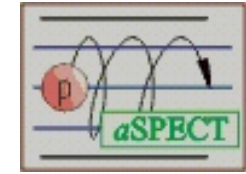


α SPECT: Measurements of Correlation Coefficients in Neutron Decay

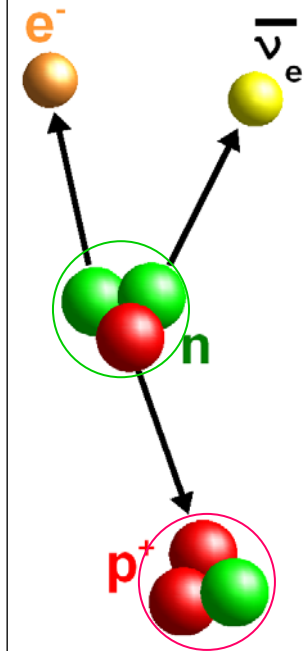
Gertrud Konrad

University of Mainz / Germany

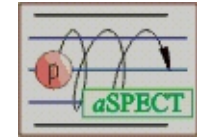
Fifth International BEYOND 2010 Conference
Cape Town, South Africa, 1 - 6, February 2010



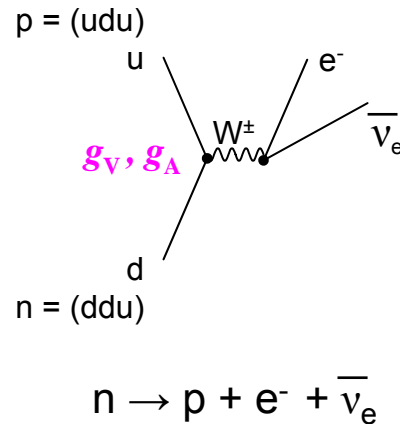
- Contributions to the Standard Model
 - Neutron Beta Decay Correlations
 - The Neutron Decay Spectrometer α SPECT
- Searches for physics beyond the Standard Model
 - Scalar and Tensor Currents
 - The Proton Asymmetry and Right-handed Currents



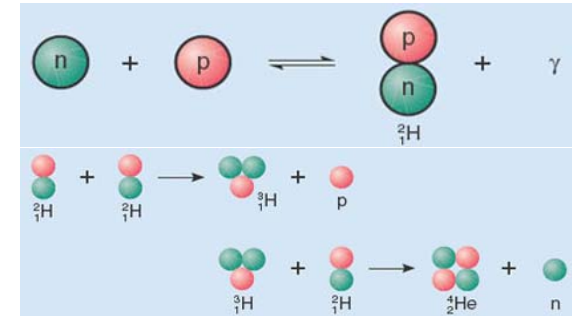
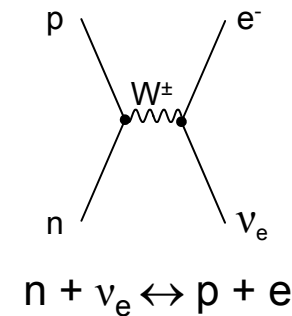
Coupling Constants of the Weak Interaction



Neutron Decay

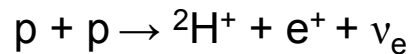
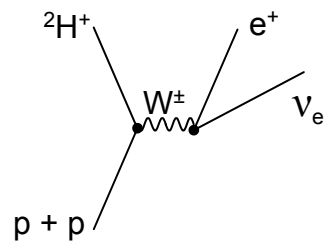


Primordial Nucleosynthesis



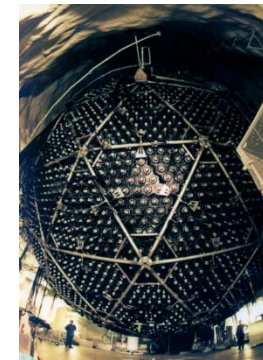
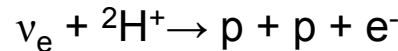
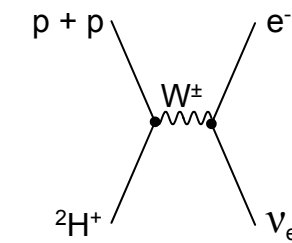
Start of Big Bang Nucleosynthesis,
Primordial ^4He abundance

Solar cycle



Start of Solar Cycle,
determines amount of Solar Neutrinos

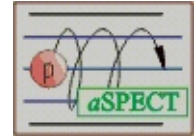
Neutrino Detection (SNO, CC)



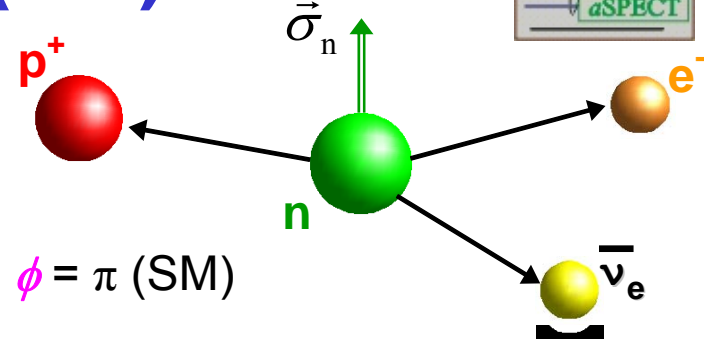
Fermi-Transitions $g_V = G_F \cdot V_{ud}$

Gamow-Teller-Transitions $g_A = G_F \cdot V_{ud} \cdot \lambda$

Neutron Decay Parameters (SM)



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



Coupling constant ratio $\lambda = |g_A/g_V| e^{i\phi}$, where phase $\phi = \pi$ (SM)

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

$$dW \propto G_F^2 V_{ud}^2 (1 + 3|\lambda|^2) \cdot \left\{ 1 + a \frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b \frac{m_e}{E_e} + \vec{\sigma}_n \cdot \left(A \frac{\vec{p}_e}{E_e} + B \frac{\vec{p}_\nu}{E_\nu} + D \frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu} \right) \right\}$$

Neutron lifetime

Neutrino-Electron Correlation

Beta-Asymmetry

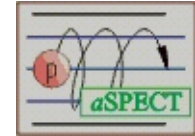
$$\tau_n^{-1} \propto G_F^2 V_{ud}^2 (1 + 3|\lambda|^2)$$

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

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

λ can be extracted from either a or $A \Rightarrow$ over-determined problem

Possible Tests of the Standard Model



- Search for Right-handed Currents
 - W_R ?
- Search for Scalar and Tensor Interactions
 - Leptoquarks? Charged Higgs Bosons?
- Search for Supersymmetric Particles
 - (Loop corrections to Beta Decay change Coupling Constants)
- Test of the **Unitarity** of the CKM-Matrix

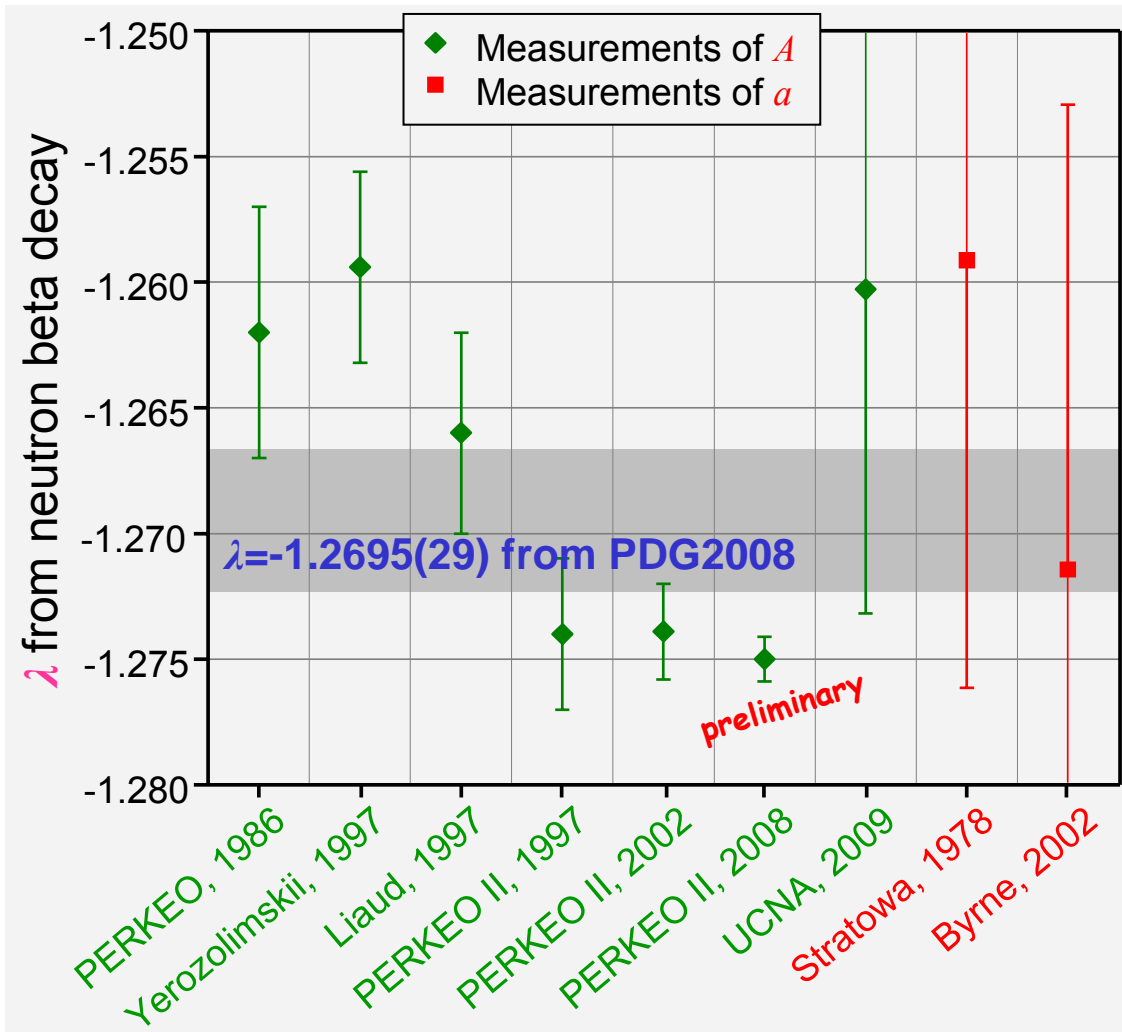
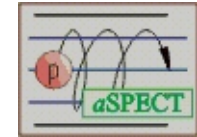
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$|V_{ud}|^2 = \frac{(4908.7 \pm 1.9) \text{s}}{\tau_n (1 + 3\lambda^2)}$$

$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$

$0^+ \rightarrow 0^+$ decays Kaon decays B/ D mesons

Determination of $\lambda = g_A / g_V$ from n decay



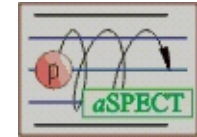
- PERKEO II is the systematically cleanest experiment
- Still the disagreement with older measurements is not explained
- A measurement of a is independent of possible unknown errors in A ; systematics are entirely different

Present best experiments have $\Delta a / a \sim 5\%$

Aim of a SPECT

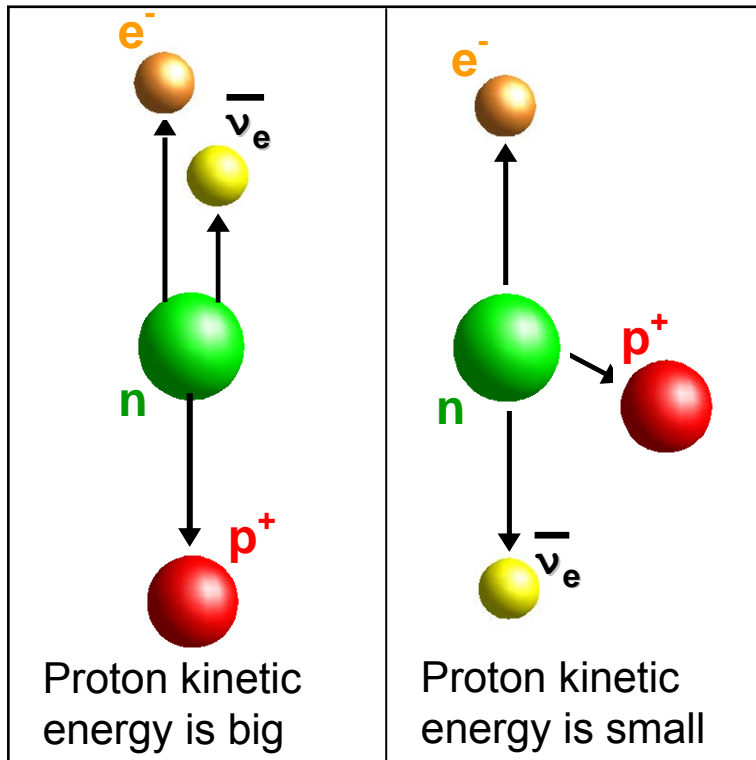
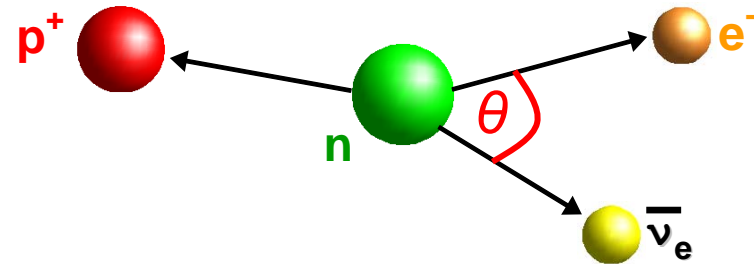
is $\Delta a / a \sim 0.3\% \hat{=} \blacksquare$

The Neutrino-Electron Correlation a and the Proton Spectrum in Neutron Decay

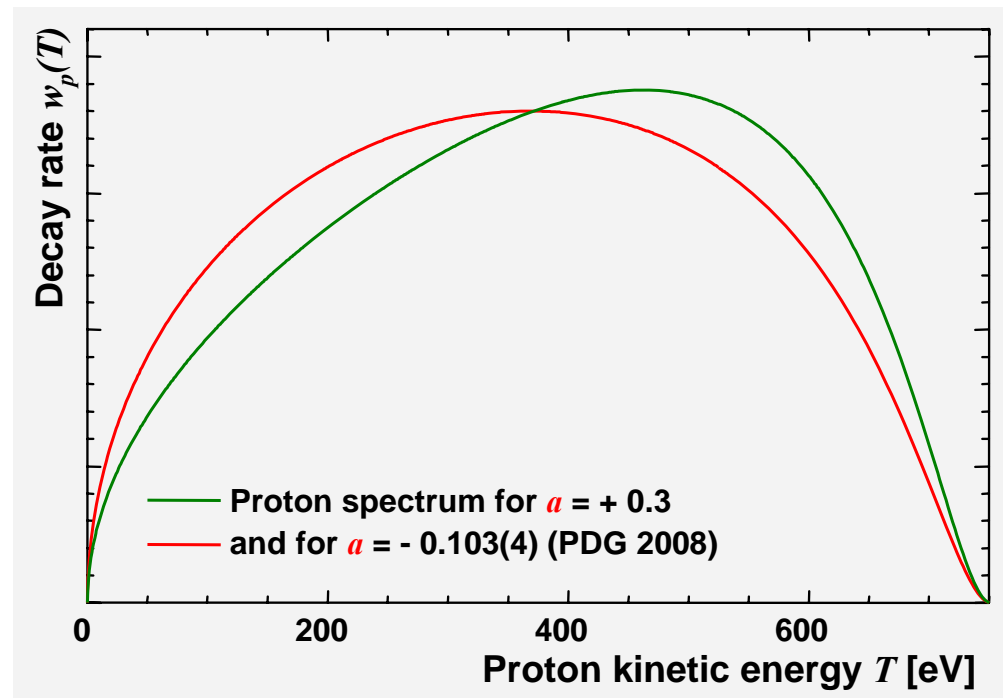


The Correlation coefficient a

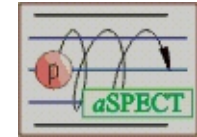
$$dW \propto \left(1 + a \frac{v_e}{c} \cos(\vec{p}_e, \vec{p}_\nu) \right)$$



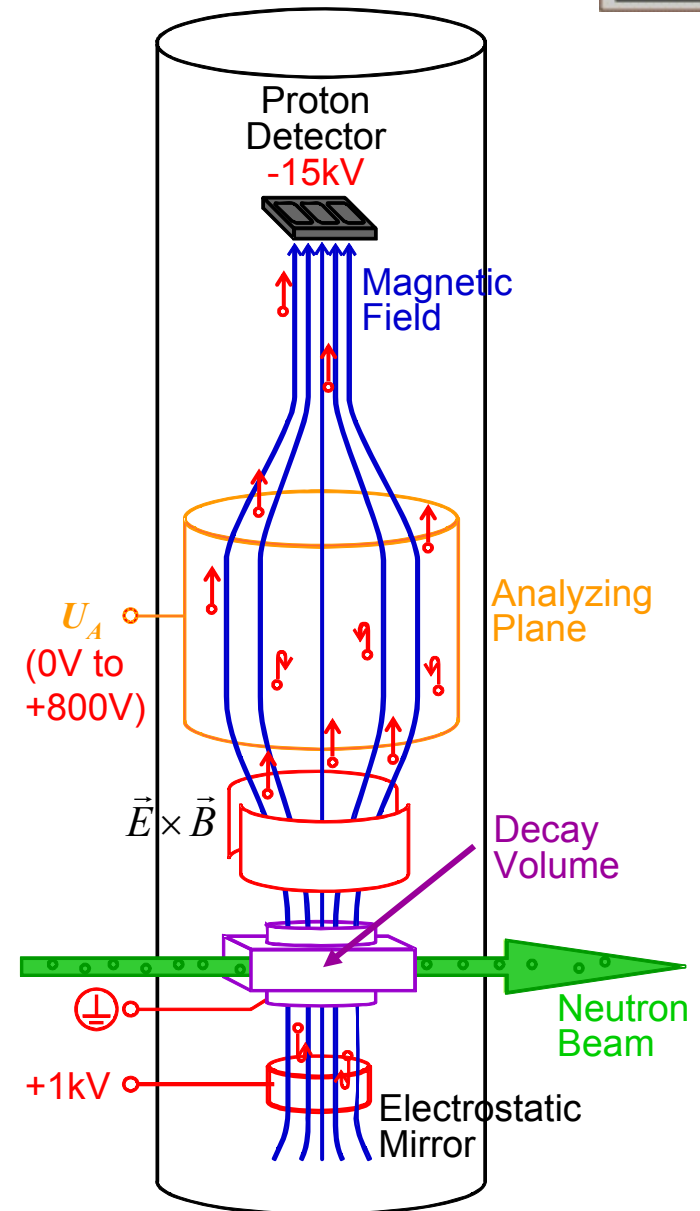
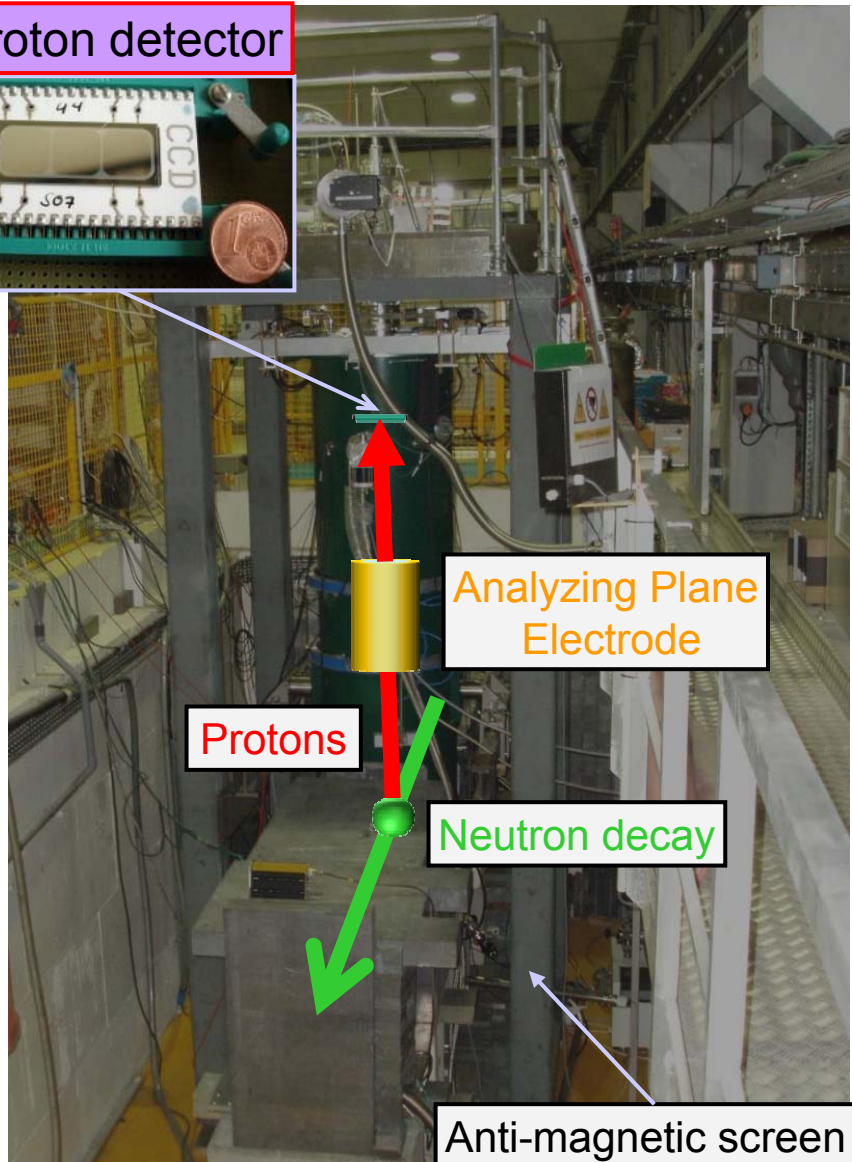
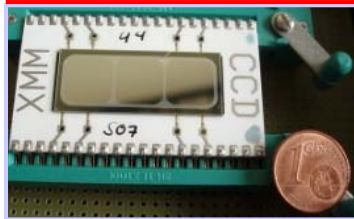
Sensitivity of the Proton Spectrum to a



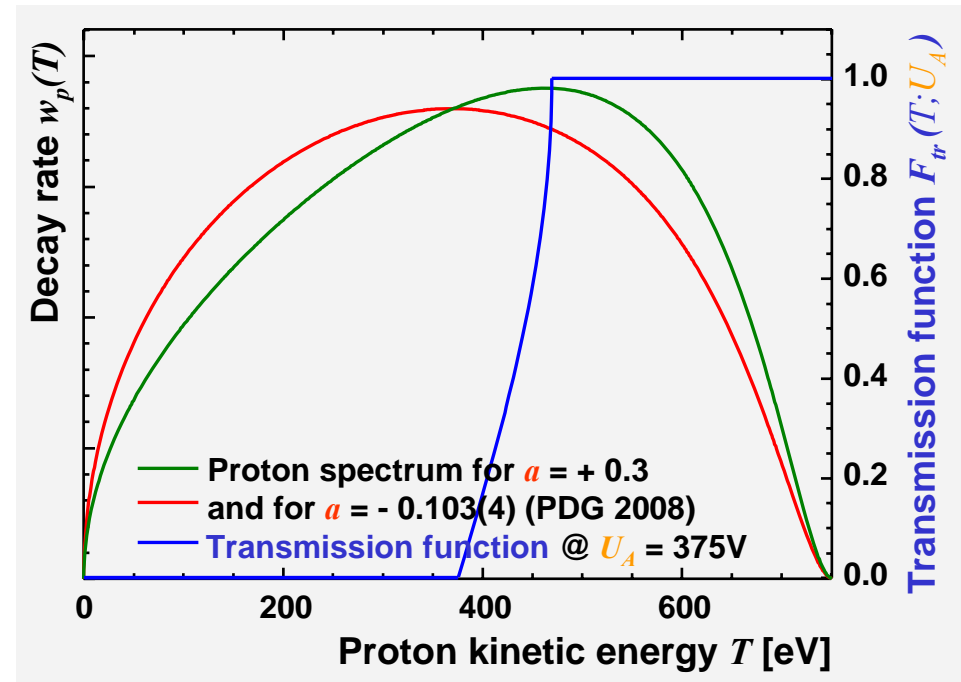
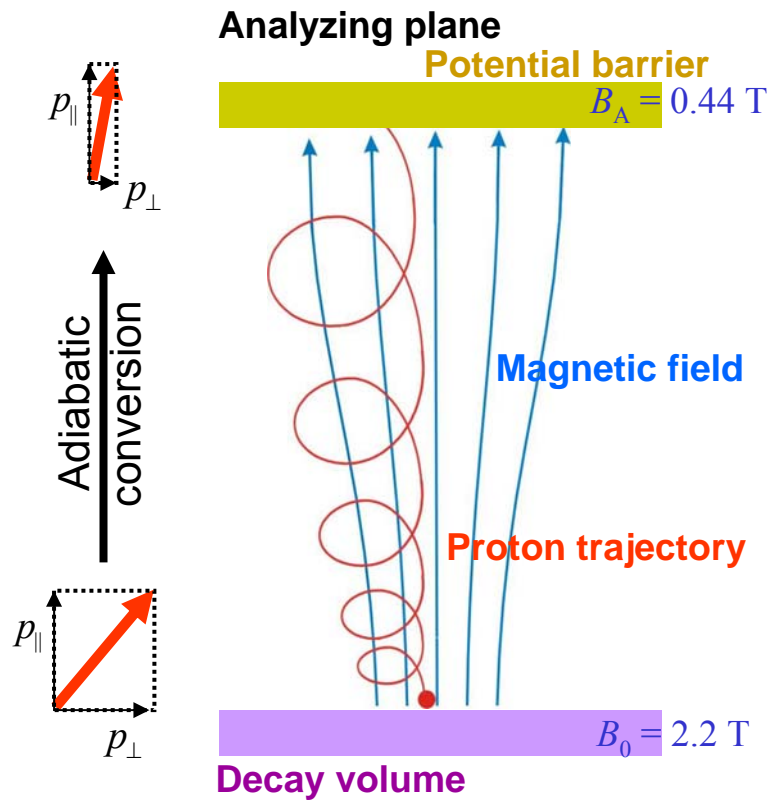
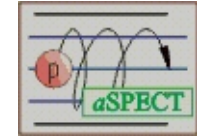
Setup of α SPECT at PF1b/ ILL and Spectrometer sketch



Proton detector



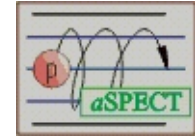
Principle of a Retardation spectrometer



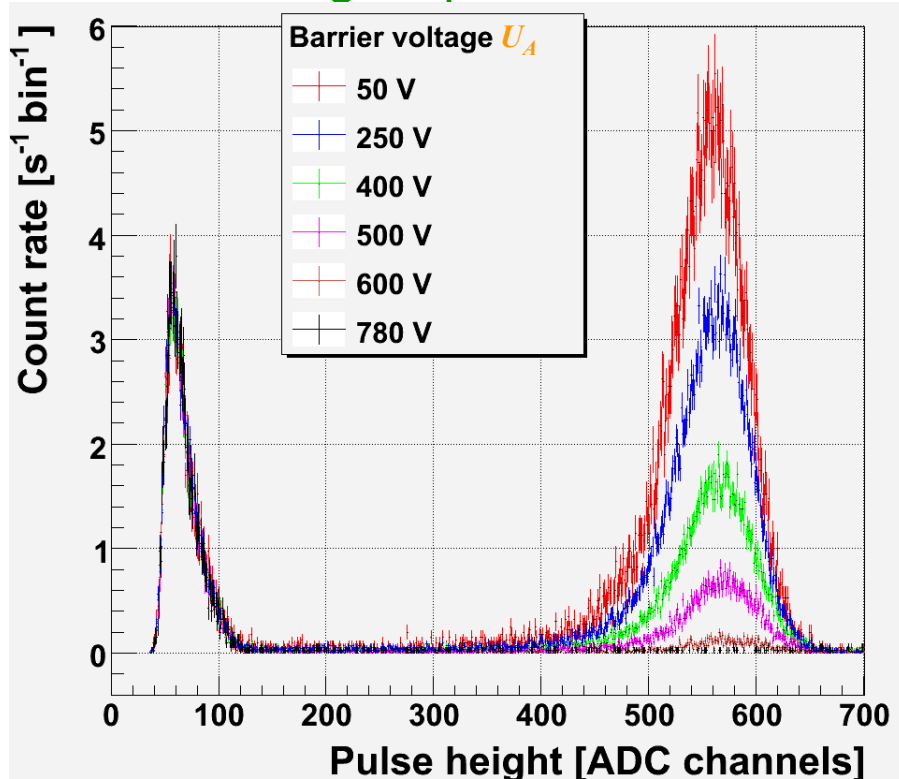
Transmission function $F_{tr}(T; U_A)$ in the **adiabatic limit**

$$F_{tr}(T; U_A) = \begin{cases} 0 & ; T < eU_A \\ 1 - \sqrt{1 - B_0/B_A (1 - eU_A/T)} & ; \text{otherwise} \\ 1 & ; T > eU_A / (1 - B_A/B_0) \end{cases}$$

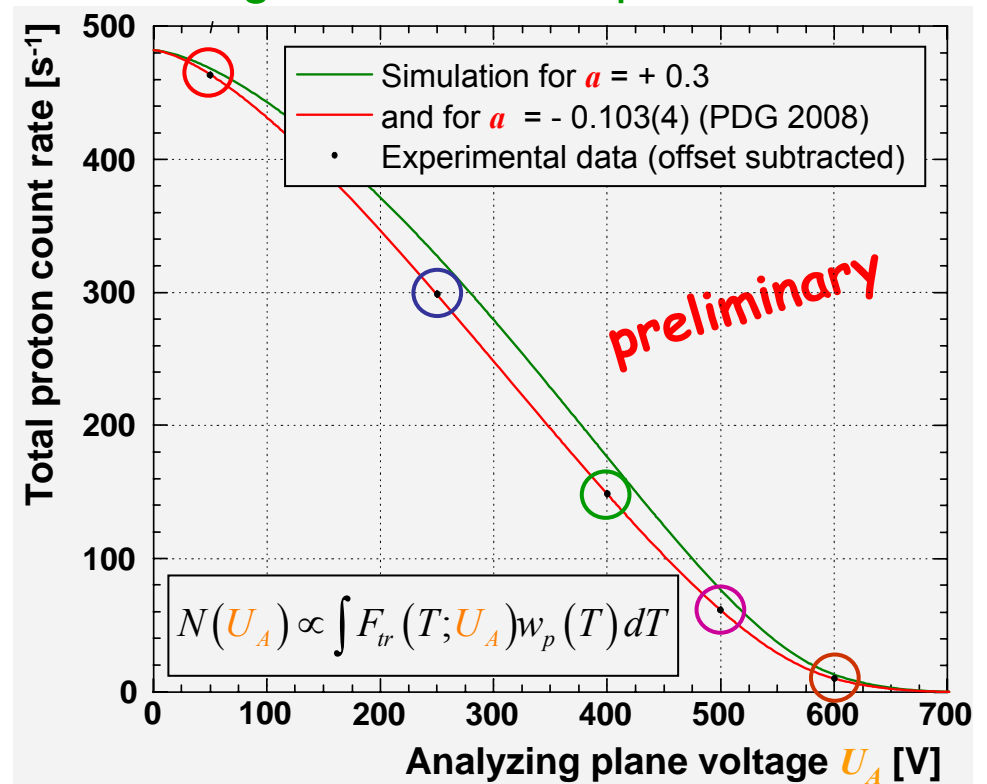
First results of 2008 beam time at ILL



Pulse height spectrum



Integrated Proton Spectrum

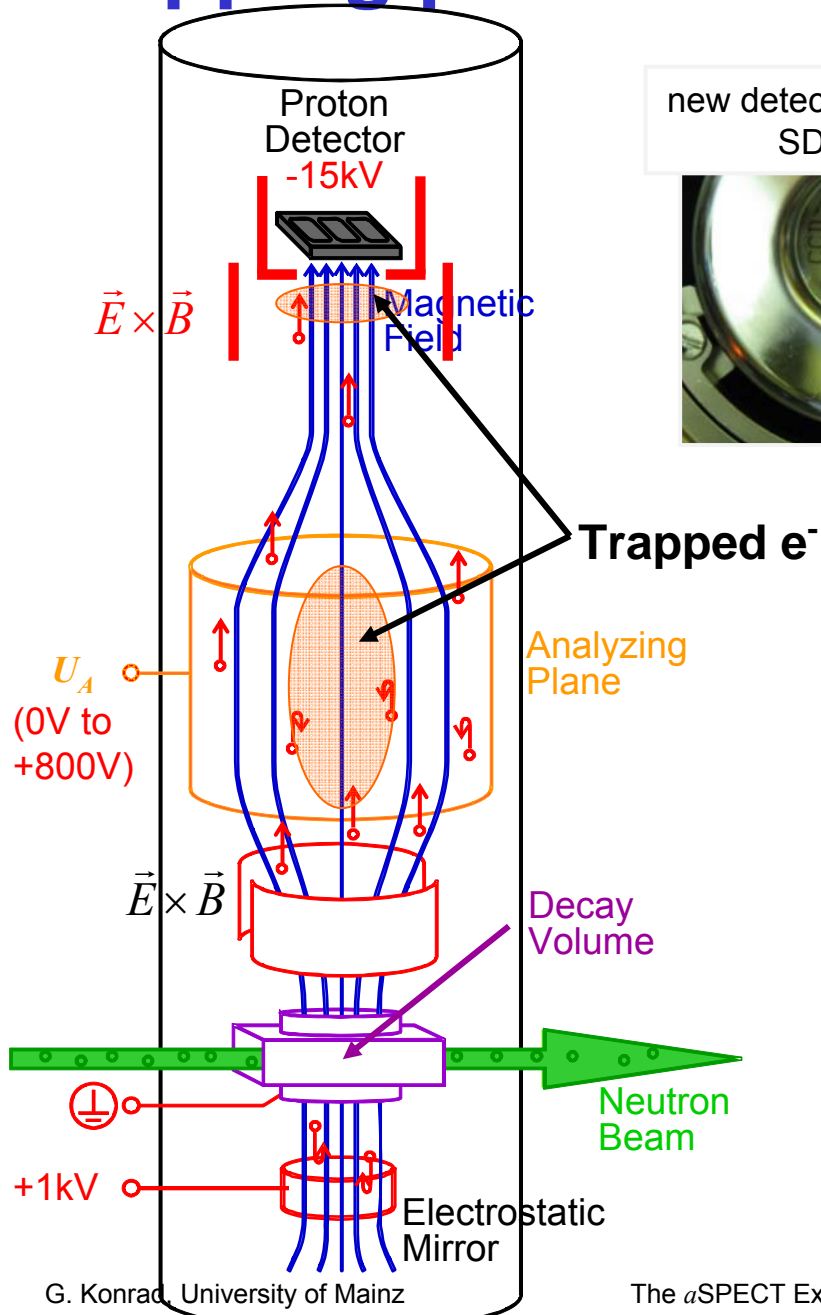
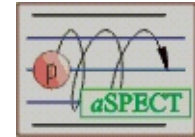


- About 470 events per second at $U_A = 50$ V (on one detector pad)
- Statistical sensitivity to a about 2 % per 24 h measurement time
- Background more stable

M. Simson *et al.*, Proceedings of the IWPPSN, Nucl. Instr. and Meth. A 611, 203 (2009), arXiv:0811.3851

G. Konrad *et al.*, Proceedings of the PANIC08, Nucl. Phys. A 827, 529c (2009)

Trapping problems reduced



new detector -HV electrode, SDD detector



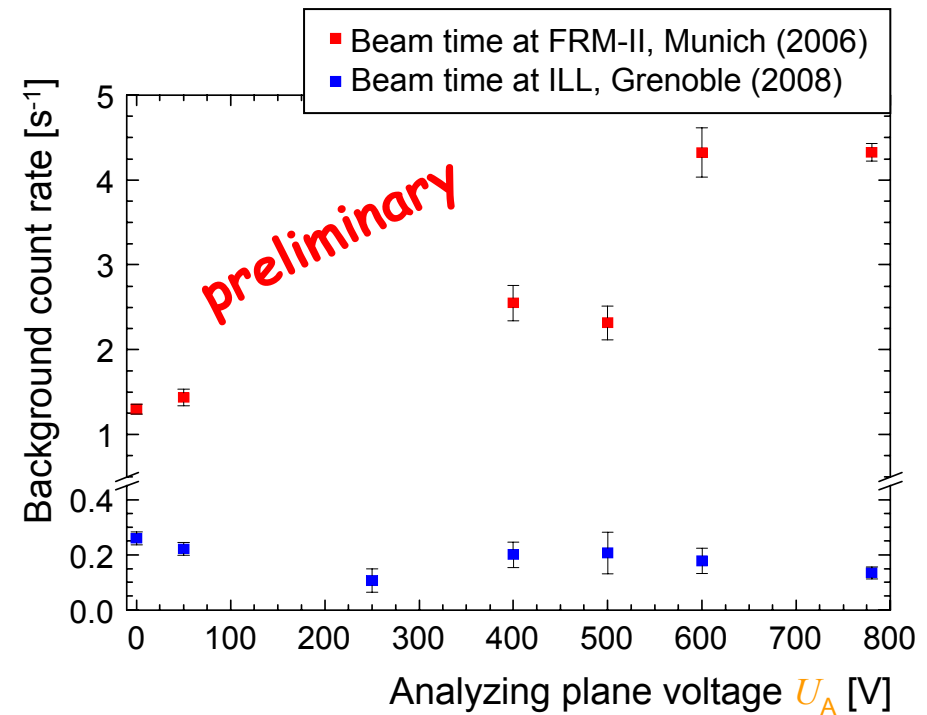
new ExB electrode



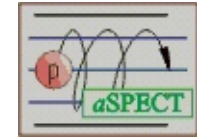
Internal getter pumps



Measurements without neutron beam



Improvements and Outlook



Present status of *a*SPECT: $(\Delta a/a)_{\text{stat}} = 2 \%$ per day

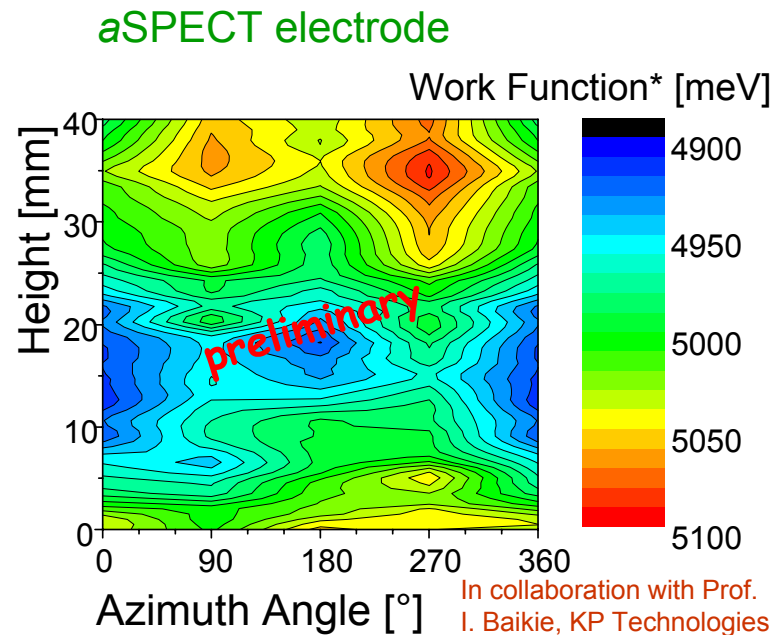
Final aim (0.3%) requires: $(\Delta B/B)_0, (\Delta B/B)_A < 10^{-4}$ and $\Delta U < 10 \text{ mV}$

1.) Online NMR



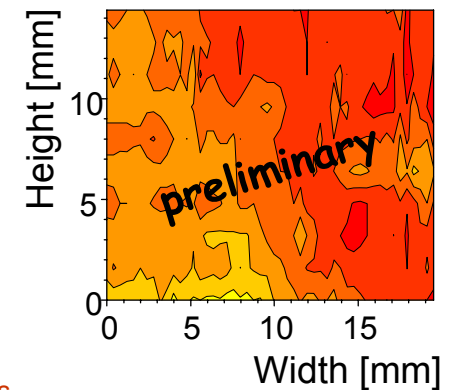
- Proof of principle with ^3He
- Accuracy better than 10^{-4}
- Field ratio stable in time

2.) Surface Voltage



Test sample

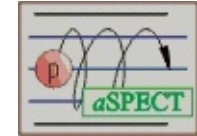
- better polishing
- better coating



*) arbitrary offset added

Possible solution: Other surface coatings, calibration

General Beta Decay Hamiltonian



$$H_{\text{if}} = \frac{2G_{\text{F}}V_{\text{ud}}}{\sqrt{2}} \sum_{j \in \{\text{V,A,S,T}\}} L_j \langle p | \Gamma_j | n \rangle \underbrace{\langle e^- | \Gamma_j \frac{1-\gamma_5}{2} | \nu_e \rangle}_{\text{Left-handed neutrino}} + R_j \langle p | \Gamma_j | n \rangle \underbrace{\langle e^- | \Gamma_j \frac{1+\gamma_5}{2} | \nu_e \rangle}_{\text{Right-handed neutrino}}$$

with operators: $\Gamma_{\text{V}} = \gamma_{\mu}$; $\Gamma_{\text{A}} = i\gamma_{\mu}\gamma_5$; $\Gamma_{\text{S}} = 1$; $\Gamma_{\text{T}} = \frac{i[\gamma_{\mu}, \gamma_{\nu}]}{2\sqrt{2}}$

Standard Model: $L_{\text{V}} = 1$; $L_{\text{A}} = \lambda$; $L_{\text{S}} = L_{\text{T}} = R_{\text{V}} = R_{\text{A}} = R_{\text{S}} = R_{\text{T}} = 0$

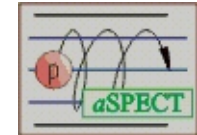
Neutron lifetime: $\tau_{\text{n}} \propto \left(\underbrace{|L_{\text{V}}|^2 + 3|L_{\text{A}}|^2}_{\text{Standard Model: } 1+3\lambda^2} + \underbrace{|L_{\text{S}}|^2 + 3|L_{\text{T}}|^2 + |R_{\text{V}}|^2 + 3|R_{\text{A}}|^2 + |R_{\text{S}}|^2 + 3|R_{\text{T}}|^2}_{\text{Standard Model: } 0} \right)$

Neutrino Electron Correlation: $a = \frac{|L_{\text{V}}|^2 - |L_{\text{A}}|^2 - |L_{\text{S}}|^2 + |L_{\text{T}}|^2 + |R_{\text{V}}|^2 - |R_{\text{A}}|^2 - |R_{\text{S}}|^2 + |R_{\text{T}}|^2}{|L_{\text{V}}|^2 + 3|L_{\text{A}}|^2 + |L_{\text{S}}|^2 + 3|L_{\text{T}}|^2 + |R_{\text{V}}|^2 + 3|R_{\text{A}}|^2 + |R_{\text{S}}|^2 + 3|R_{\text{T}}|^2}$

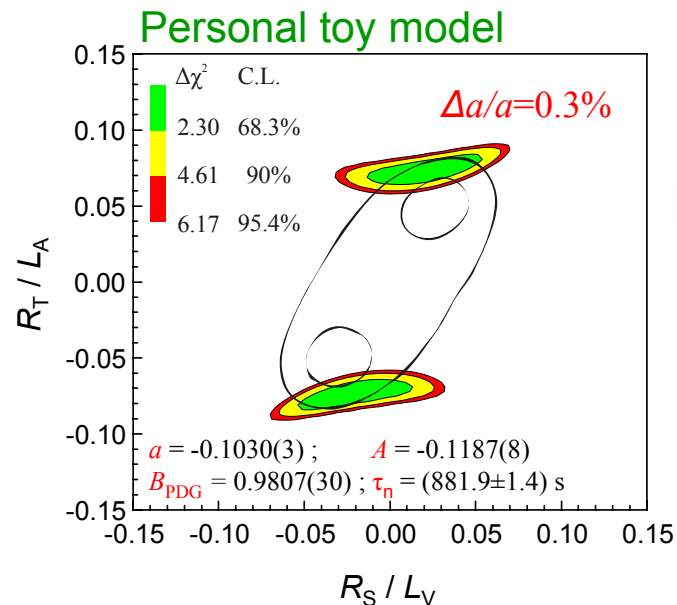
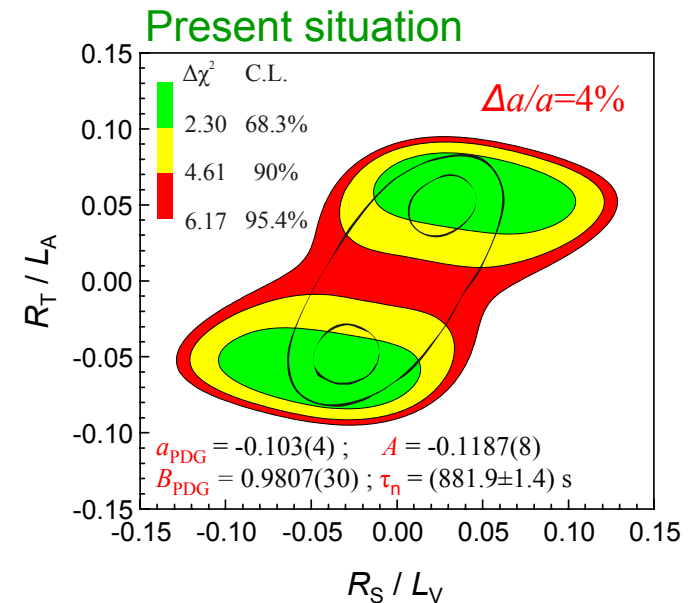
Beta Asymmetry: $A = \frac{2 \text{Re} \left(-|L_{\text{A}}|^2 - L_{\text{V}}L_{\text{A}}^* + |L_{\text{T}}|^2 + L_{\text{S}}L_{\text{T}}^* + |R_{\text{A}}|^2 + R_{\text{V}}R_{\text{A}}^* - |R_{\text{T}}|^2 - R_{\text{S}}R_{\text{T}}^* \right)}{|L_{\text{V}}|^2 + 3|L_{\text{A}}|^2 + |L_{\text{S}}|^2 + 3|L_{\text{T}}|^2 + |R_{\text{V}}|^2 + 3|R_{\text{A}}|^2 + |R_{\text{S}}|^2 + 3|R_{\text{T}}|^2}$

Glück *et al.*, NPA 593, 125 (1995), Jackson, PR 106, 517 (1957)

Search for right-handed scalar and tensor currents

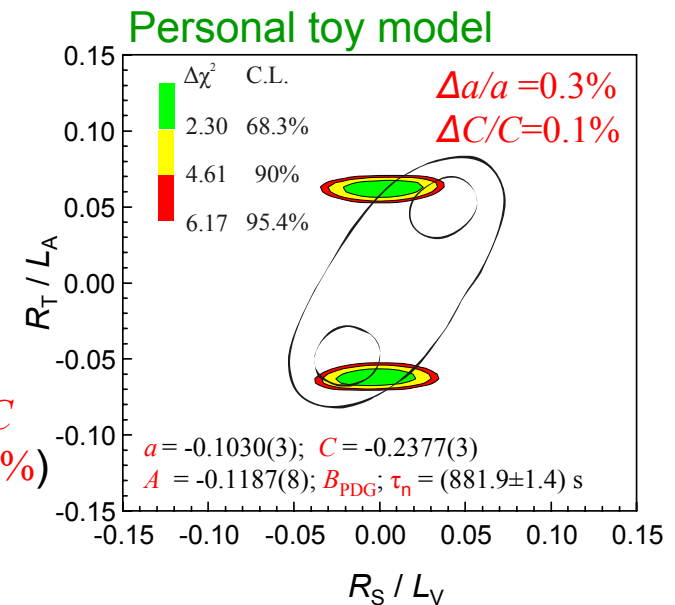


- Time reversal invariance assumed
- Limits are worse then for left-handed S-T currents. Only quadratic sensitivity of observables.
- Shown are limits from n decay (own average for A and τ_n). The black lines correspond to 1σ , 2σ from N. Severijns *et al.*, RMP78, 991 (2006)
- Limits on scalar part can best be improved with B (or “artificial” correlation C).

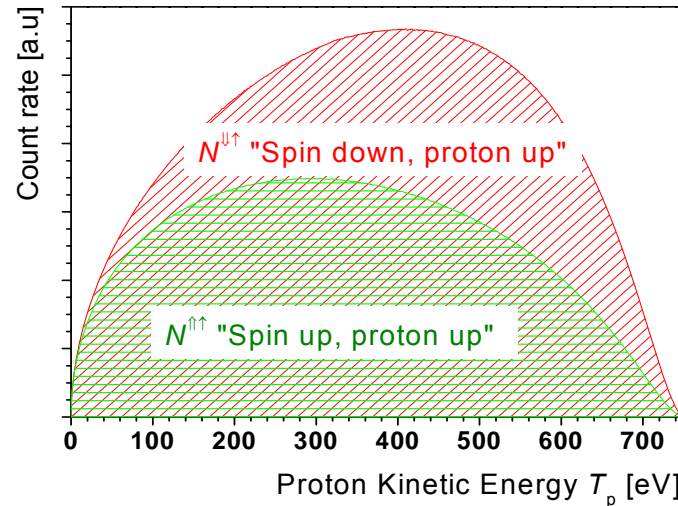
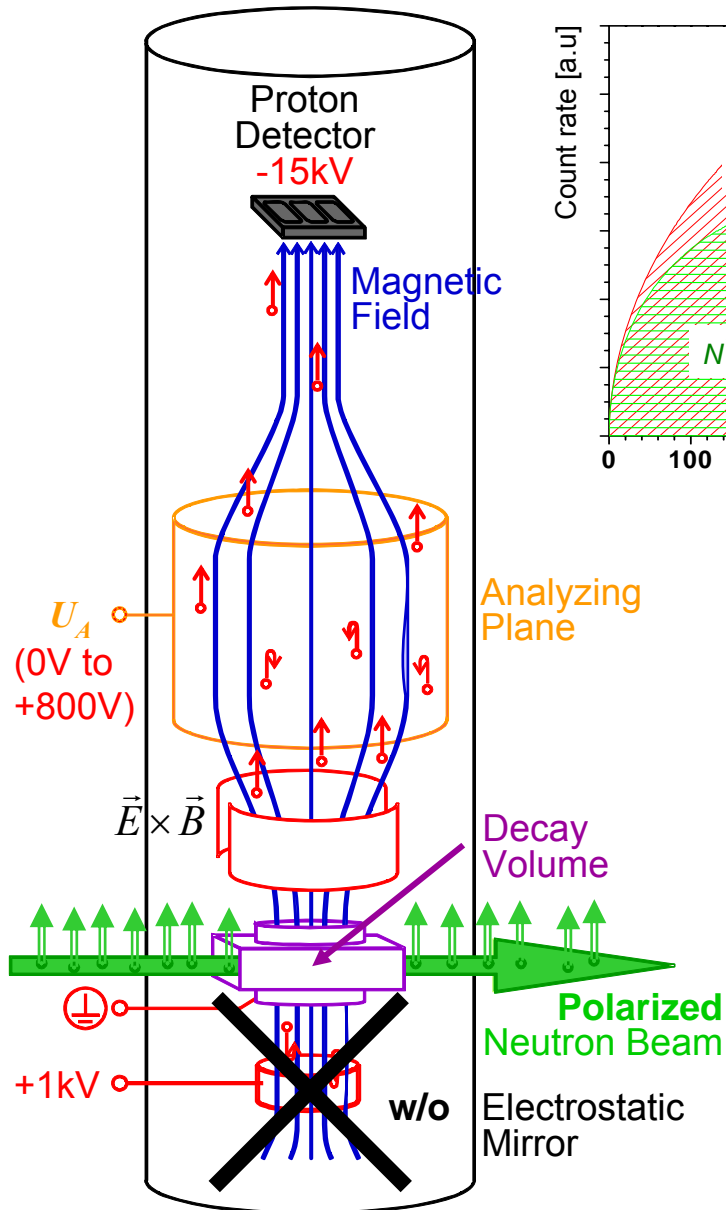
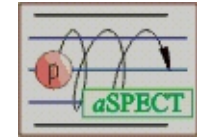


Left: Improved precision in only a

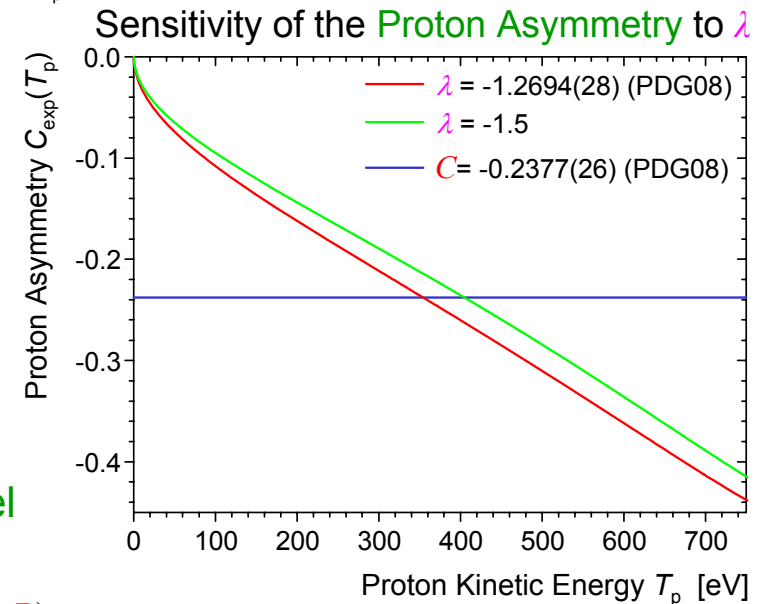
Right: Improved precision in a and C (at present $\Delta C/C = 1\%$)



The Proton Asymmetry C



$$C_{\text{exp}} = \frac{N^{\uparrow\uparrow} - N^{\downarrow\uparrow}}{N^{\uparrow\uparrow} + N^{\downarrow\uparrow}}$$



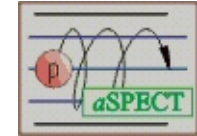
Standard Model

$$C = \int C_{\text{exp}}(T_p) dT_p$$

$$= -0.27484(A+B)$$

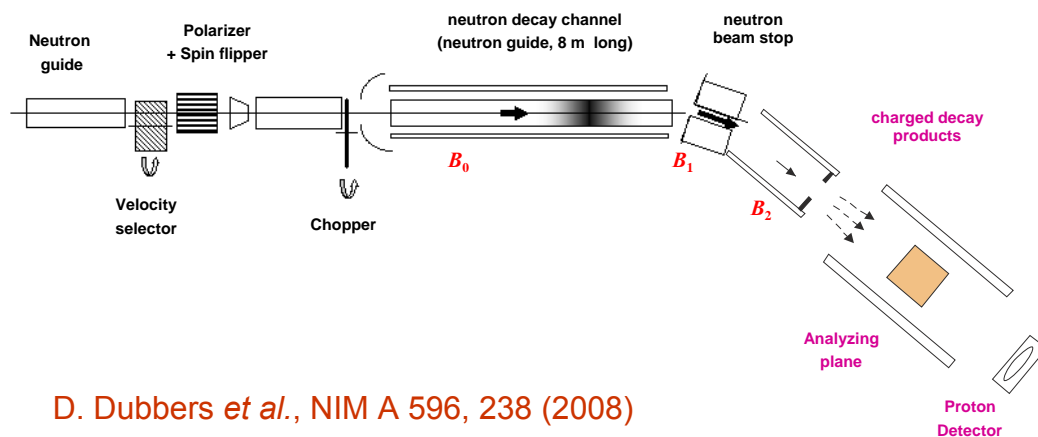
$$= -0.2377(26) \text{ M. Schumann et. al, PRL100, 151801 (2008)}$$

Search for Right-handed Currents

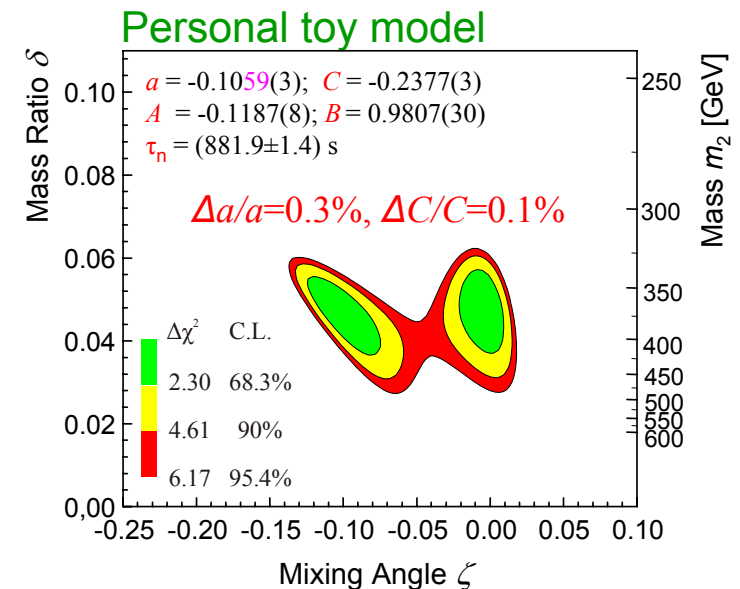
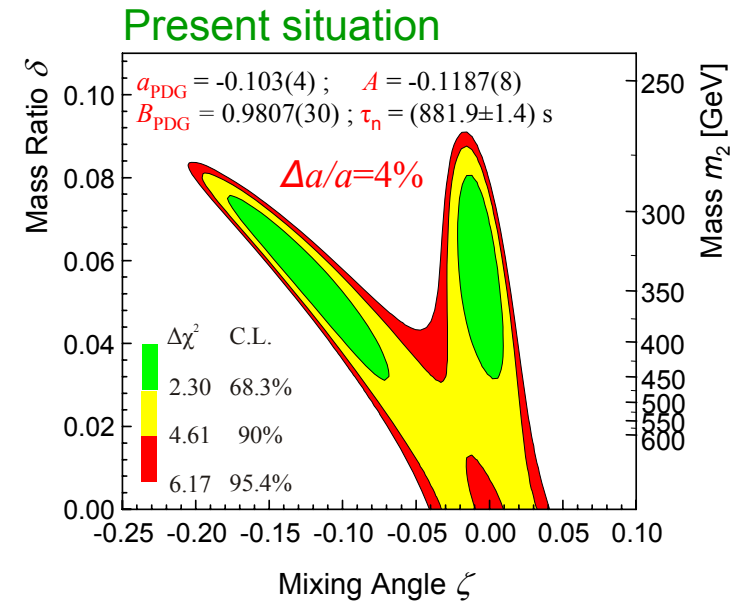


$$W_1 = \cos \zeta W_L + \sin \zeta W_R, \quad W_2 = -\sin \zeta W_L + \cos \zeta W_R$$

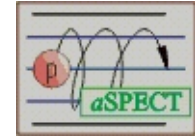
- Manifest left-right symmetric model with further parameters $\delta = m_1^2/m_2^2$ and $\lambda' = g'_A/g'_V$
- Shown are limits only from neutron decay (own average for A and τ_n)
- Complementary to High-energy limits (in more general models)
- The PERC project (at ILL or FRM-II): Increase count rates by a factor 100 compared to best experiments.



D. Dubbers *et al.*, NIM A 596, 238 (2008)



Summary



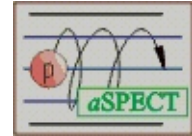
● *a*SPECT

- From our last measurement we expect a new value for *a* well below the present literature value of 5%
- A statistical accuracy of $\Delta a/a \sim 0.3\%$ can be obtained within one further beam time at ILL
- Our final goal is $\Delta C/C \sim 0.1\%$

● Neutron particle physics

- Rich experimental program with the study of neutron decay correlations
- New physics might be found with precision measurements. Maybe soon!

The *a*SPECT collaboration



- Present collaborators

F. Ayala Guardia¹, S. Baeßler², M. Borg¹, F. Glück³, W. Heil¹, I. Konorov⁴,
K.K.H. Leung^{4,5}, R. Muñoz Horta¹, B. Ostrick¹, M. Simson^{4,5}, Y. Sobolev¹,
T. Soldner^{4,5}, H.-F. Wirth⁶, O. Zimmer^{4,5}, G. K.¹

¹*University of Mainz, Germany*

²*University of Virginia, USA*

³*University of Karlsruhe, Germany*

⁴*TU Munich, Germany*

⁵*ILL Grenoble, France*

⁶*LMU Munich, Germany*

- Thanks to our past collaborators

H. Angerer⁴, J. Byrne⁷, K. Eberhardt¹, M. van der Grinten⁷, M. Orlowski¹,
G. Petzoldt⁴, D. Rich^{8,†}

⁷*University of Sussex, UK*

⁸*FRM-II Garching, Germany*

Thank you for your interest!