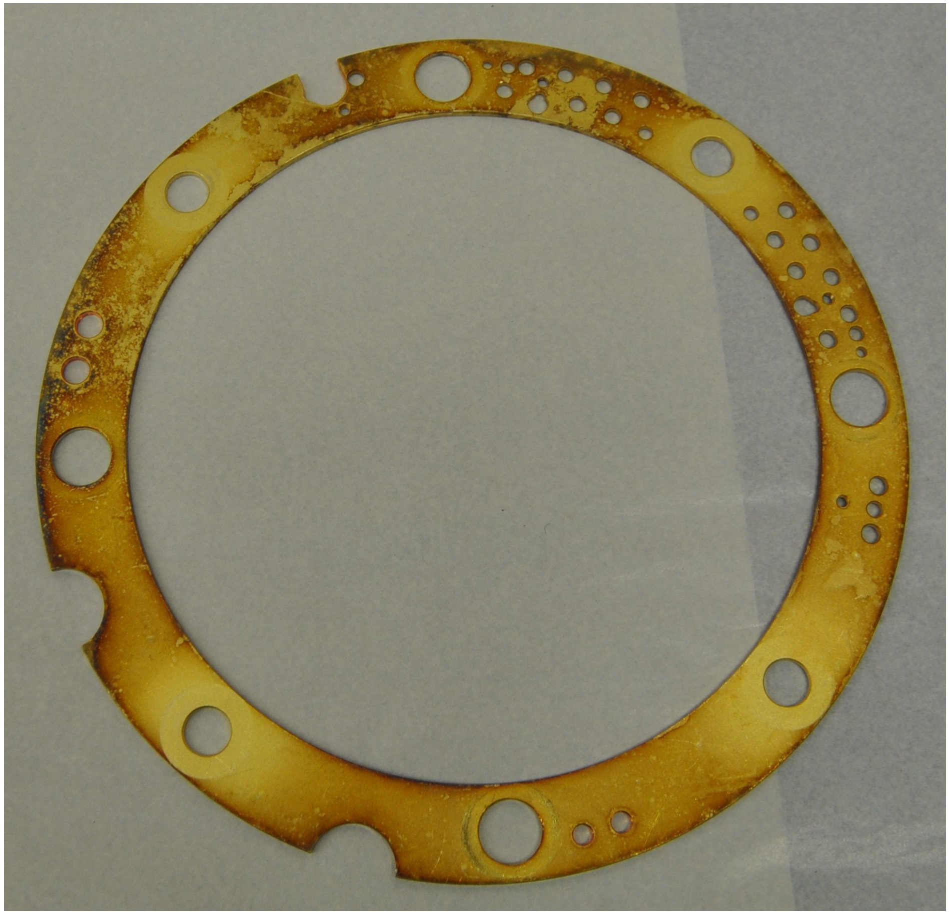
Examples of improvements of electrodes for the reduction of field emission and discharge suppression:

Remove sharp edges and points

Background and Discharges

Examples of improvements of electordes for the reduction of field emission and discharge suppression:

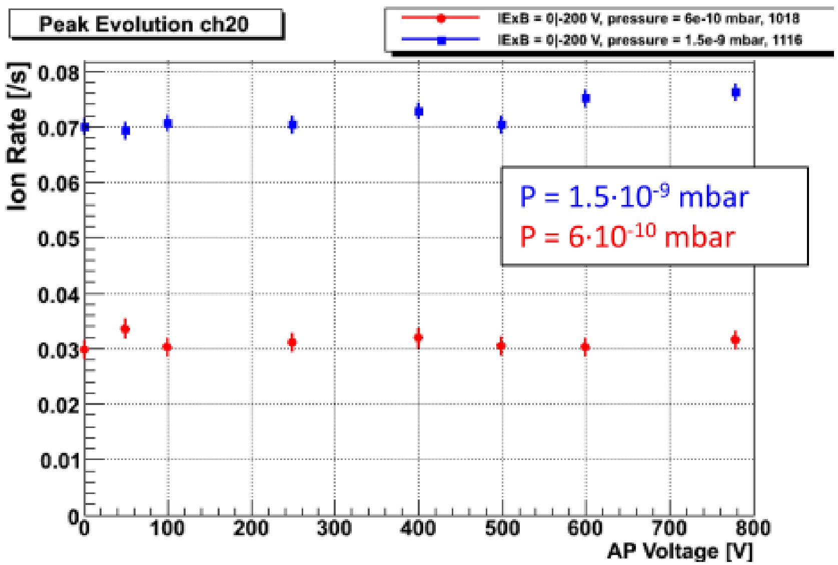
New Au-coating of all relevant electrodes



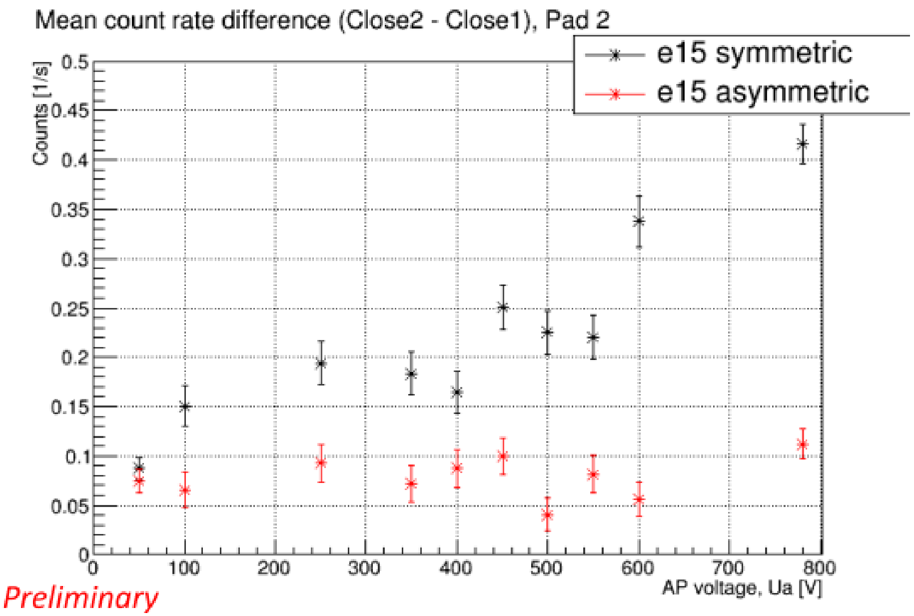
Dipole electrode above the main AP electrode

Background and Discharges

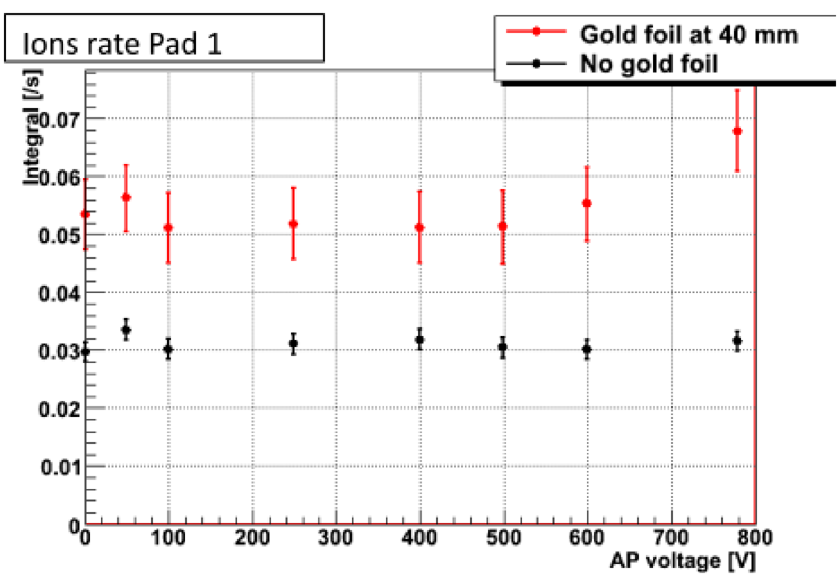
Some results regarding the retardation-voltage dependent background:



Intrinsic background



Effect of the E15 dipole electrode



Background due to ionization by electrons

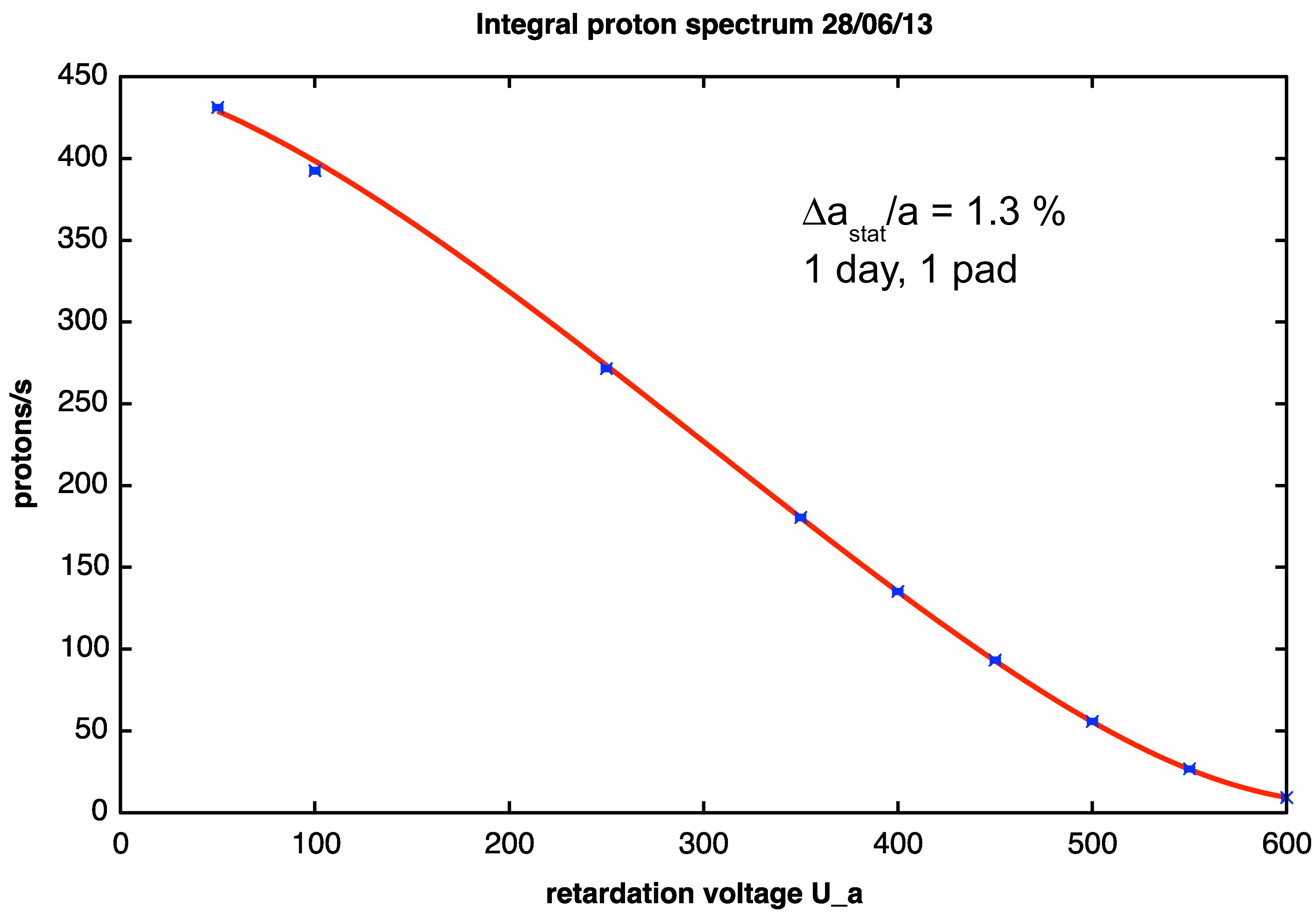
→ All energy-dependencies (except maybe E15 symmetric) are fine for a measurement with $\Delta a/a = 1\%$ (R. Maisonobe, PhD thesis 2014)

But: needs to be checked with simulations!

Status

Measured integral proton recoil energy spectrum

Statistics available: 3 measurements, 2-3 days each, 2 detector pads



Status

Several support measurements are ongoing:

- Measurement of the **work function** of the DV and AP electrodes used.

- Detailed test measurements with the **preamplifier and shaper** used.

Detailed analsyis ongoing
(Goal: quantitative determination of the systematic uncertainties, including simulations)

At present:

- Check of the data integrity

Till mid of 2015:

- Investigation of systematic effects
  - analysis of *a* for different experimental settings
  - extensive simulation of decay protons

Till begining of 2016:

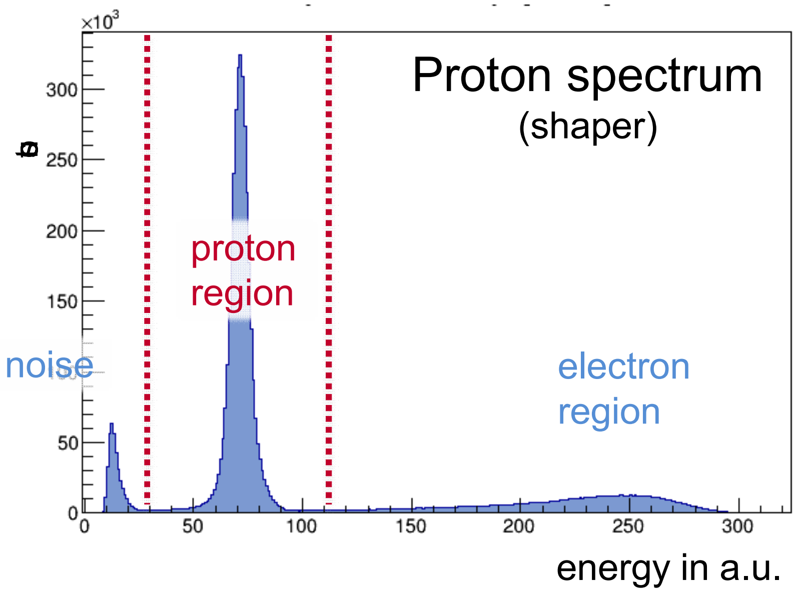
- Quantitative determination of all systematic and statistical errors

We expect a total systematic uncertainty of $\Delta a/a$ ~ 1-2%

The next steps

Next step: the n-lifetime experiment τSPECT

- Reduced losses due to magnetic storage
- Measure the decay curve:
  Online detection of the decay protons and eletrons
- Many components already available from *a*SPECT
- Pulsed UCN-source at TRIGA working, ideal for lifetime measurement



Initial funding from PRISMA

Development and component tests are ongoing!

What about small a?

- Determine the leading systematic uncertainties of *a*SPECT.
- Figure out ways to decrease them experimentally.
- Only after the "“Standard Analysis“.

The collaboration

From left to right

M. Simson, ILL
T. Soldner, ILL
O. Zimmer, ILL
R. Virot, ILL
R. Maisonobe, ILL
A. Wunderle, Mainz
W. Heil, Mainz
G. Konrad, Wien,
S. Baessler, U of Virginia
M. Beck, Mainz
Ch. Schmidt, Mainz

plus

F. Glück, KIT

**Supported by
DFG SPP1491**

Systematic uncertainties

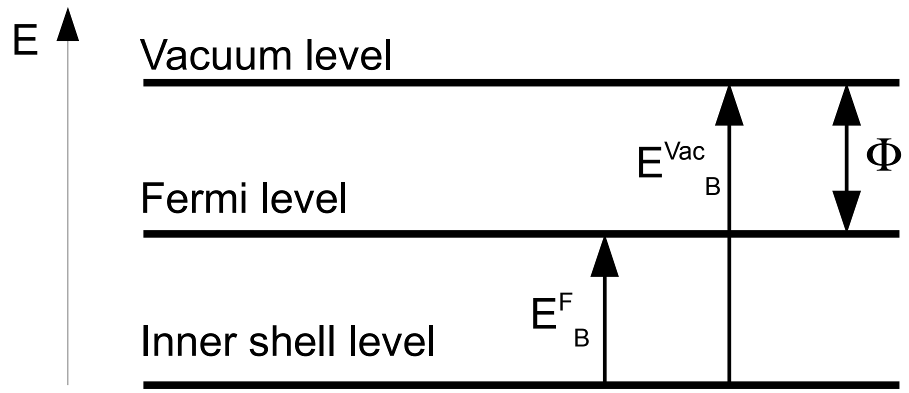
Systematic uncertainties of 2008

Game killers: Detector saturation, charging collimation, discharges

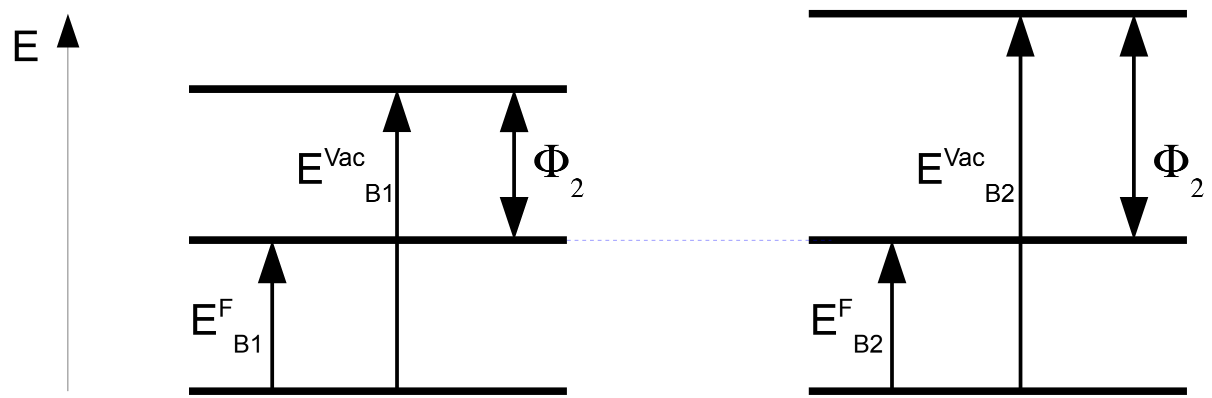
Type	$\Delta a/a$	PhD thesis
B-field Gradient	0.05%	GK
B-field ratio r_B	0.3%	GK, FAG
ΔU (MC)	0.11%	GK
Non-adiabaticity	0.3%	GK
Background U_A dependence	0.2%	Borg
Background peak 1	0.3%	Borg
Background peak 2	0.3%	Borg
Proton backscattering	0.16%	GK, Simson
Electronic noise	0.05%	GK
Dead time	0.145%	Borg, Simson
Edge effect	0.5%	GK
Work function AP	0.4%	GK
Work function DV	0.3%	GK
Work funciton p refelctions	0.4%	GK
Absolute work function	1.1%	GK

Systematic uncertainties

Applied potentials are modified by the work function



Two materials in contact: Fermilevels are connected



→ additional potential difference in vacuum of $\Phi_2 - \Phi_1$.

→ measure the work function using a Kelvin probe

Kelvin probe principle

Principle:

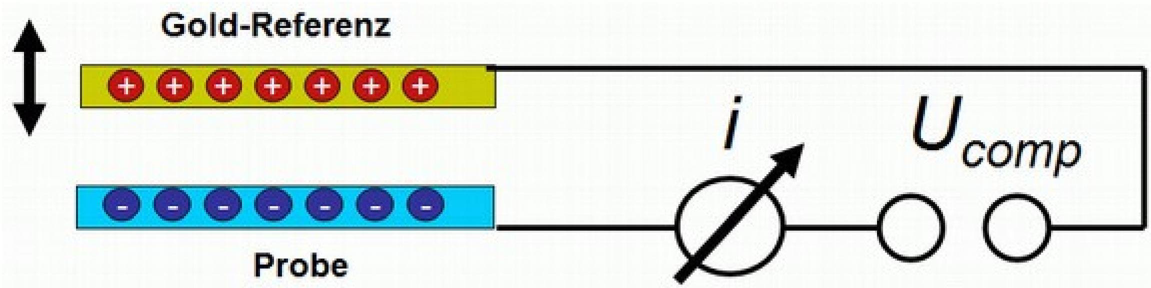
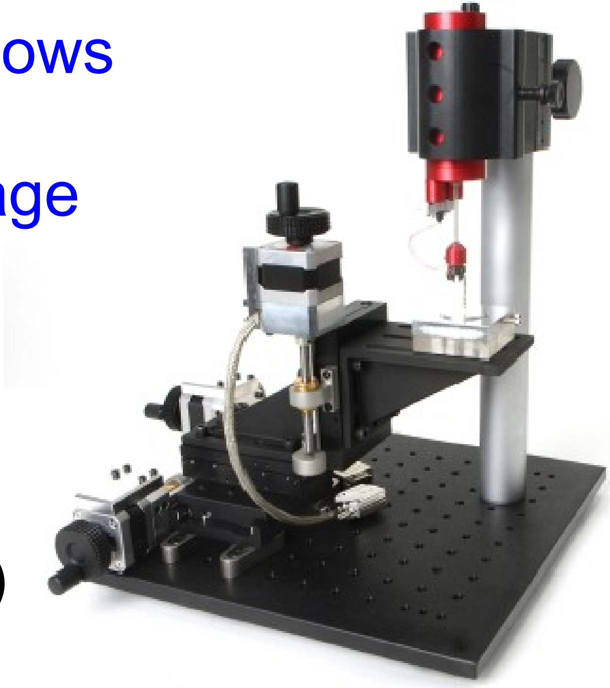


Fig: Frauenhofer Institut für Solare Energiesysteme

- test-electrode and electrode surface form a capacitor,
- mechanically vibrate test-electrode
  → capacitance changes → periodic current flows

Compensate contact potential with external voltage

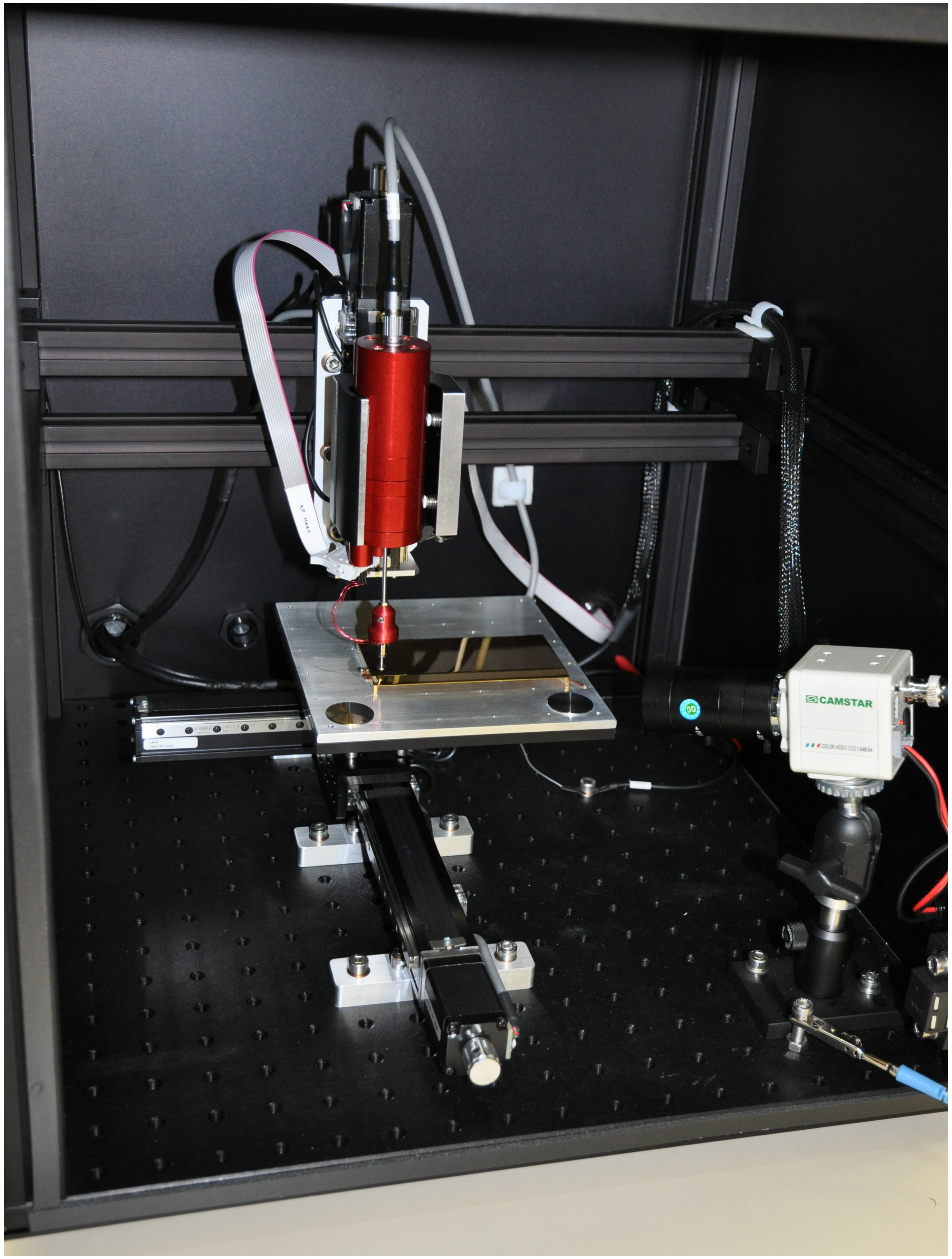
External voltage $U_{comp} = \Delta\Phi / e$

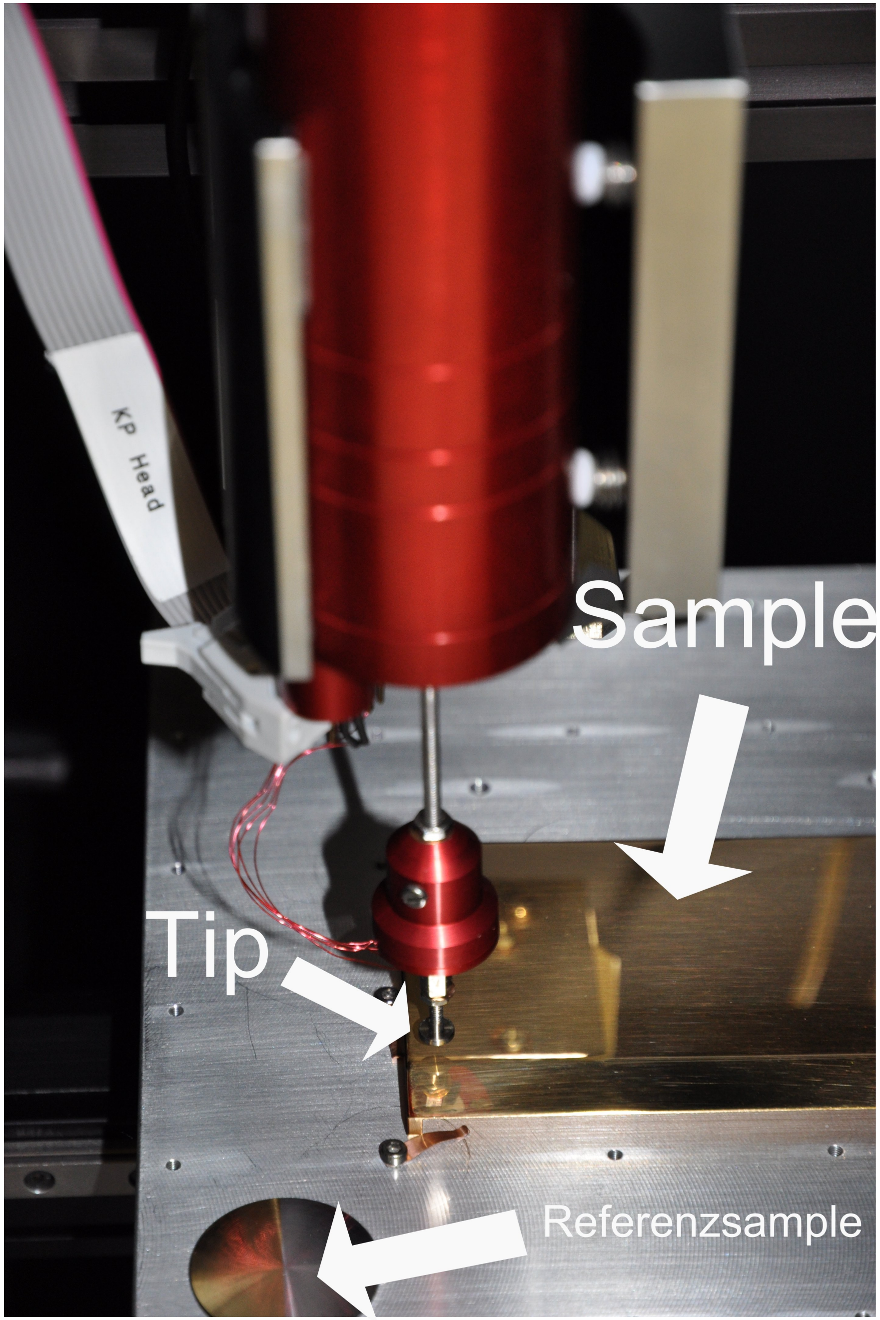


Sensitivity achievable: 1-3 meV (KP Technology)
Sensitivity needed for KATRIN: < 10meV

Fig.: KP Technology

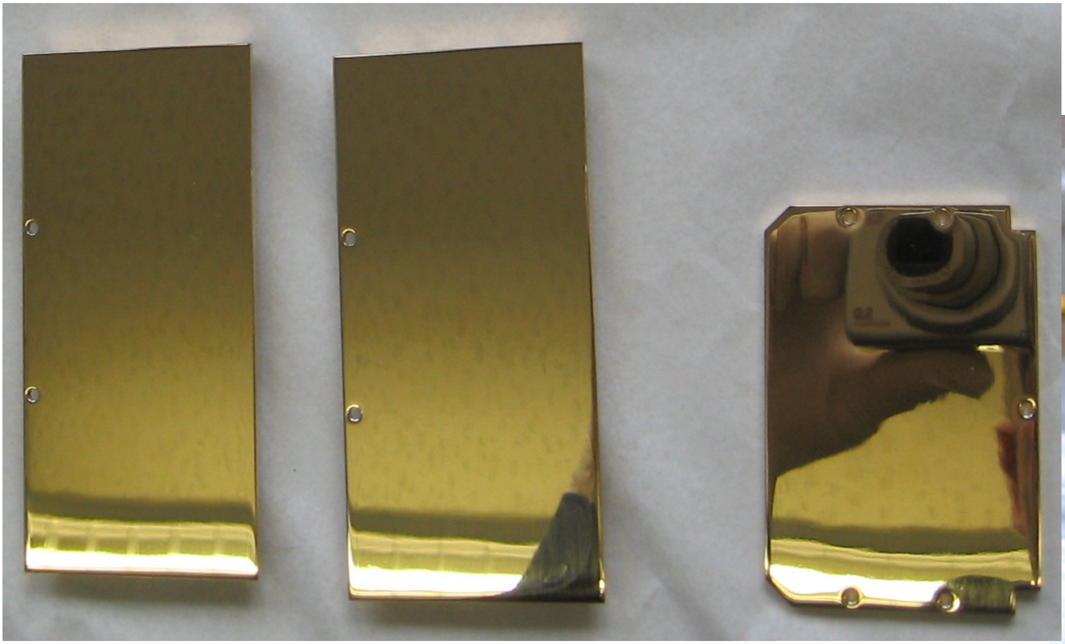
The Kelvin probe



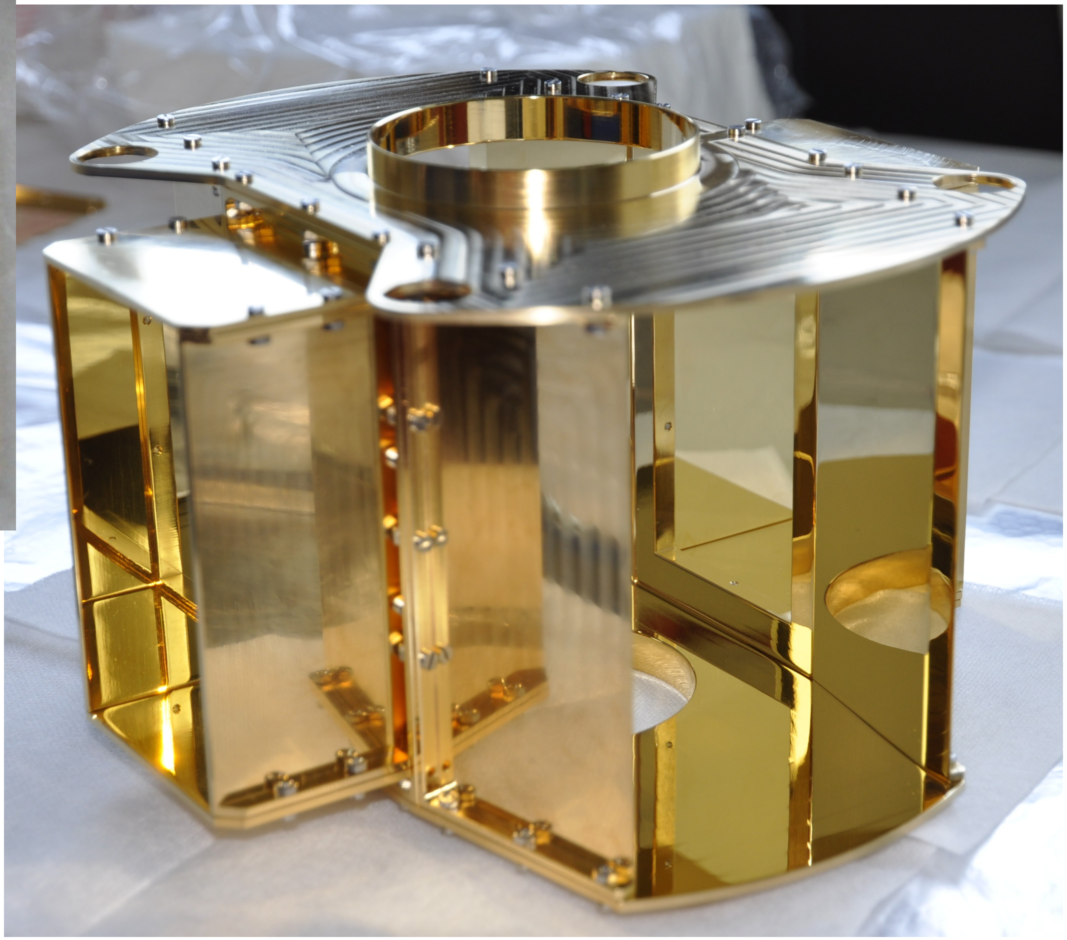


Electric potential

New decay volume and analyzing plane electrode



Decay volume:



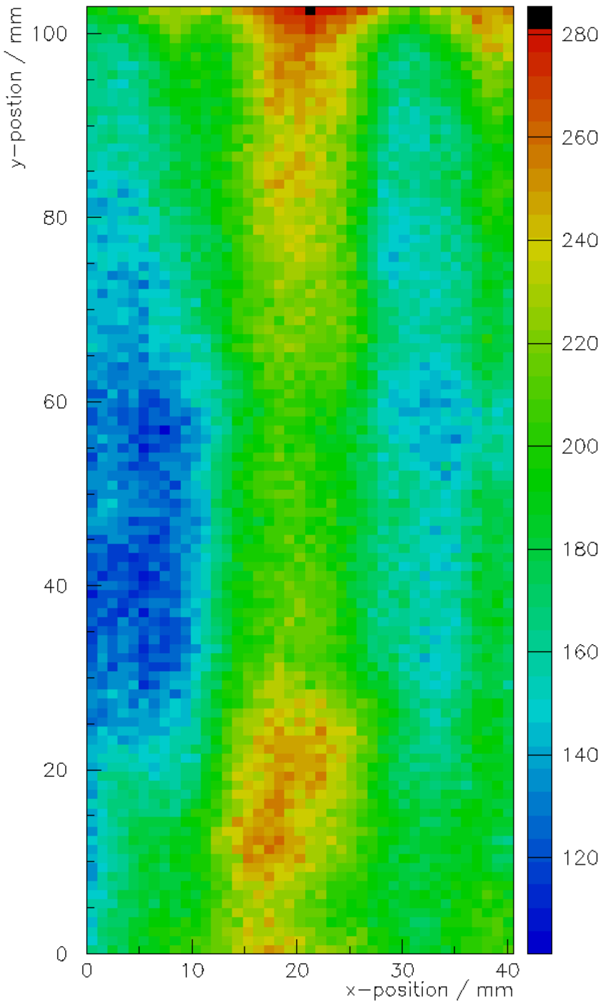
Flat surfaces, 1 μm Au on 10 μm Ag on polished Cu surface

→ well defined surface properties
→ work function can be measured easily

Diploma thesis Ch. Schmidt, Mainz 2012

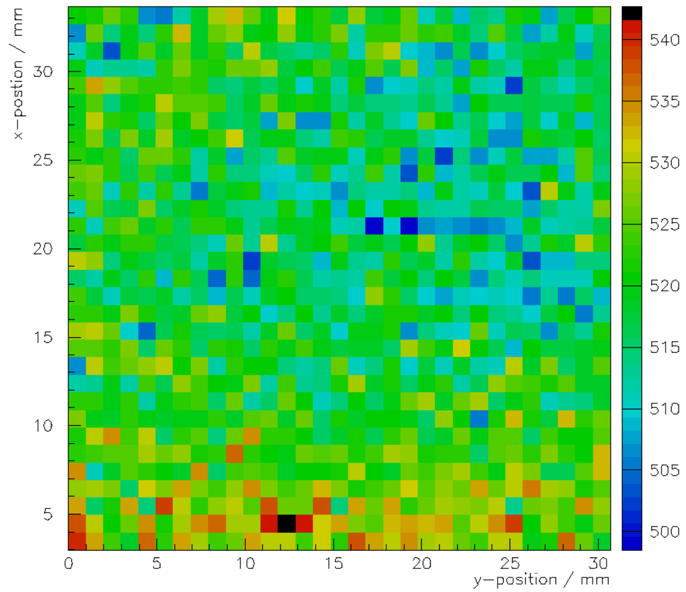
Essential Improvements

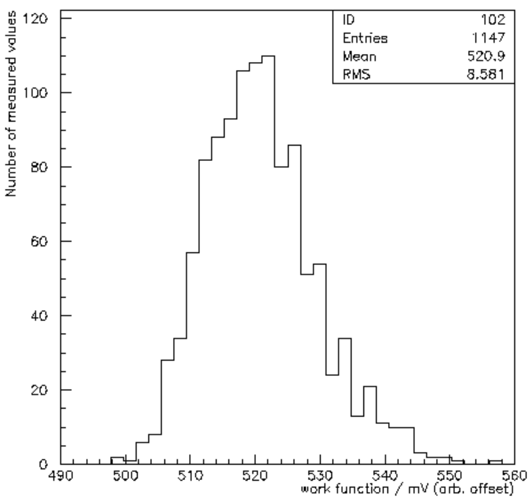
Gold plated Cu-electrode surface for *a*SPECT



rms fluctuation σ = 34 mV

Au(111) on sapphire for the rear wall of KATRIN

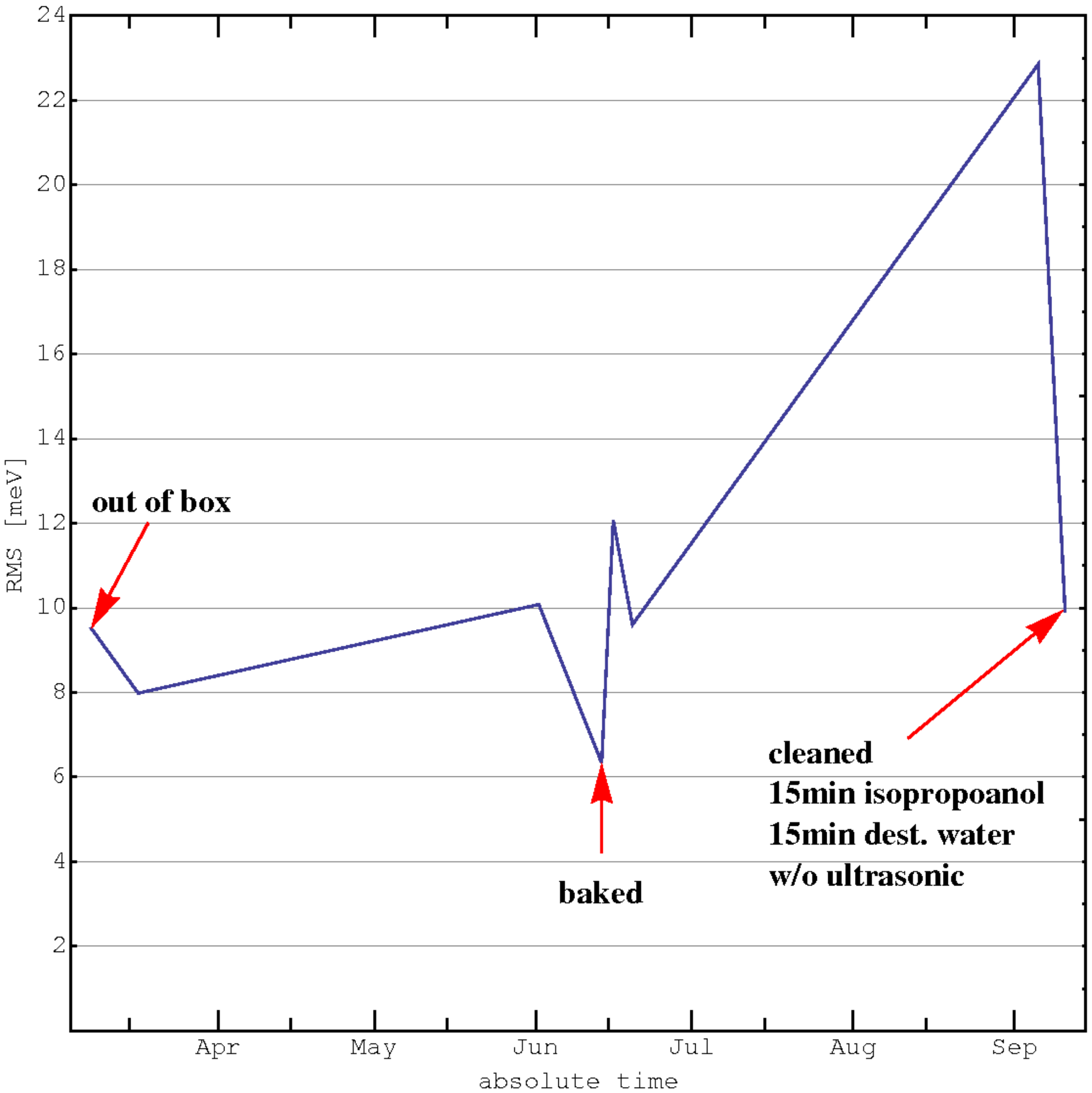


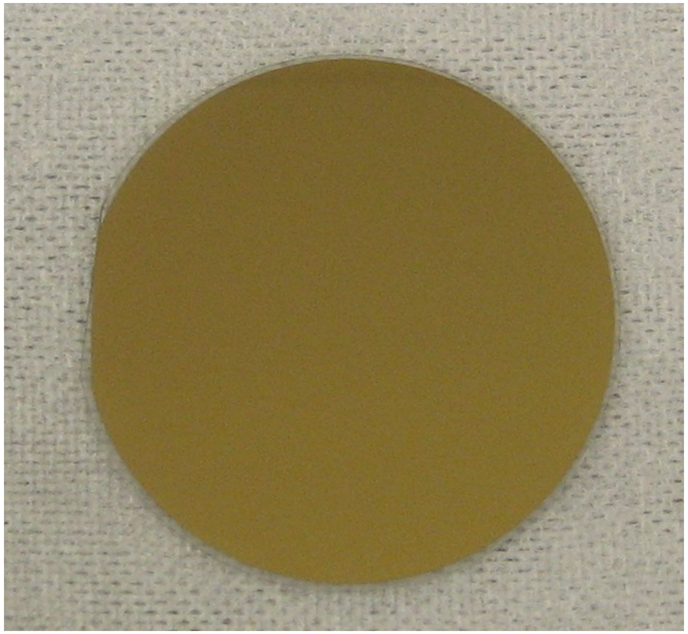


rms fluctuation σ = 8.6 mV

WF time development

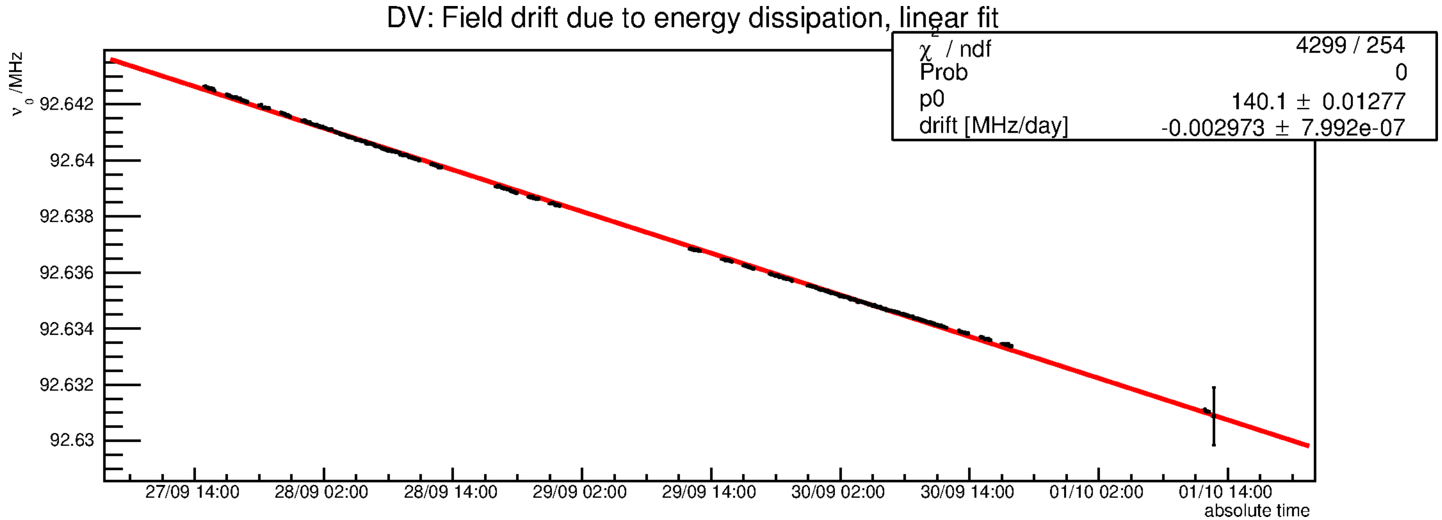
Stability of the work function fluctuations in time: Au(111)/sapphire sample II

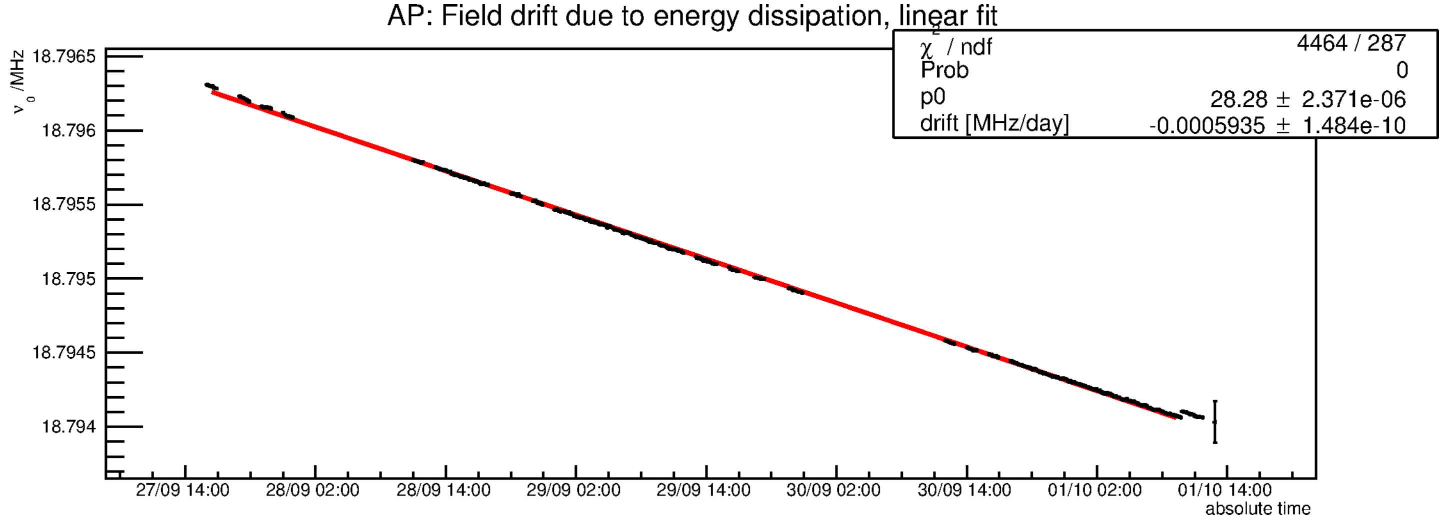




→ clean samples show less fluctuations of the work funciton

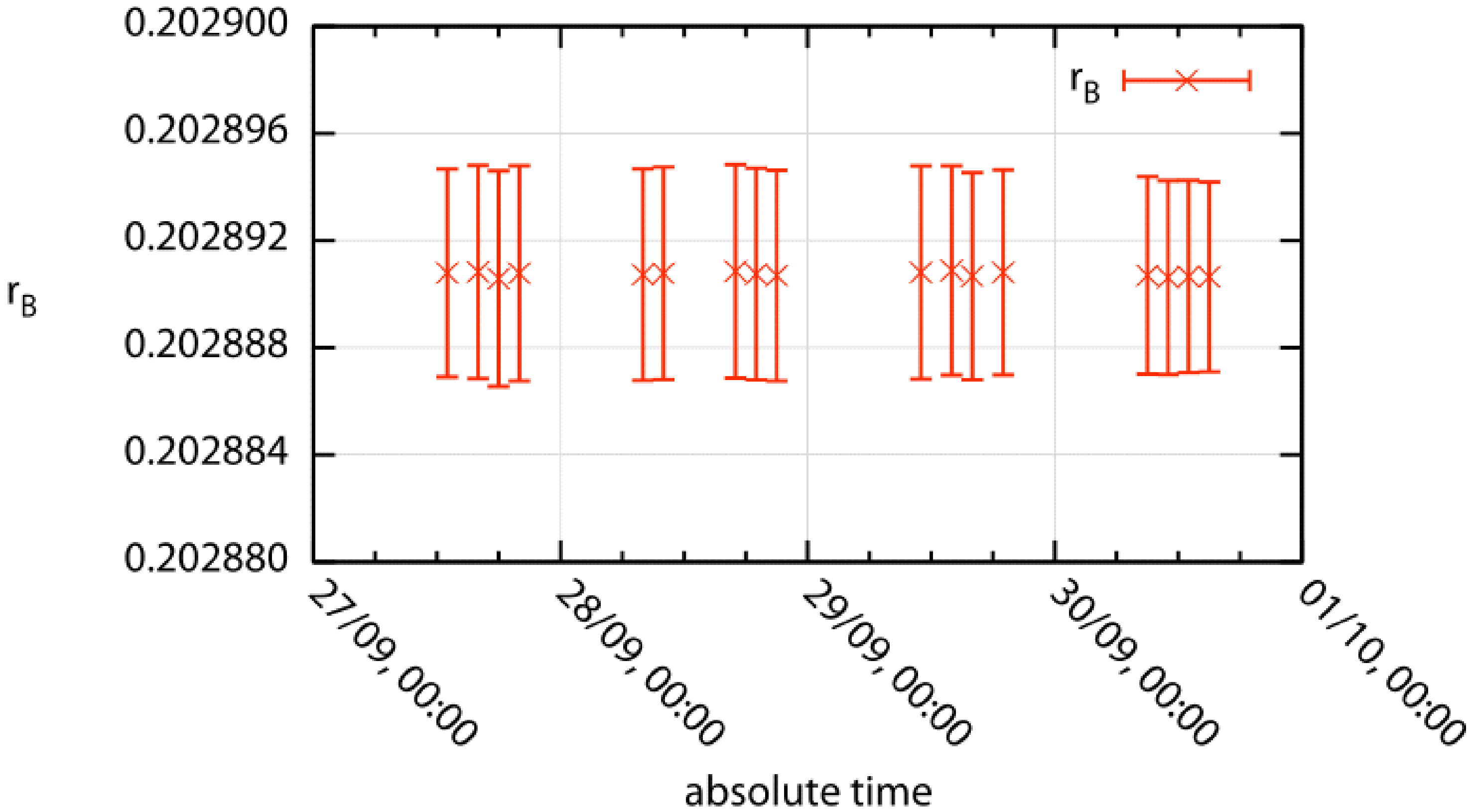
Long-term drift of the B-fields:





Essential Improvements

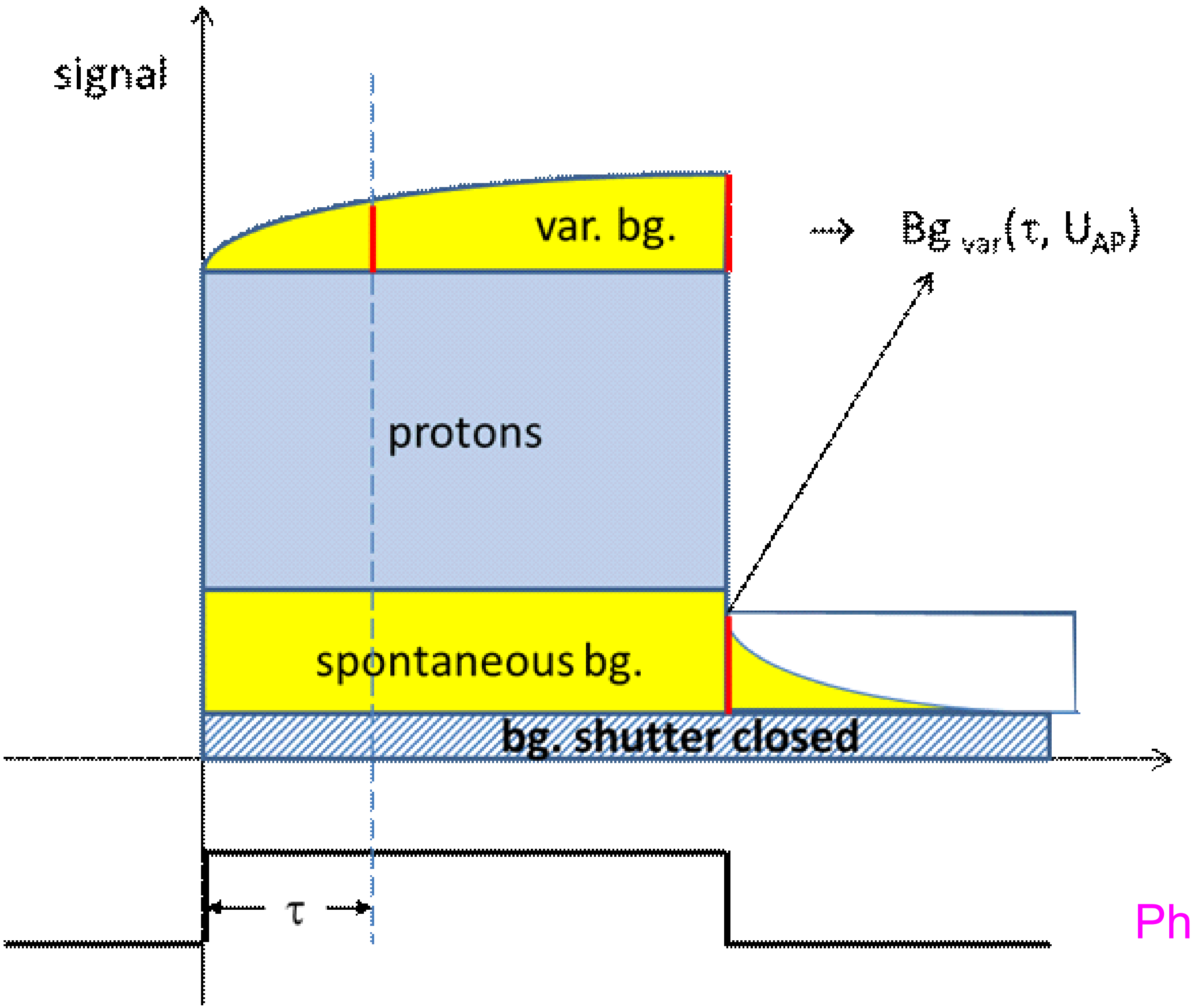
Long-term stability of r_B:



→ Long-term drift of r_B well within a peak width, i.e. drift $\Delta r_B/r_B << 1\cdot10^{-5}$

Background and Discharges

The background at *a*SPECT consists of several components with potentially different dependence on the AP potential.



- beam off ↔ beam on
- variable ↔ constant
- spontaneous
- retardation voltage dependence

PhD thesis R. Maisonobe 2014