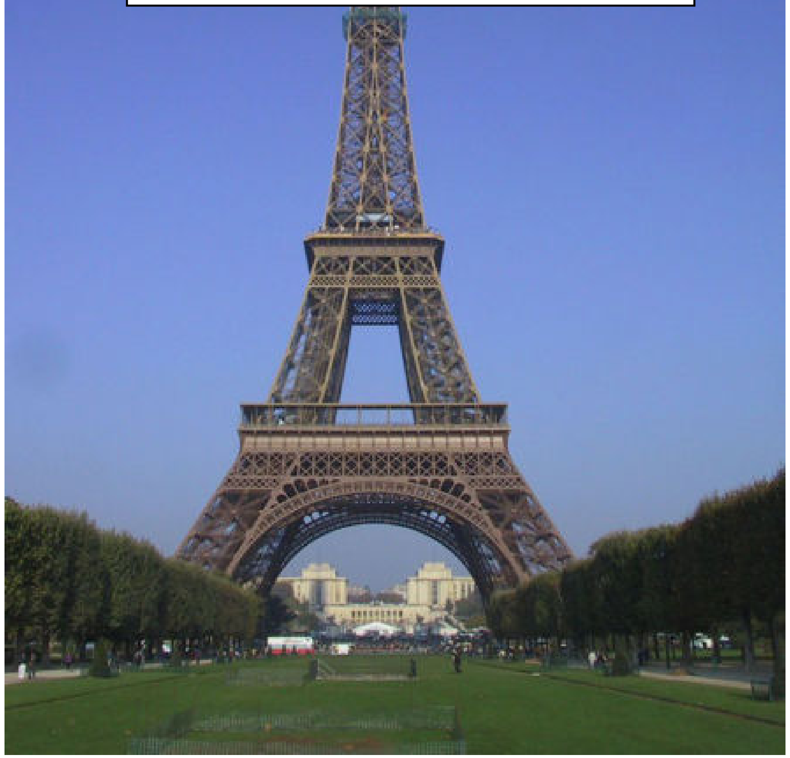
First results on the Proton Spectrum with the Neutron Decay Spectrometer *a*SPECT

Stefan Baeßler

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

- Neutral Currents
- W,Z-Bosons
- 3 Quark Generations
- Higgs-Bosons



Outline

1. Theory of Neutron Beta Decay
2. The Lifetime of the Free Neutron
3. The Beta Asymmetry and PERKEO-II
4. Results of the first test beam time with the Neutron Decay Spectrometer *a*SPECT
5. Improvements for *a*SPECT
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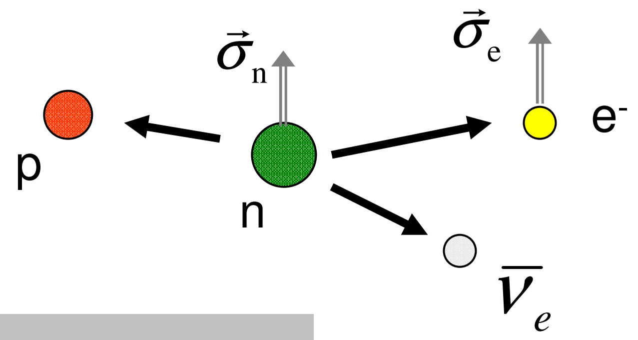
The Decay Probability

$$H_{\text{weak}} = G_{\text{F}} V_{\text{ud}} \langle n | \gamma^{\mu} - \lambda \gamma^{\mu} \gamma^{5} | p \rangle \langle \nu_e | \gamma_{\mu} - \gamma_{\mu} \gamma_5 | e^{-} \rangle$$



Jackson et al., PR 106, 517 (1957):

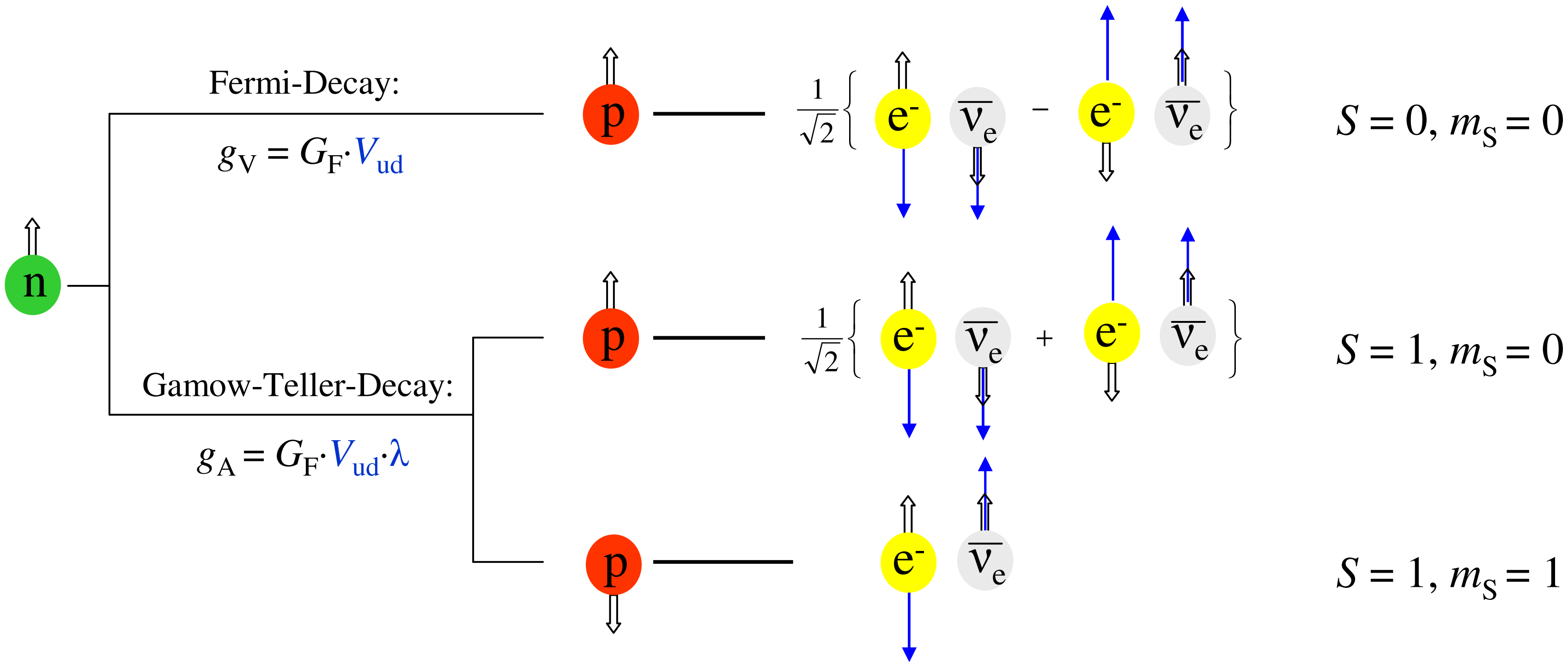
$$dW \propto \rho(E_{\text{e}}) \cdot \left\{ 1 + a \frac{\vec{p}_{\text{e}} \cdot \vec{p}_{\nu}}{E_{\text{e}} E_{\nu}} + b \frac{m_{\text{e}}}{E_{\text{e}}} + \left(A \frac{\vec{p}_{\text{e}}}{E_{\text{e}}} + B \frac{\vec{p}_{\nu}}{E_{\nu}} + D \frac{\vec{p}_{\text{e}} \times \vec{p}_{\nu}}{E_{\text{e}} E_{\nu}} + \ldots + R \frac{\vec{p}_{\text{e}} \times \vec{\sigma}_{\text{e}}}{E_{\text{e}}} \right) \cdot \vec{\sigma}_{\text{n}} \right\}$$

Beta-Asymmetry $A = -2 \frac{|\lambda|^2 + \text{Re}\,\lambda}{1 + 3|\lambda|^2}$

Neutrino-Electron-Correlation $a = \frac{1 - |\lambda|^2}{1 + 3|\lambda|^2}$

Neutron lifetime $\tau_{\text{n}}^{-1} = \int \rho(E_{\text{e}}) \propto G_F^2 V_{\text{ud}}^{2} \left(1 + 3|\lambda|^2 \right)$

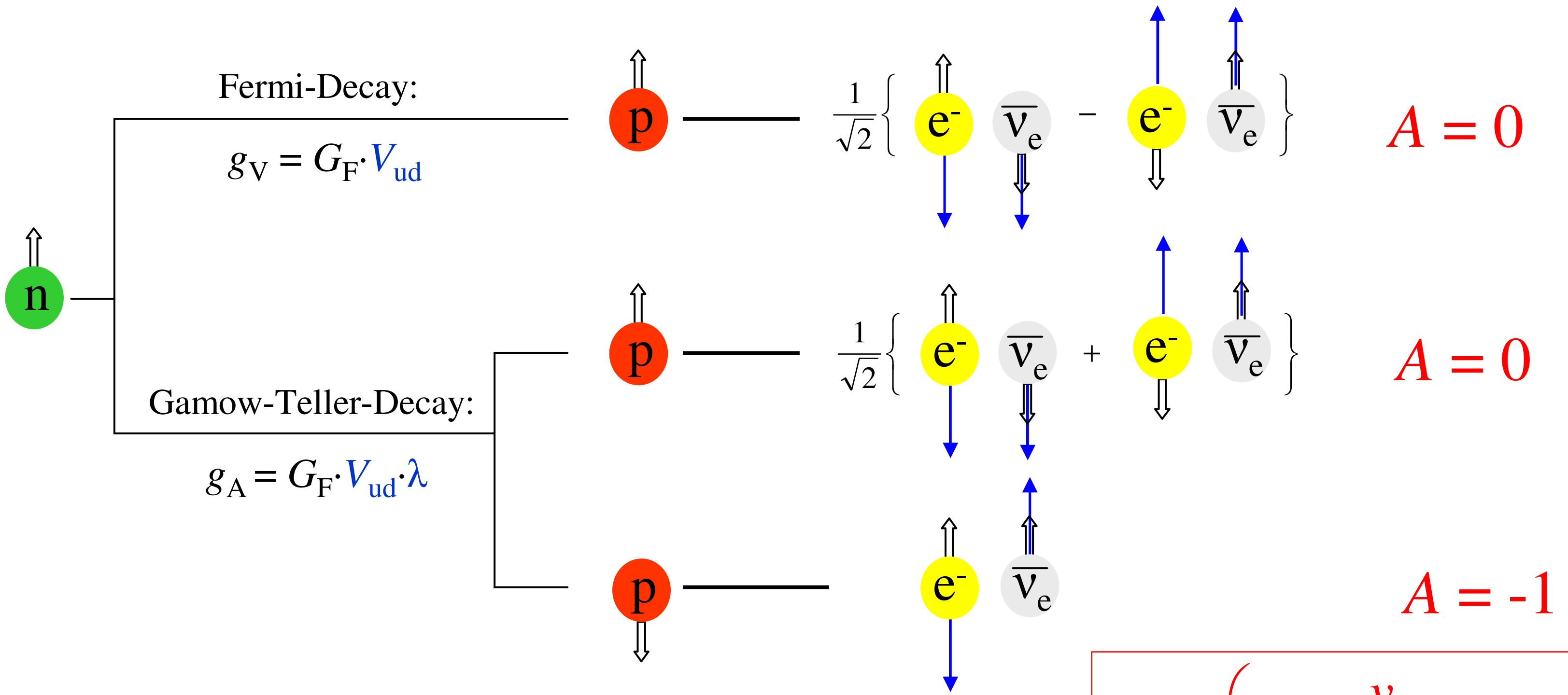
Determination of the Coupling Constants



Two unknown parameters, g_A and g_V, need to be determined in 2 experiments

1. Neutron-Lifetime: $\tau_n^{-1} \propto \left(g_V^2 + 3 g_A^2 \right)$ $\quad \tau_n \approx 885$ s

Determination of the Coupling Constants



$$dw \propto \left(1 + A\frac{v}{c}\cos\left(p_e, \sigma_n\right)\right)$$

Two unknown parameters, g_A and g_V, need to be determined in 2 experiments

1. Neutron-Lifetime: $\tau_n^{-1} \propto \left(g_V^2 + 3g_A^2\right)$ $\quad \tau_n \approx 885\ \mathrm{s}$

2. Beta-Asymmetry: $A = -2\frac{\lambda^2 + \lambda}{1 + 3\lambda^2} \approx -0.1$ $\quad \lambda = \frac{g_A}{g_V}$

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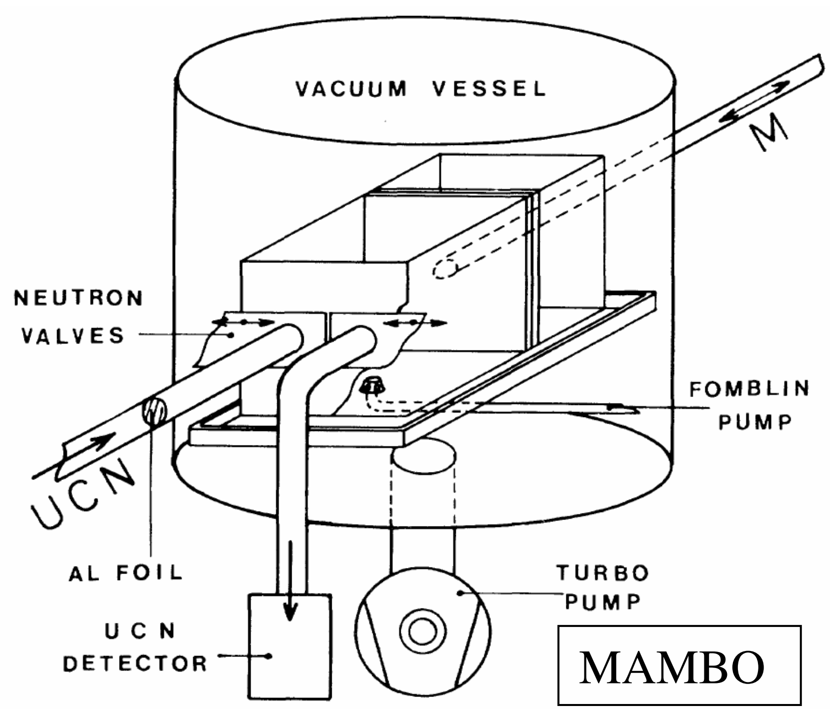
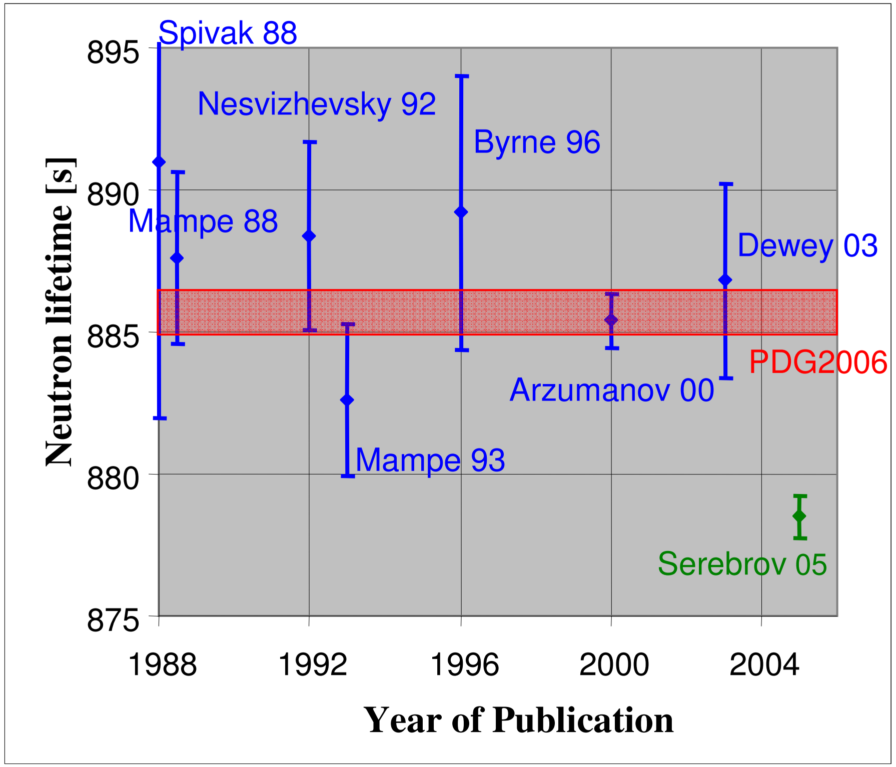
Neutron Lifetime Measurements

Decrease of Neutron Counts N with storage time t: $N(t) = N(0)\exp\{-t/\tau_{eff}\}$

$1/\tau_{eff} = 1/\tau_{\beta} + 1/\tau_{wall\ losses}$





Many new attempts planned, mostly with magnetic bottles

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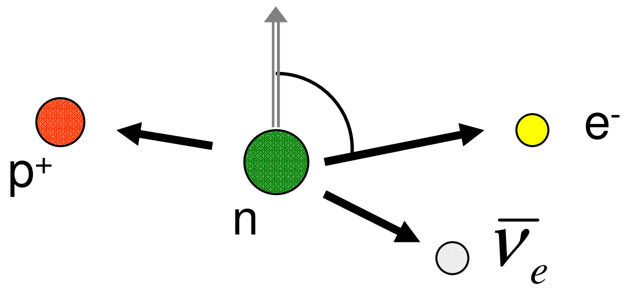
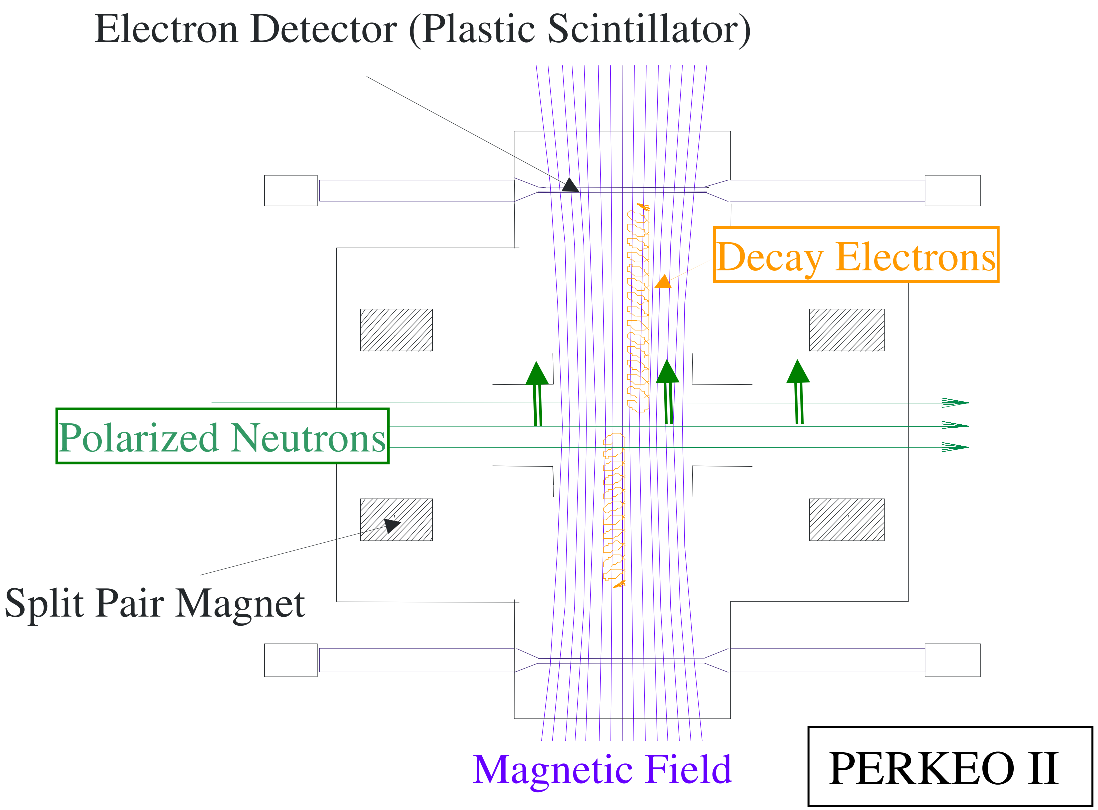
The Beta Asymmetry



$$dw \propto \left(1 + A\frac{v}{c}\cos\left(p_e, \sigma_n\right)\right)$$

$$A \propto \frac{N_{up} - N_{down}}{N_{up} + N_{down}}$$



Beam time	Result	Publication
1995	*A* = -0.1189(12)	H. Abele, S. B. et al., Phys. Lett. B 407, 212 (1997)
1997	*A* = -0.1189(7)	H. Abele, S. B. et al., PRL 88, 211801 (2002)
2004	*A* = -0.1195(4)	(preliminary)

Possible Tests of the Standard Model

1. Search for Right-handed Currents

   W_R?

2. Search for Scalar and Tensor interactions

   Leptoquarks? Charged Higgs Bosons?

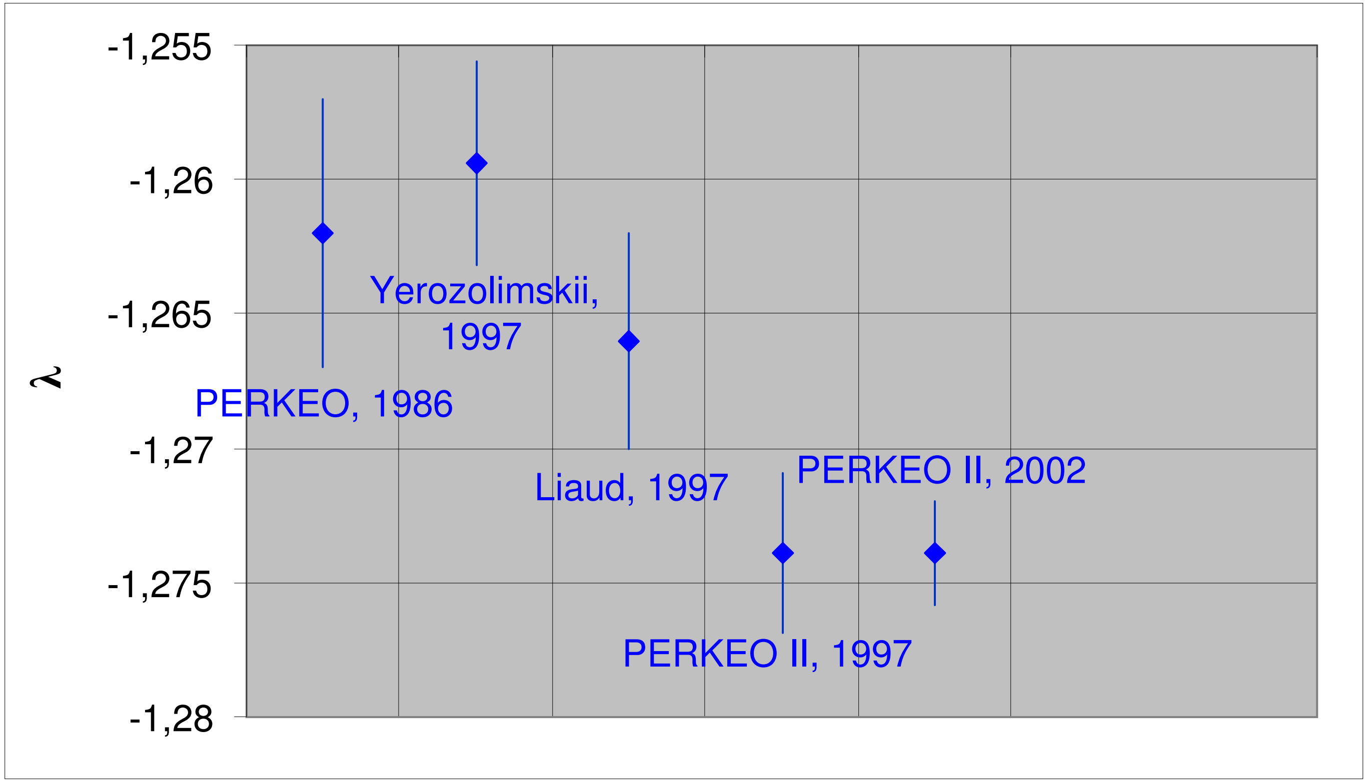
3. Search for Supersymmetric Particles

   (Loop corrections to beta decay change coupling constants)

4. Test of the Unitarity of the Cabbibo-Kobayashi-Maskawa-Matrix

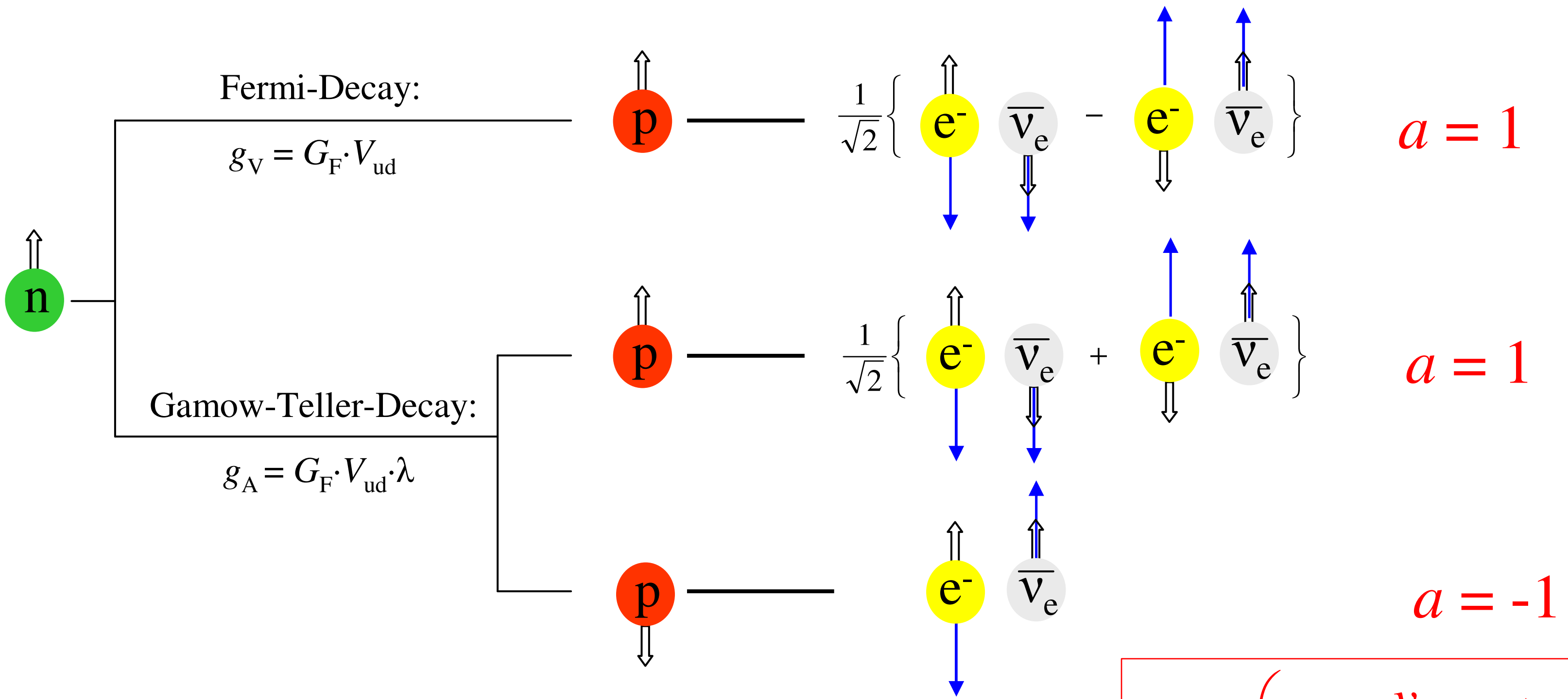
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{td} & V_{tb} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix} \qquad |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

Determination of $\lambda = g_A/g_V$



- PERKEO II is the systematically cleanest experiment
- Still the disagreement with older measurements is not explained

Determination of the Coupling Constants



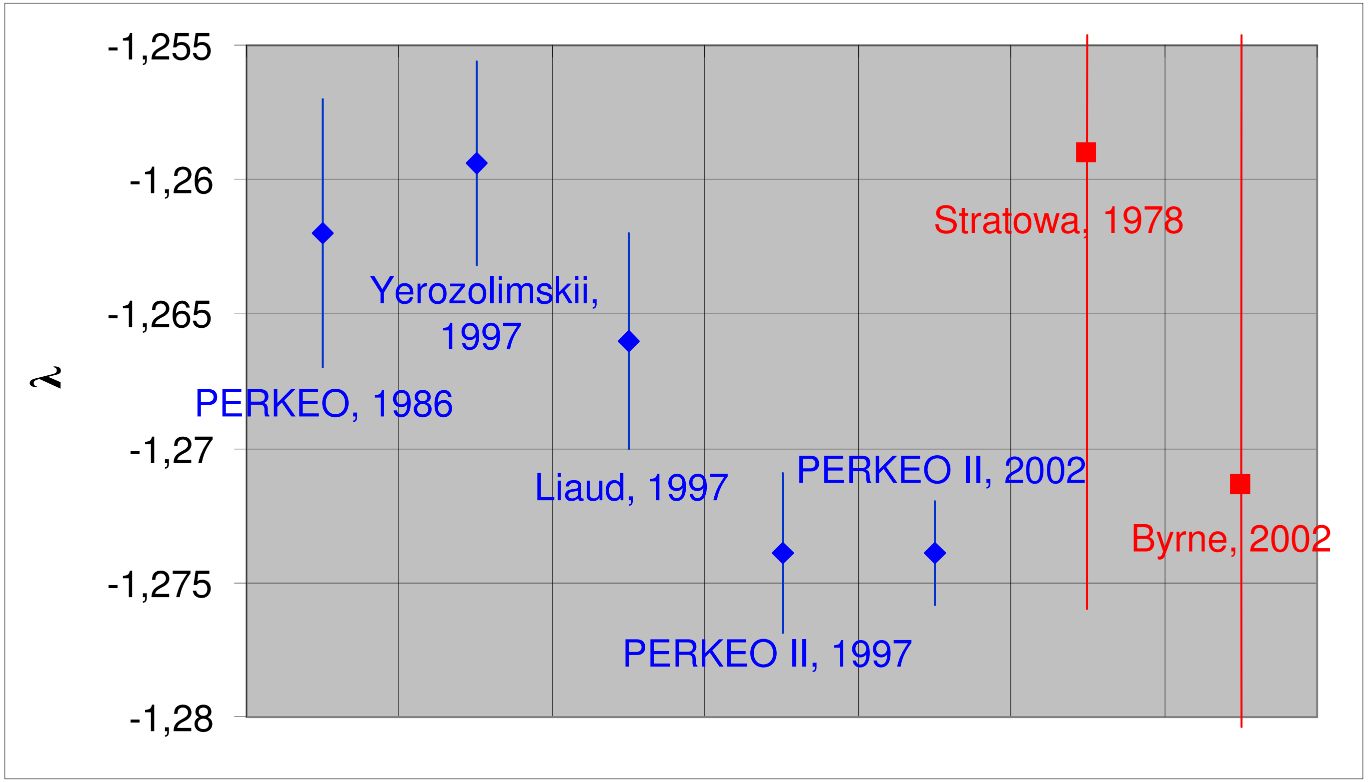
$$dw \propto \left(1 + a\frac{v}{c}\cos\left(p_e, p_{\bar{\nu}_e}\right)\right)$$

Two unknown parameters, g_A and g_V, need to be determined in 2 experiments

1. Neutron-Lifetime: $\tau_n^{-1} \propto \left(g_V^2 + 3g_A^2\right)$ $\quad \tau_n \approx 885\ \text{s}$

2b. Neutrino-Electron-Correlation *a*: $a = \dfrac{1-\lambda^2}{1+3\lambda^2} \sim -0.1$ $\quad \lambda = \dfrac{g_A}{g_V}$

Determination of $\lambda = g_A/g_V$



• A measurement of a is independent of possible unknown errors in A, systematics are entirely different.

• Present experiments have $\Delta a/a$ ~ 5%, our aim is $\Delta a/a$ ~ 0.3%

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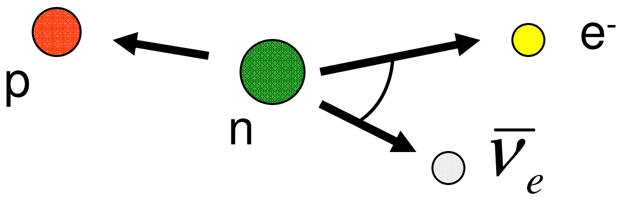
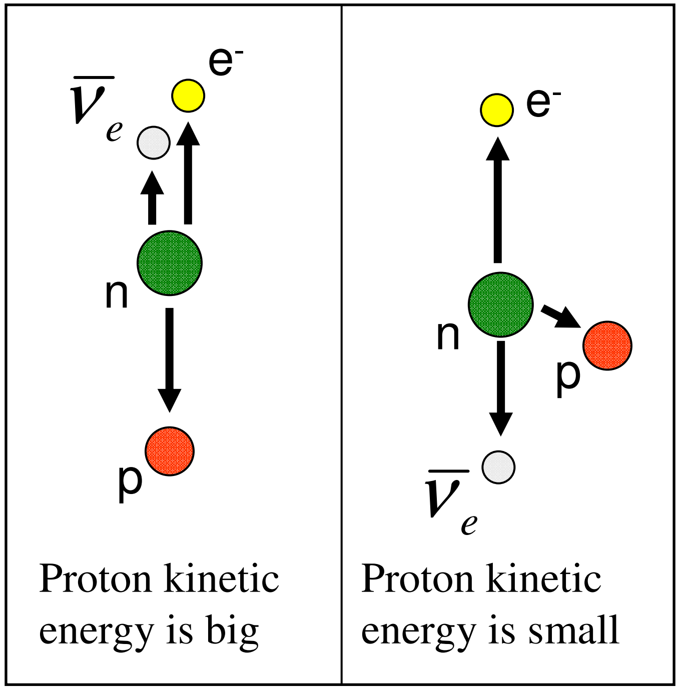
The Neutrino Electron Correlation and the Proton Spectrum in Neutron Decay

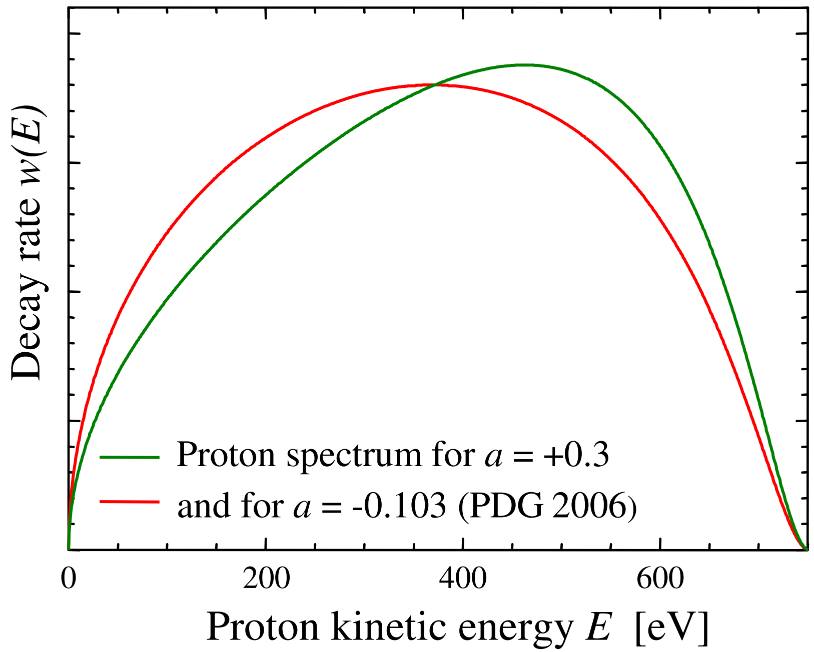
The correlation coefficient *a*



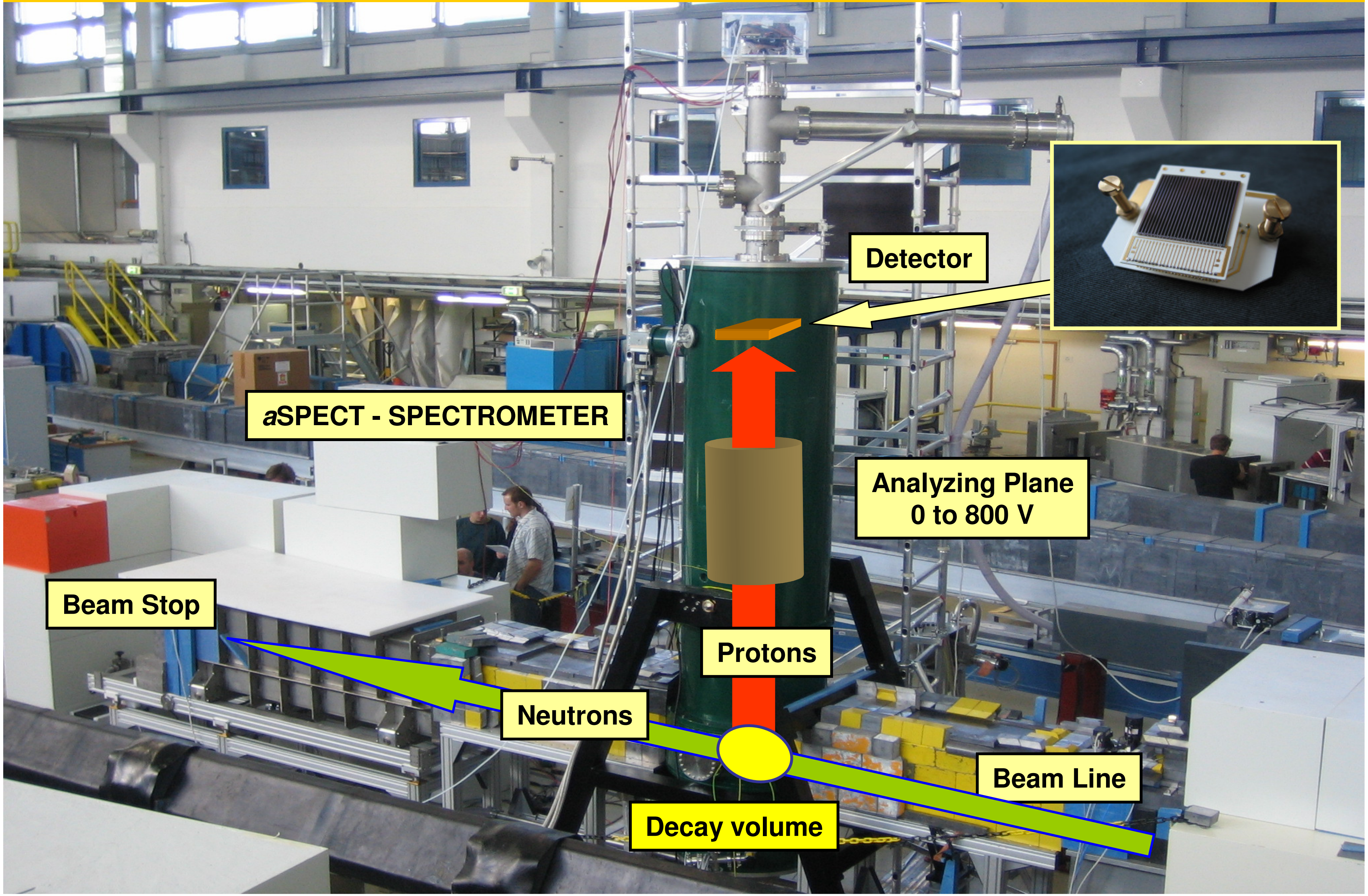
$$dw \propto \left(1 + a\frac{v}{c}\cos\left(p_e, p_{\bar{\nu}_e}\right)\right)$$



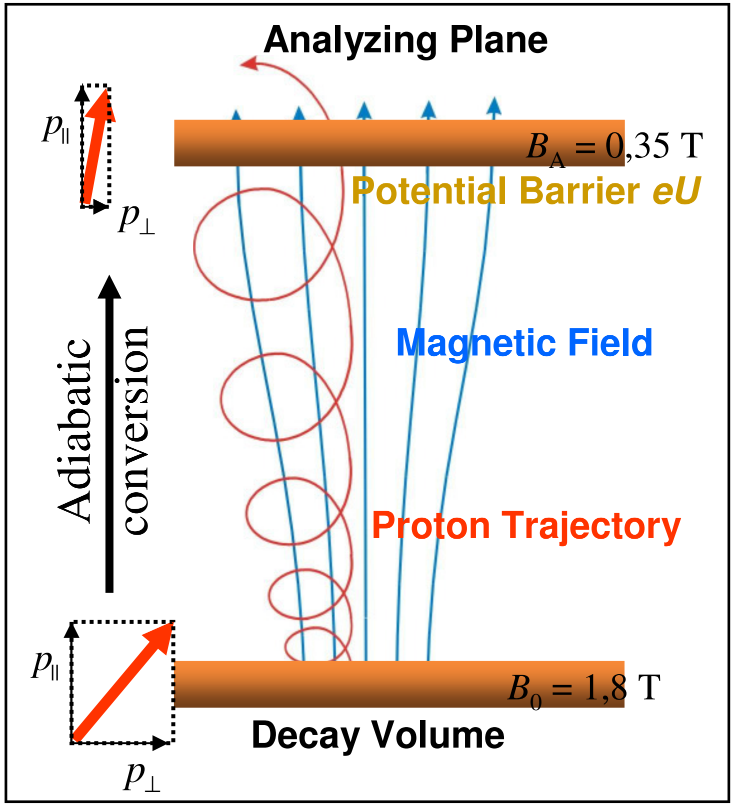
Sensitivity of the Proton Spectrum to *a*:

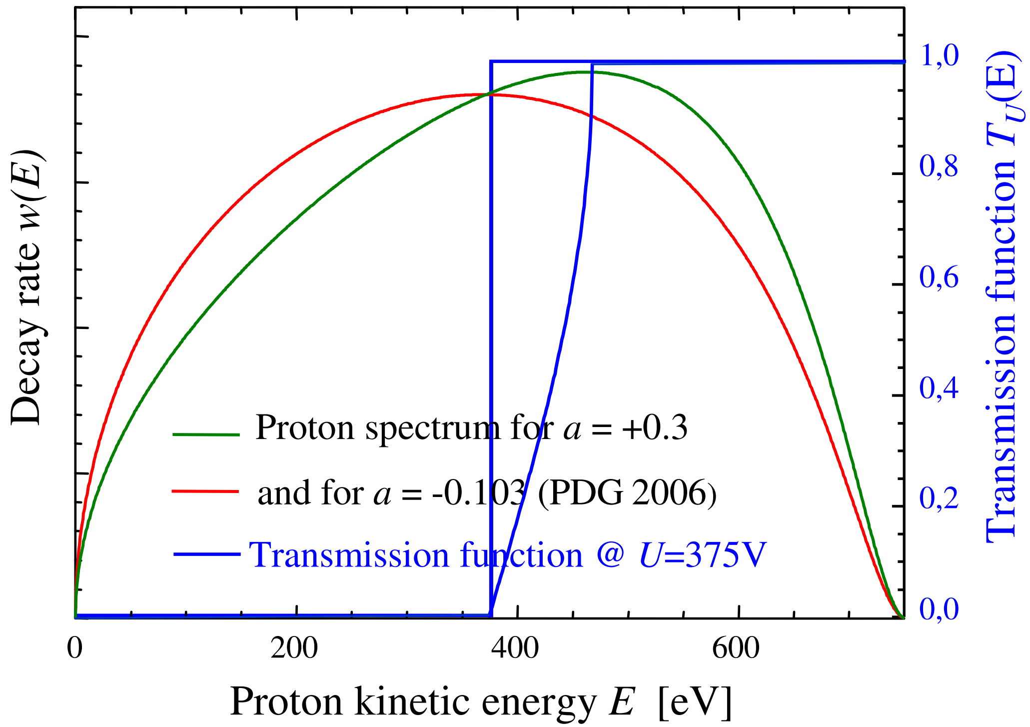


Setup @ MEPHISTO



Principle of a Retardation Spectrometer





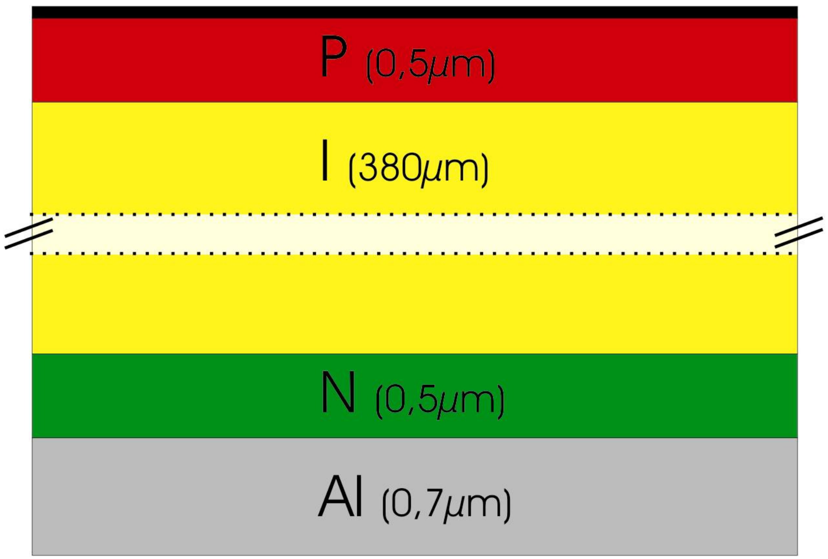
Transmission function $T_U(E)$ in the adiabatic limit:

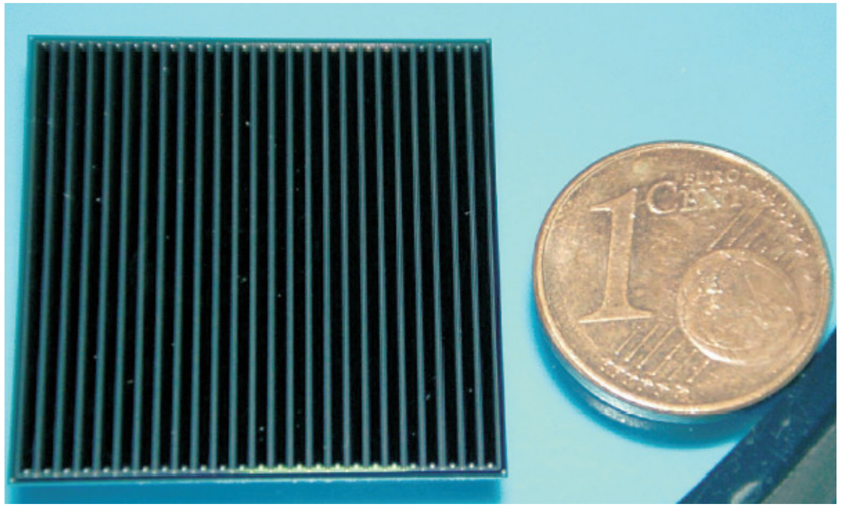
$$T_U(E) = \begin{cases} 0 & ; \quad E < eU \\ 1 - \sqrt{1 - B_0/B_A\,(1 - eU/E)} & ; \quad \text{otherwise} \\ 1 & ; \quad E > eU/(1 - B_A/B_0) \end{cases}$$

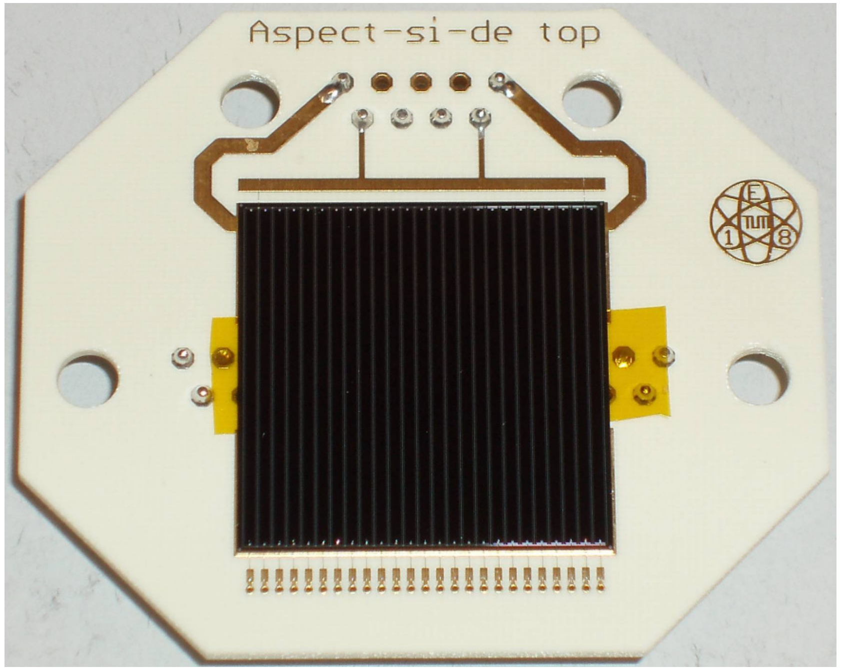
The Proton Detector

Segmented Si - PIN - Diode

- Active Area 25 × 25 mm²
- Segmented in 25 Stripes
- Thin Entrance Window
  - Dead Layer: 67 nm
  - Energy Loss for 30 keV protons: ~ 8 keV

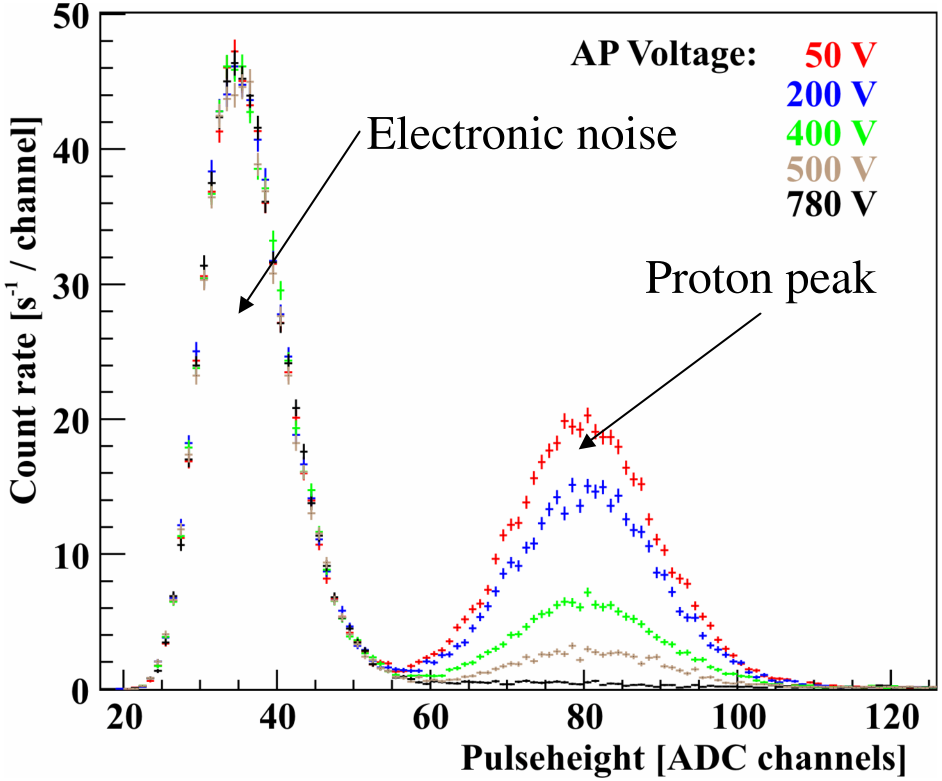




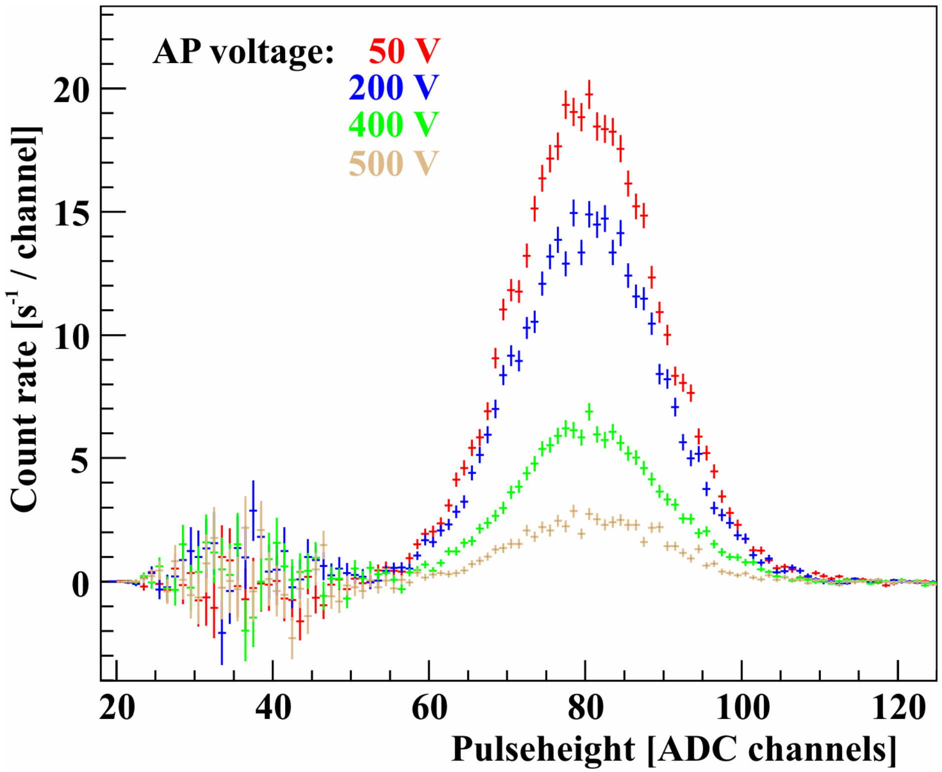


Proton Spectra

Pulse height spectrum:

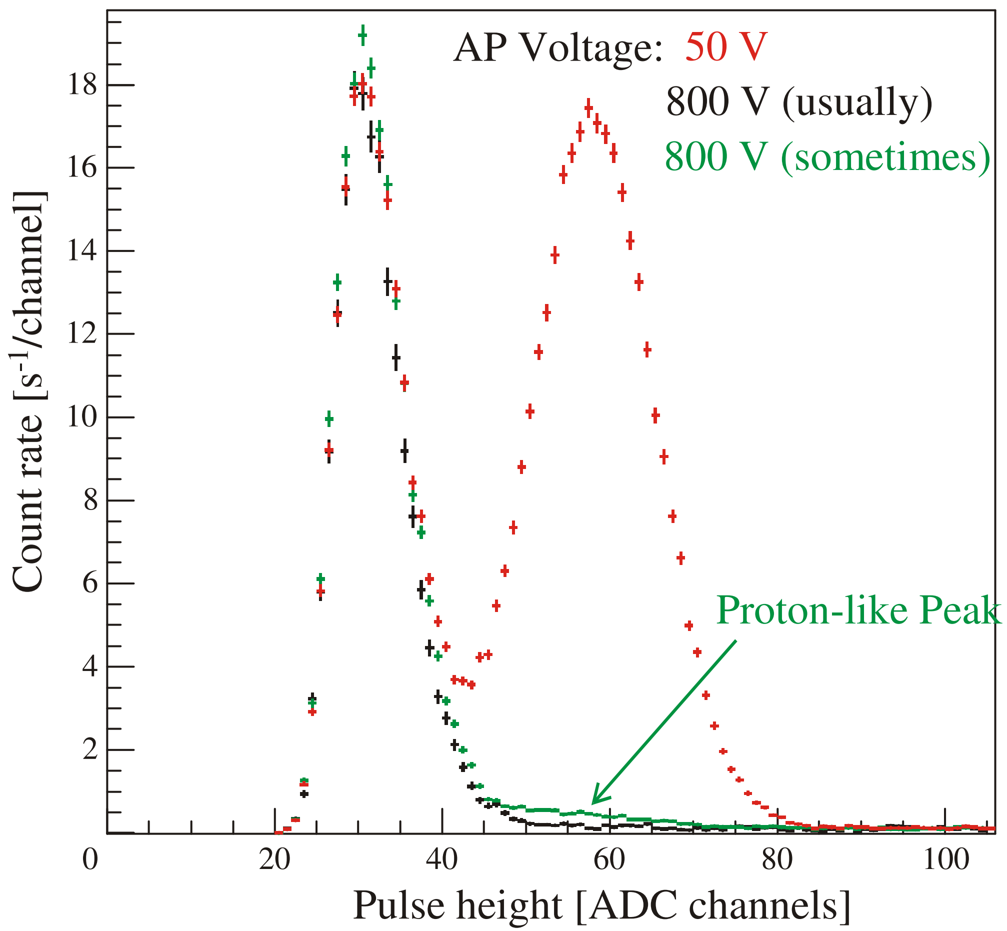


after background subtraction:



- Proton spectrum looks ok, Count rate ~ 500 Hz
- Signal to background ratio > 10:1
- Proton Signal not well separated from electronic noise

Proton Spectra

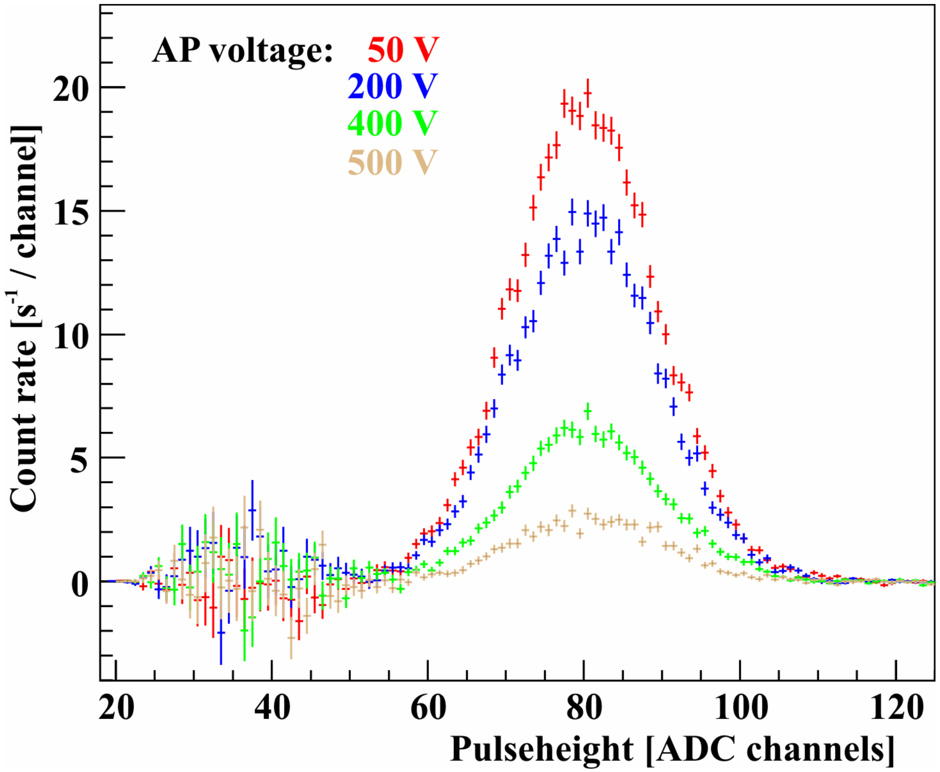


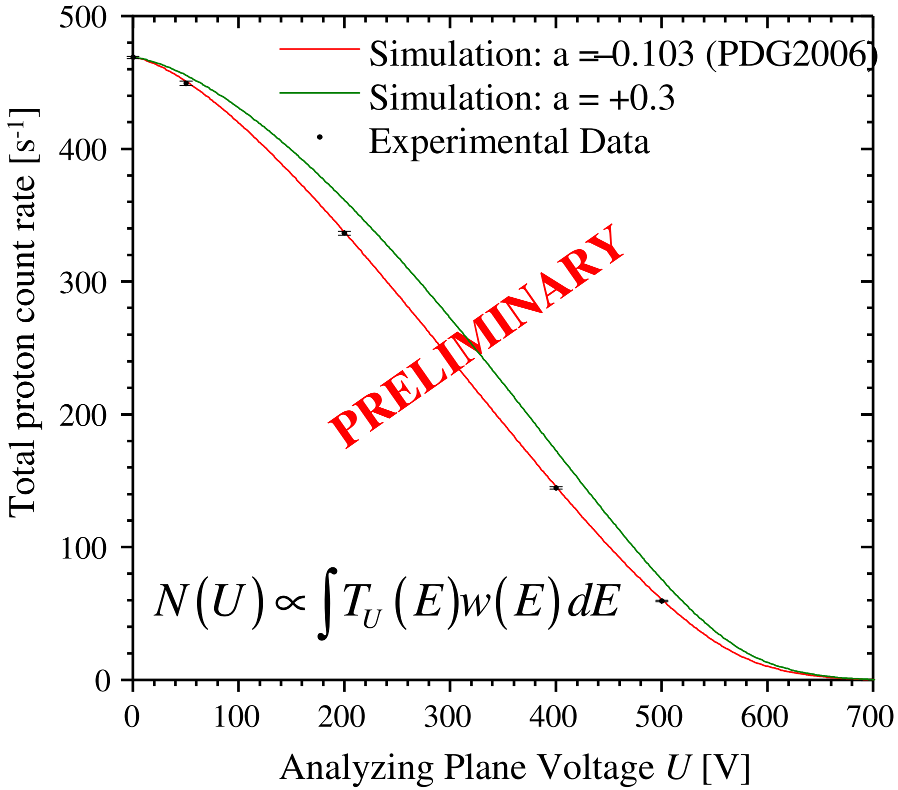
Proton-like peak:

- not stable in time
- leads to non-statistical fluctuations in the proton count rate

⇒ additional systematic uncertainty, limits our present accuracy

Extraction of *a*





- Only a short data set is shown
- Function of *a*SPECT is demonstrated

Systematic Uncertainties

- Magnetic field measurements: Accurate Field Mapping in Decay Volume and Analyzing Plane, but: Hysteresis
- Electric Potential measurements: Accurate Voltage Measurement with Multimeter, but Surface Charges and Inhomogeneities of the Work Function
- Signal to Background Ratio 10:1, Background is measured, but problems with instabilities exist.
- Test of the adiabatic approximation, not analyzed yet:

Magnetic field	100%	50%	40%	30%	20%
$\Delta a/a$	10^{-5}	4×10^{-4}	0.5%	4%	20%

- First principles calculation of effects of the rest gas

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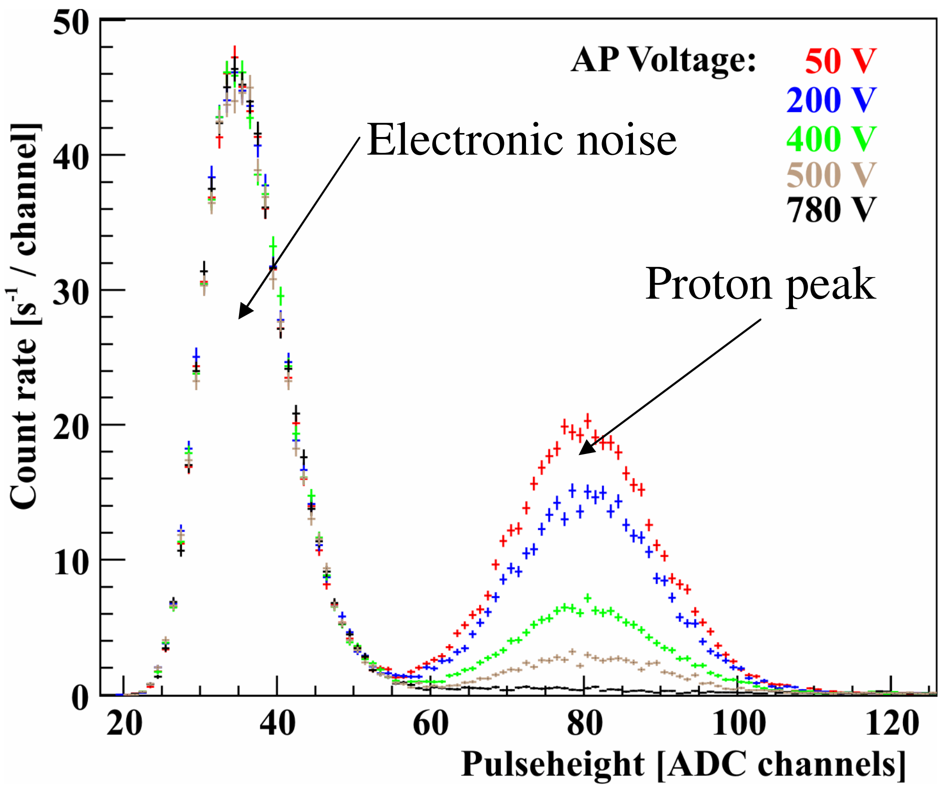
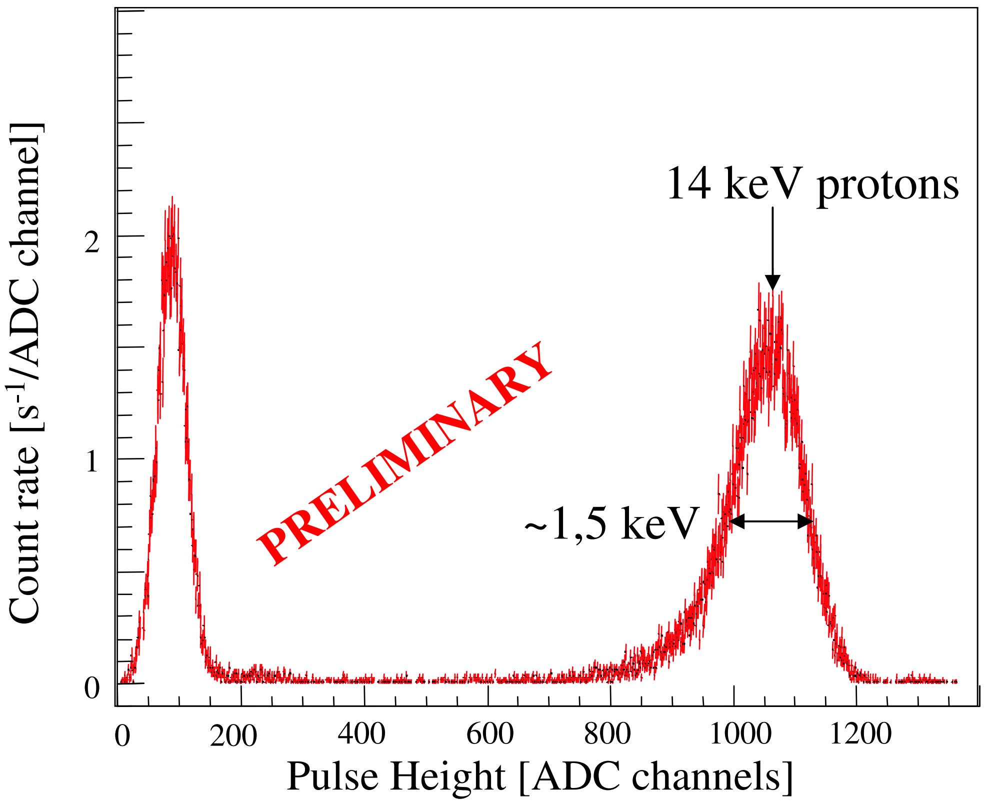
5. Improvements for *a*SPECT: New Proton Detector, Calibration Source, Kelvin Probe, Anti-Magnetic Screen
6. Further measurements

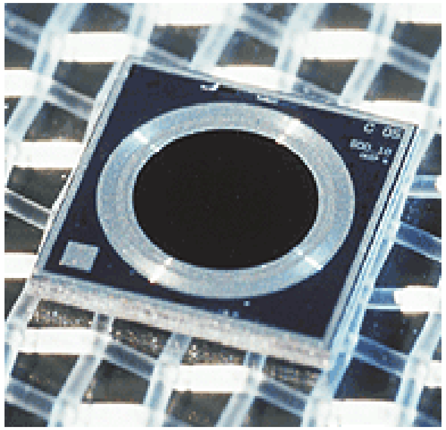
Old Proton Detector

Pulse height spectrum:



New Proton Detector

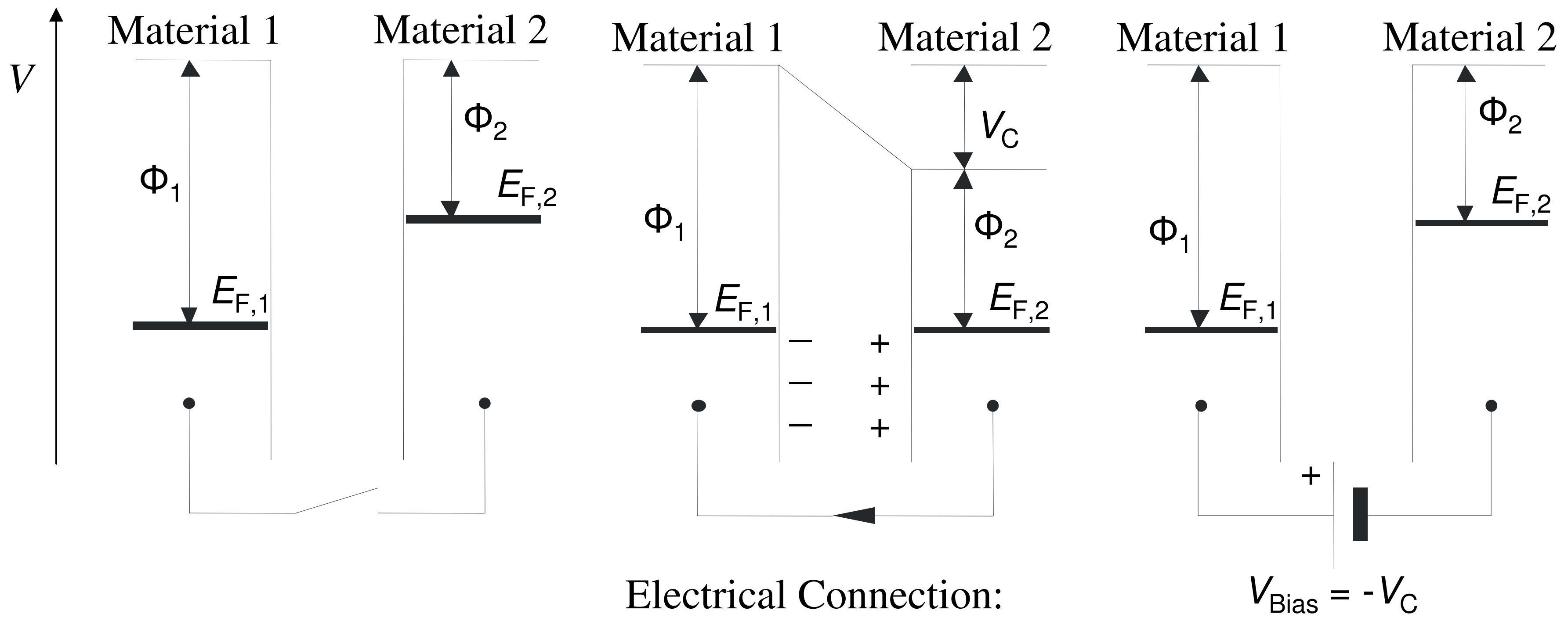




Silicon Drift Detector

- Strict separation of proton peak and electronic noise
- Lower proton energy → lower detector-HV sufficient

Kelvin Probe: Tool to measure Work Functions



2 Materials with different work functions, isolated

1st material: to be tested

2nd material: tip with known work function

Electrical Connection:

→ Charging, until Fermi levels are equal

→ External electric field

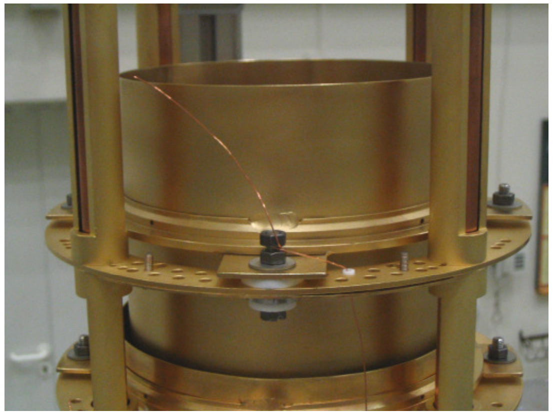
→ If Material 2 is moved: Capacitance changes, Measurable Current

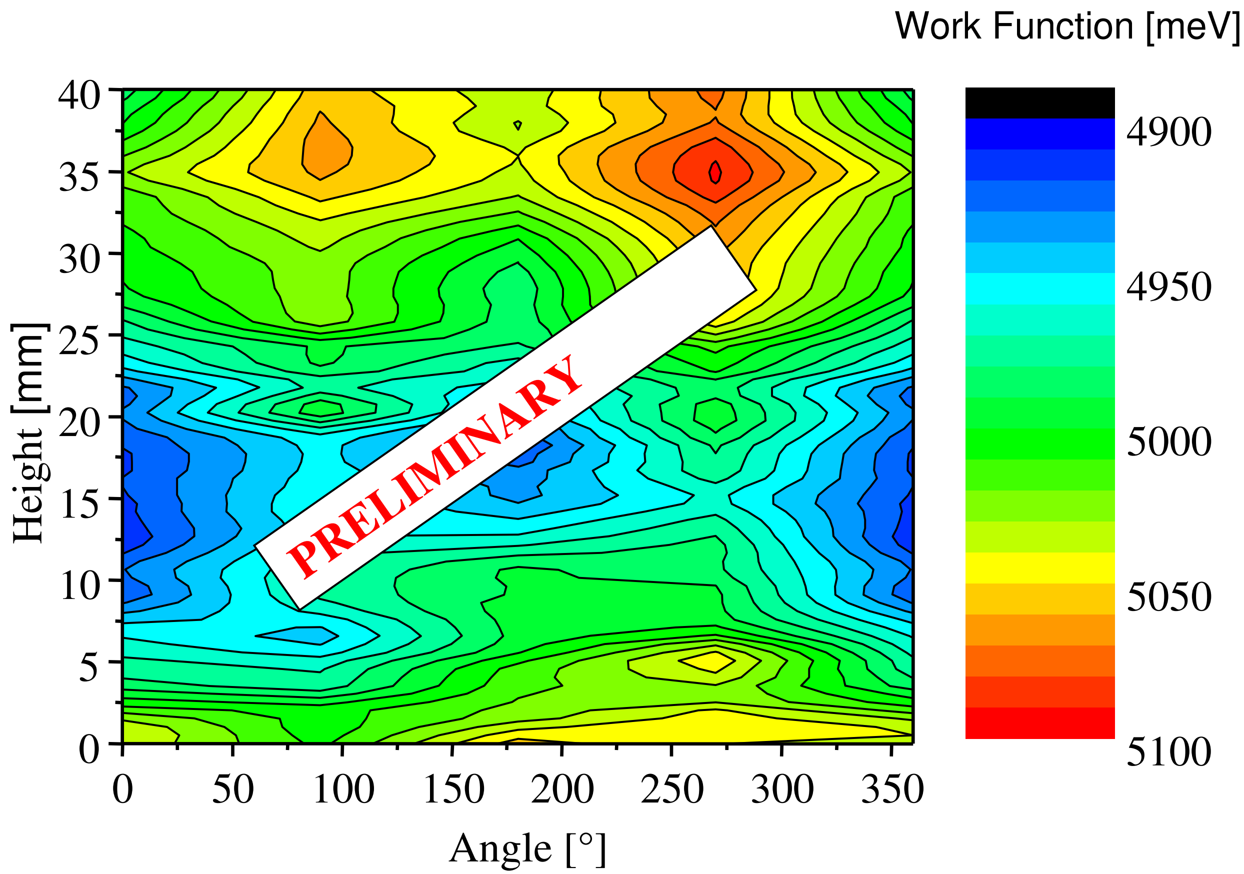
Bias Voltage

→ Charge disappears, no external electric field

→ No current if Material 2 is moved

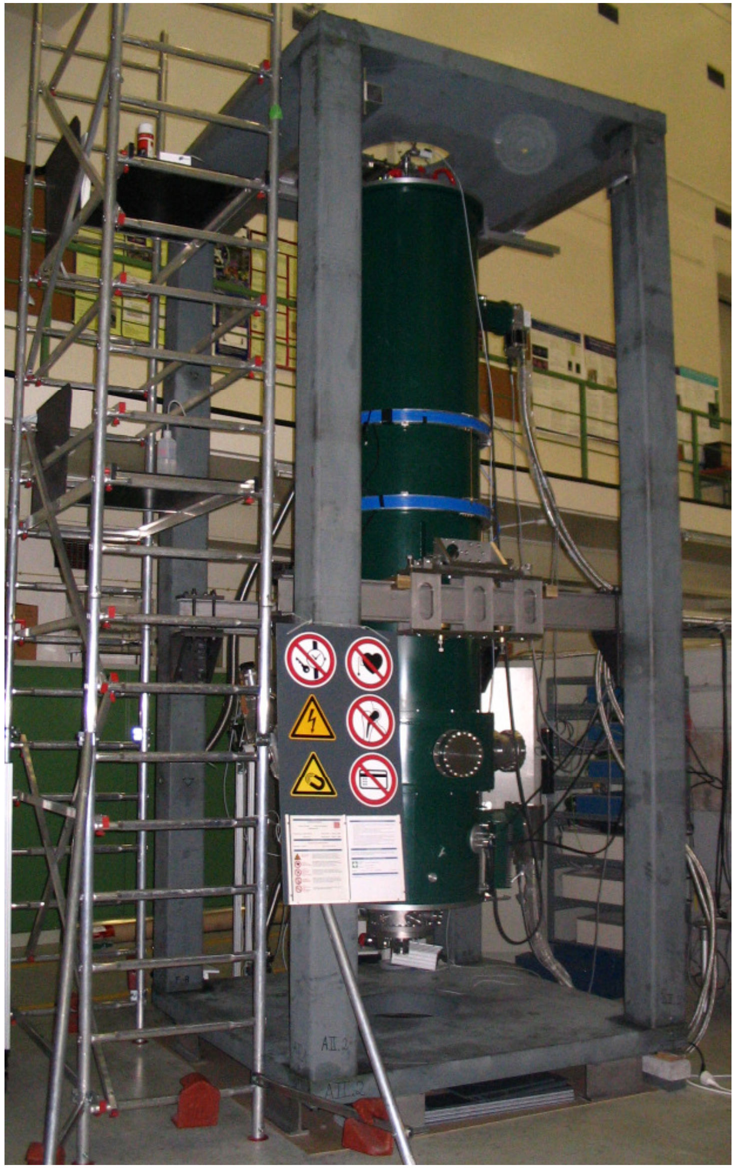
Kelvin Probe: First results



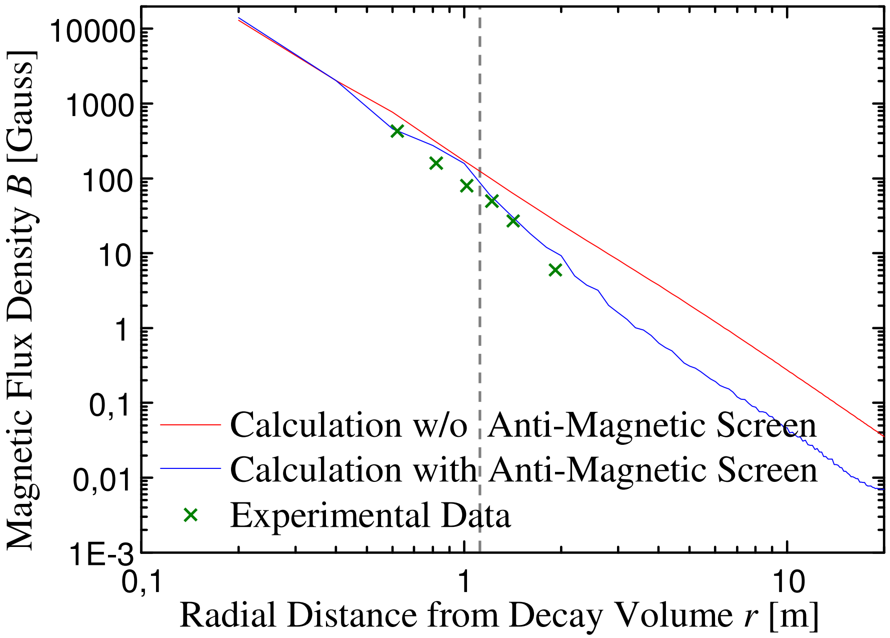


In collaboration with Prof. I. Baikie, KP Technologies

Design of an Antimagnetic Screen



Influence on the External Magnetic Field:



Influence on the Internal Magnetic Field:

- influence quite small
- the value of B_0/B_A changes

⇒ Planned: Online-monitoring of B_0/B_A with 2 static NMR probes

The *a*SPECT collaboration

- Institut für Physik, Universität Mainz, Germany:
  F. Ayala Guardia, M. Borg, L. Cabrera Brito, F. Glück, W. Heil, G. Konrad, N. Luquero Llopis, R. Muñoz Horta, M. Orlowski, Ch. Palmer, Y. Sobolev, S. B.
- Institut für Kernchemie, Universität Mainz, Germany:
  K. Eberhardt
- Physik-Department E18, TU München, Germany:
  I. Konorov, G. Petzoldt, M. Simson, H.-F. Wirth, O. Zimmer
- Forschungsneutronenquelle Heinz-Maier-Leibnitz, Garching, Germany:
  D. Rich

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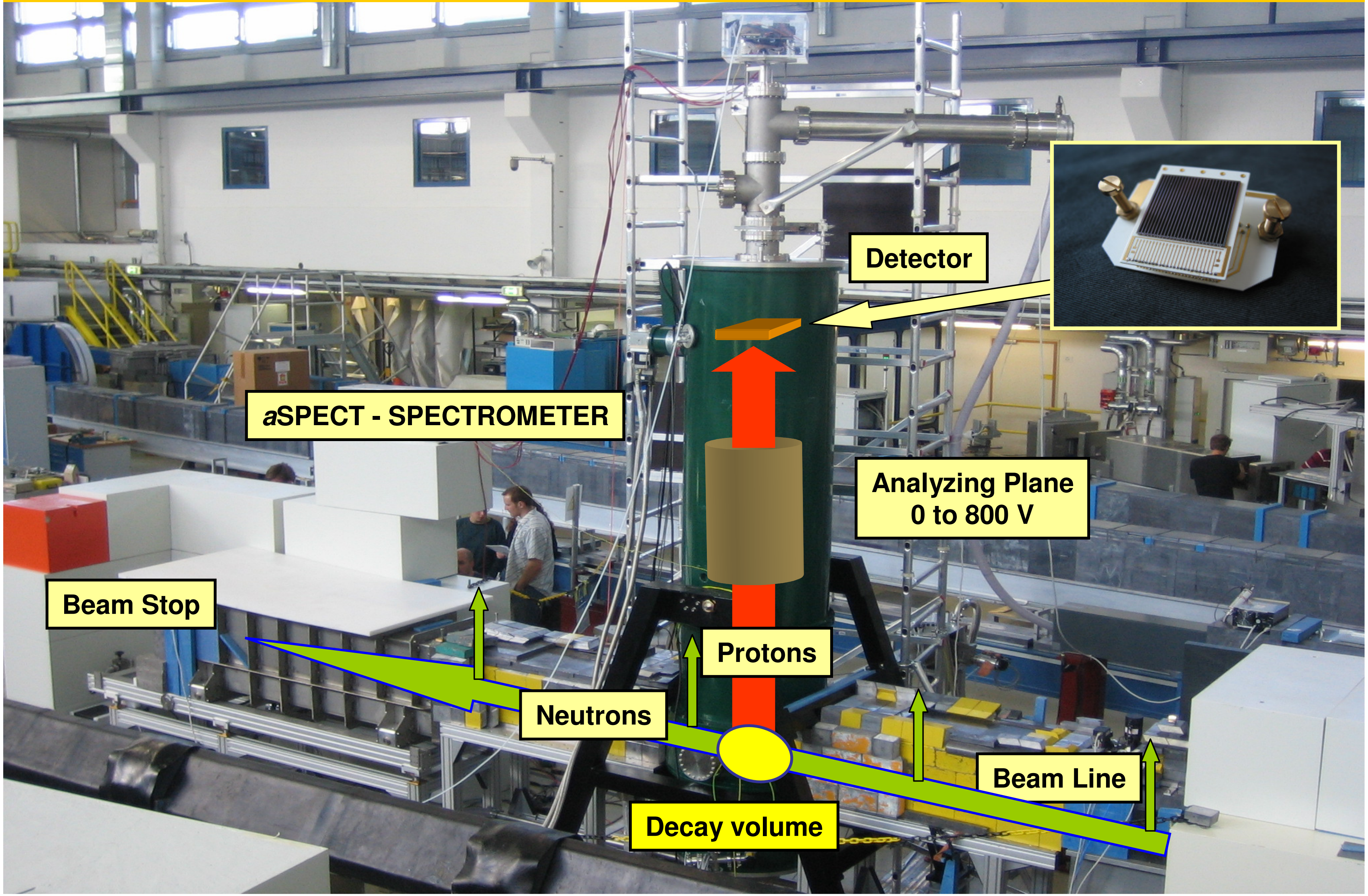
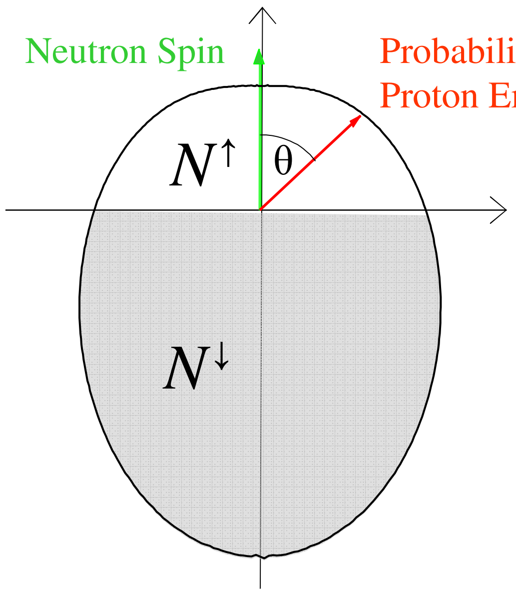
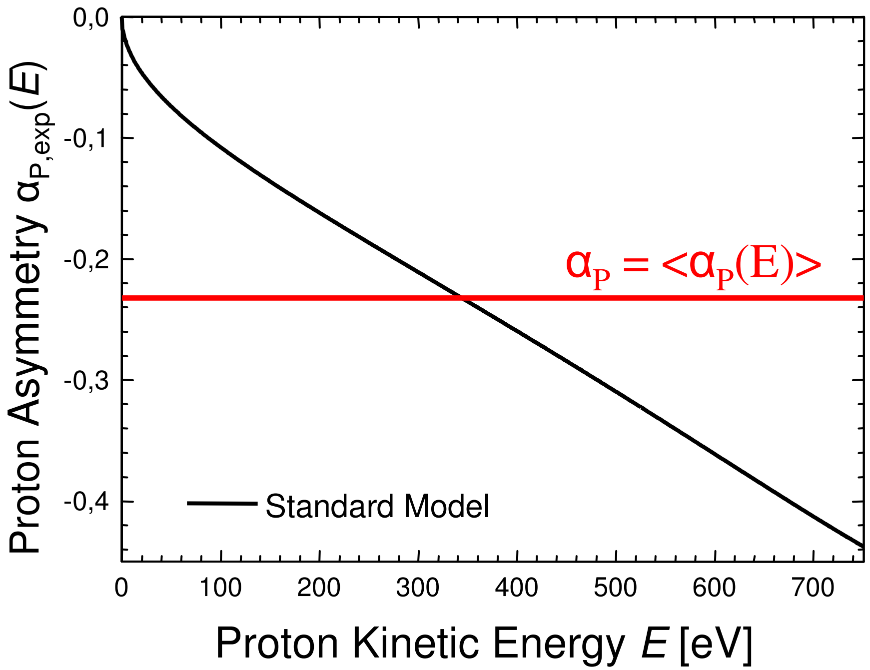
Modification to measure the Proton Asymmetry



Expected Proton Asymmetry

Angular dependence of the proton emission:



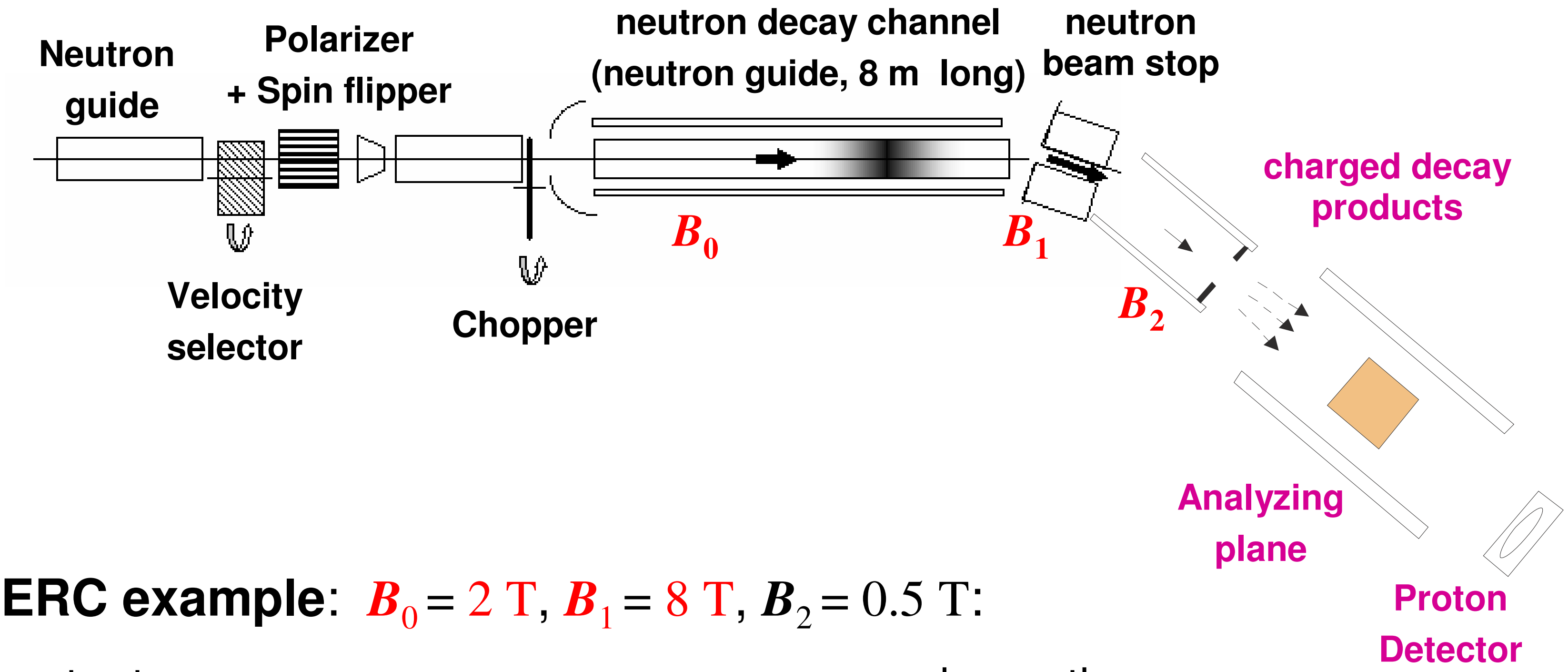


Present best (only) measurement:

(integrated over all energies)

$$\alpha_P = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} = -0.238(11)$$

The future (@ILL, FRM-2, SNS?): PERC



PERC example: $B_0 = 2$ T, $B_1 = 8$ T, $B_2 = 0.5$ T:

count rates:		beam time:
70000 s^{-1},	continuous unpolarized n-beam	½ h
14000 s^{-1},	continuous beam polarized to 98%	2 h
6000 s^{-1},	pulsed unpolarized beam	10 h
370 s^{-1},	pulsed beam polarized to 99.5%	4 d

for ~10^{-4} statistical error

Summary

• Investigation of Parity Violation is 50 years old, but still necessary

• More precision and reliability are needed with the neutron measurements

• The aim of *a*SPECT, $\Delta a/a \sim 0.3\%$, is still within reach, but there is still some way to go.

• New experiments will hopefully give new insights into Parity Violation

Thank you for your interest !!

JOHANNES GUTENBERG UNIVERSITÄT MAINZ