Measurement of the Fierz interference term with PERKEO III

Karina Bernert

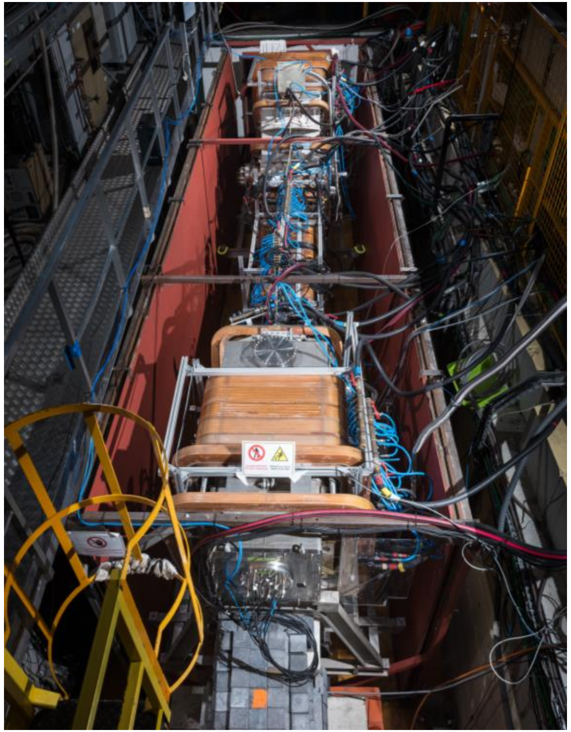
Technical University of Munich

Physics Department

Particle Physics at Low Energy

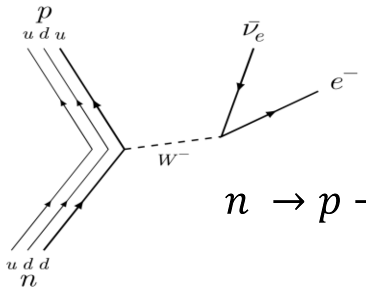
Joint ESS ILL User Meeting

Lund, 7th of October 2022



PERKEO III at PF1b

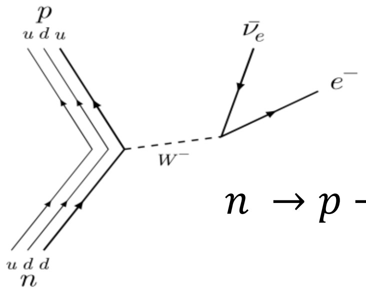
Search for BSM physics with neutron decay



$$n \rightarrow p + e^- + \bar{\nu}_e$$

Testing the Standard Model with
high precision spectroscopy

Search for BSM physics with neutron decay



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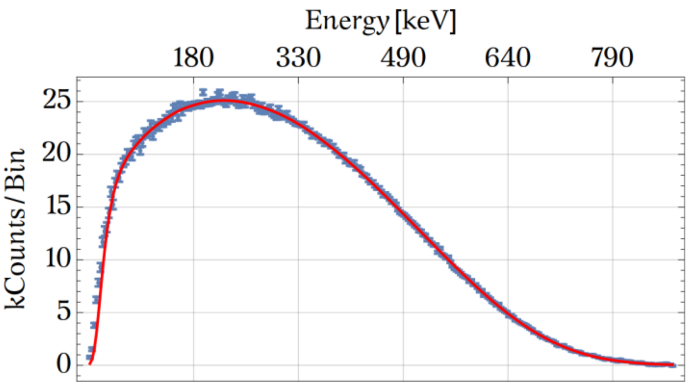
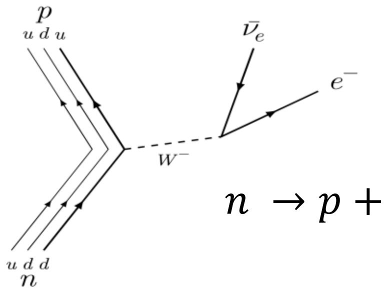


PhD Thesis C. Roick 2018

Search for BSM physics with neutron decay



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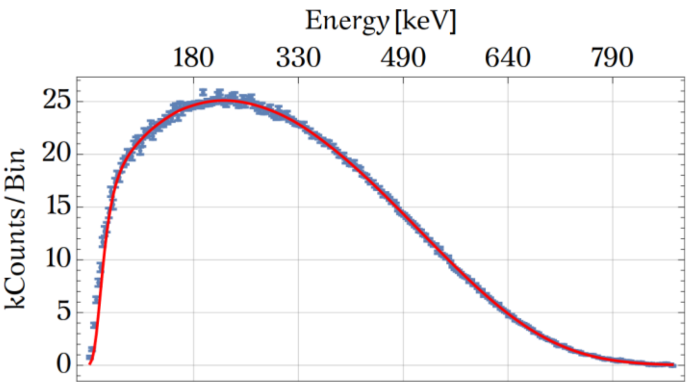
Testing the Standard Model with high precision spectroscopy

Differential decay width can be described in terms of several correlation coefficients: [JTW57]

$$d\Gamma_n \propto \rho(E_e)\left(1 + b\frac{m_e}{E_e} + a\frac{\overrightarrow{p_e}\cdot\overrightarrow{p_\nu}}{E_e E_\nu} + \hat{s}_n \cdot \left[A\frac{\overrightarrow{p_e}}{E_e} + B\frac{\overrightarrow{p_\nu}}{E_\nu} + D\frac{\overrightarrow{p_e}\times\overrightarrow{p_\nu}}{E_e E_\nu}\right]\right)$$



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[JTW57]: Jackson, Treiman, Wyld (1957). Possible Tests of Time Reversal Invariance in Beta Decay

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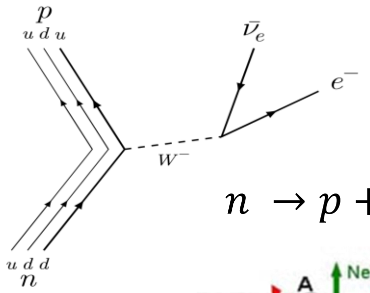

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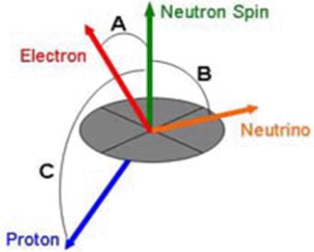
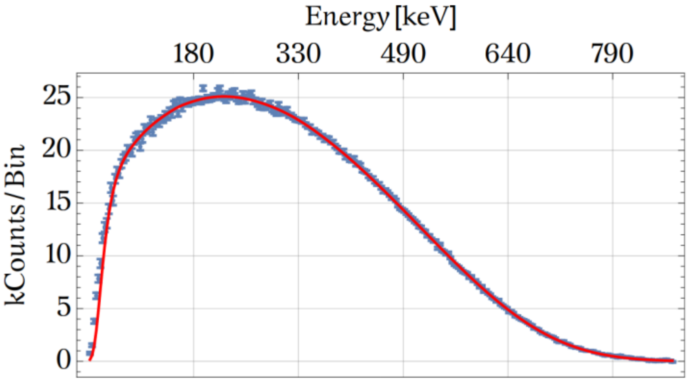


a	Electron Neutrino Angular Correlation
b	Fierz Interference Term
A	Beta Asymmetry
B	Neutrino Asymmetry
C	Proton Asymmetry
D	Triple Correlation Coefficient

Coefficients are either 0 or depend on $\lambda = {}^{g_A}/{}_{g_V}$ within SM



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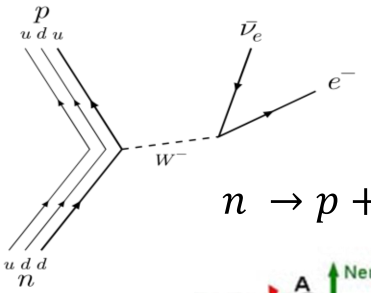

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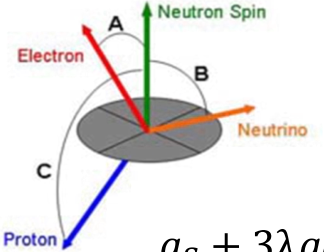

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$$b \cong \frac{g_S g_V + 3 g_A g_T}{g_V^2 + g_S^2 + 3(g_A^2 + g_T^2)} \cong 2\frac{g_S + 3\lambda g_T}{1 + 3\lambda^2}$$

- There are no scalar or tensor interactions in SM

  $\rightarrow g_S = g_T = 0 \rightarrow b = 0$
- But if we measure $b \neq 0$

  $\rightarrow g_S \neq 0$ or $g_T \neq 0$

→ New physics

[JTW57]: Jackson, Treiman, Wyld (1957). Possible Tests of Time Reversal Invariance in Beta Decay

Two ways to get the Fierz term b

$$d\Gamma_n \propto \rho(E_e)\left(1 + b\frac{m_e}{E_e} + a\frac{\overrightarrow{p_e}\cdot\overrightarrow{p_\nu}}{E_e E_\nu} + \hat{s}_n \cdot \left[A\frac{\overrightarrow{p_e}}{E_e} + B\frac{\overrightarrow{p_\nu}}{E_\nu} + D\frac{\overrightarrow{p_e}\times\overrightarrow{p_\nu}}{E_e E_\nu}\right]\right)$$

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1st Method: using polarized neutrons

Combined fit of b and electron asymmetry A

$$A_{\text{exp}}(E_e) = \frac{N^\uparrow(E_e) - N^\downarrow(E_e)}{N^\uparrow(E_e) + N^\downarrow(E_e)} = \frac{1}{2}A(\lambda)P_n\beta(E_e)$$

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Statistical sensitivity, background contributions, and detector resolution affect the parameter correlations between λ and b

→ Statistical uncertainty dominates!

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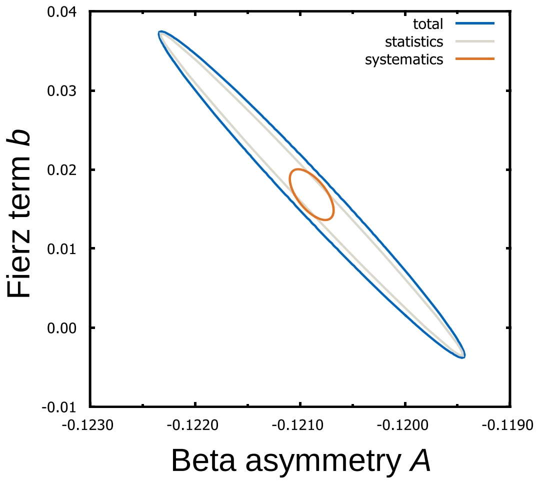
PERKEO III[1]: $b = 0.017(20)_{\text{stat}}(3)_{\text{sys}} = 0.017(21)$

Current best value

from free neutron decay



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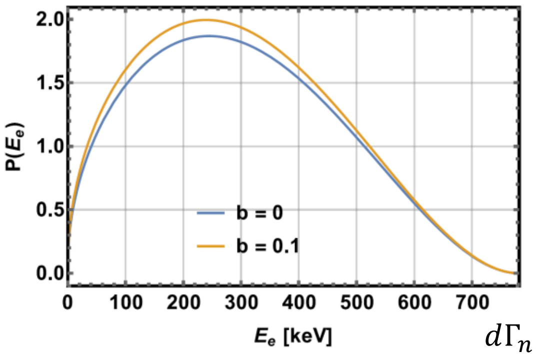

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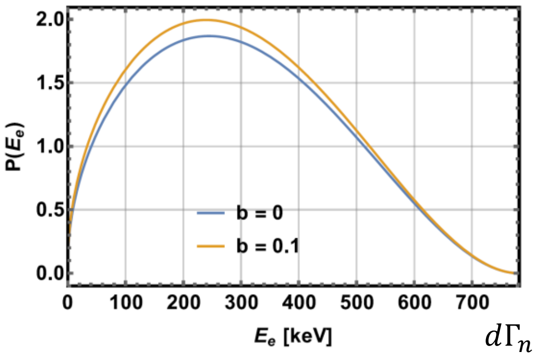

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First result from free neutron decay by UCNA[2]:

$$b = 0.067(0.005)_{\mathrm{stat}}\binom{+0.090}{-0.061}_{\mathrm{sys}}$$

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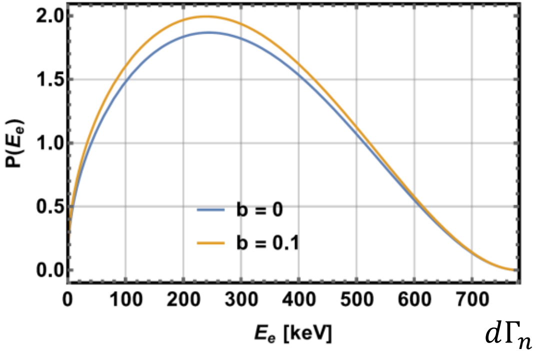

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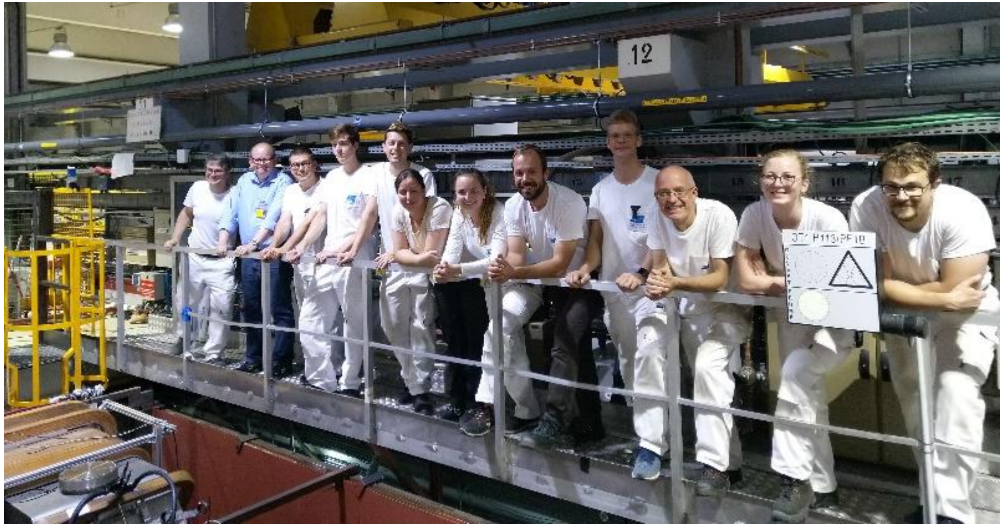
2019/2020 PERKEO III campaign at the ILL

- Measurement of Fierz term b using unpolarized neutrons (Method 2)

- Total uncertainty goal:

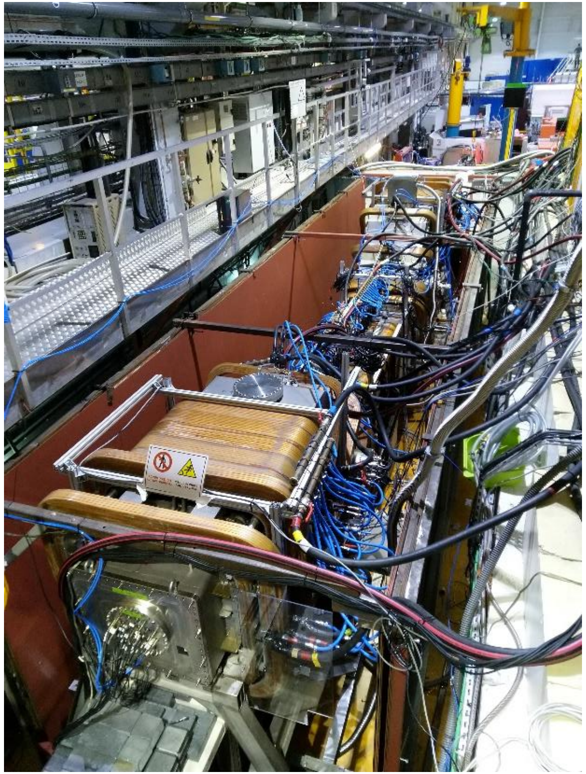
$$\Delta b \sim 5 \times 10^{-3}$$

(Factor of four improvement to present limit using free neutron decay!)

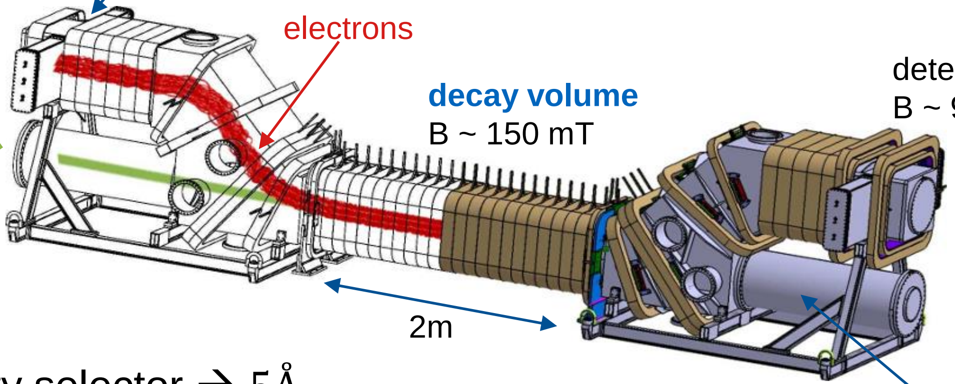


TU Munich, ILL, TU Vienna, University of Heidelberg

PERKEO III



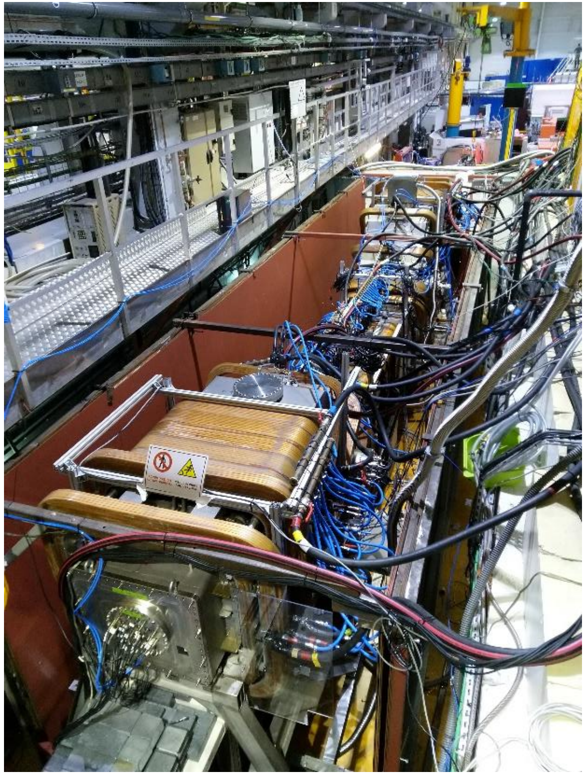
Originally built by University of Heidelberg, now operated by TUM, TU Vienna, HD & ILL.



- Velocity selector → 5Å
- $\sim 800\ \text{decays}/s$ in pulsed, unpolarized mode

Months of preparation and setup
Three weeks of measurement
} $\sim 10^9$ events

PERKEO III



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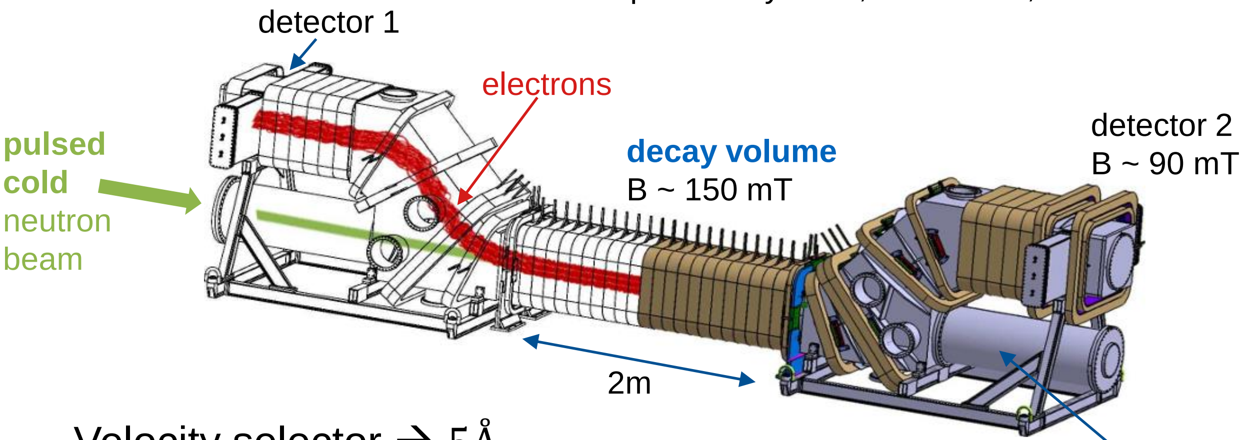

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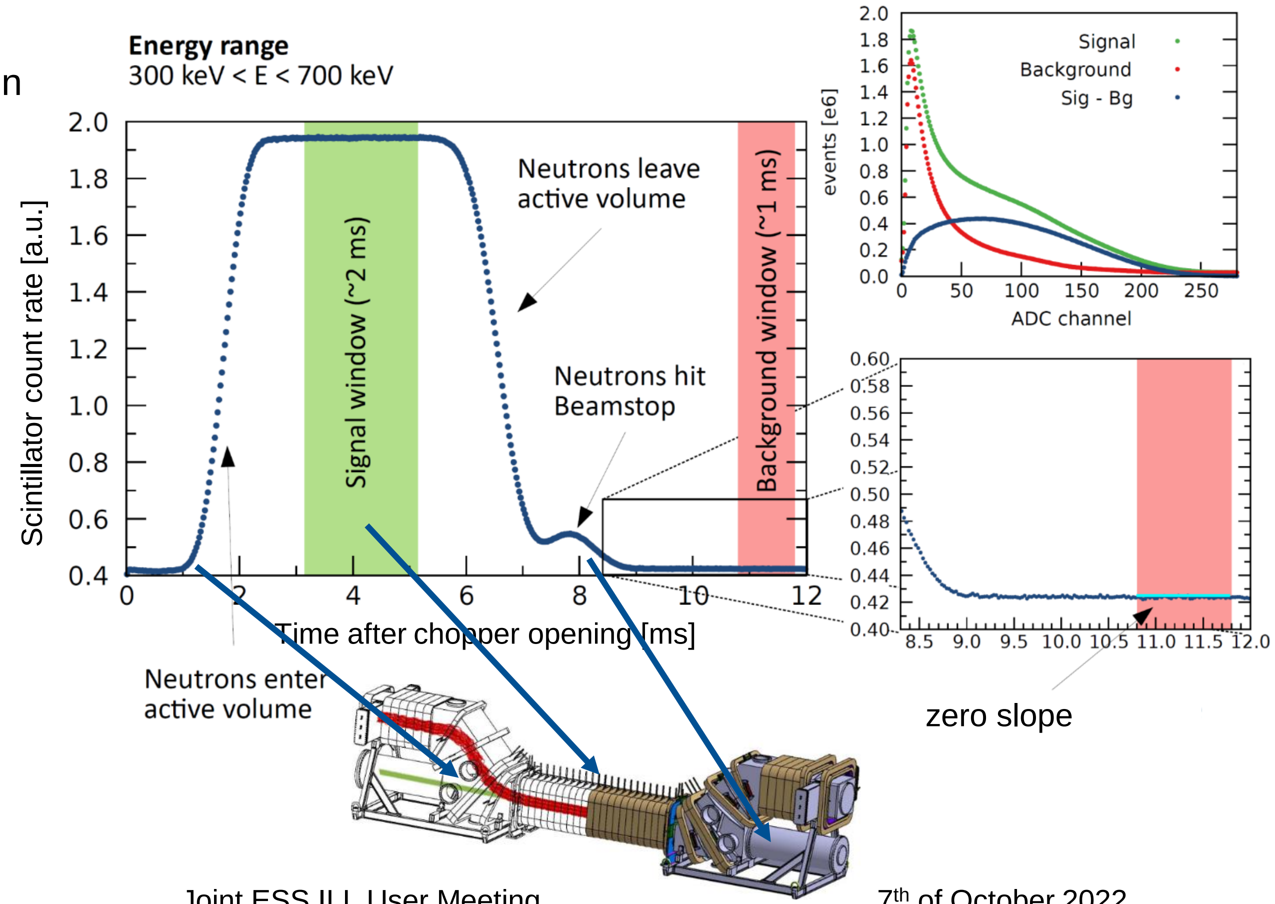
→ Statistics ✓

Advantage of pulsed neutron beam

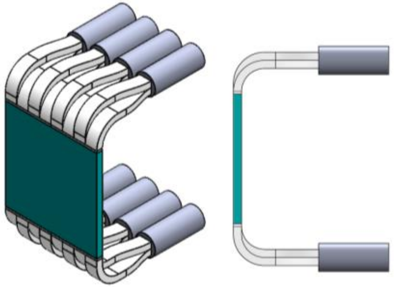
Same background condition in signal and background time window

→ Nearly perfect background subtraction



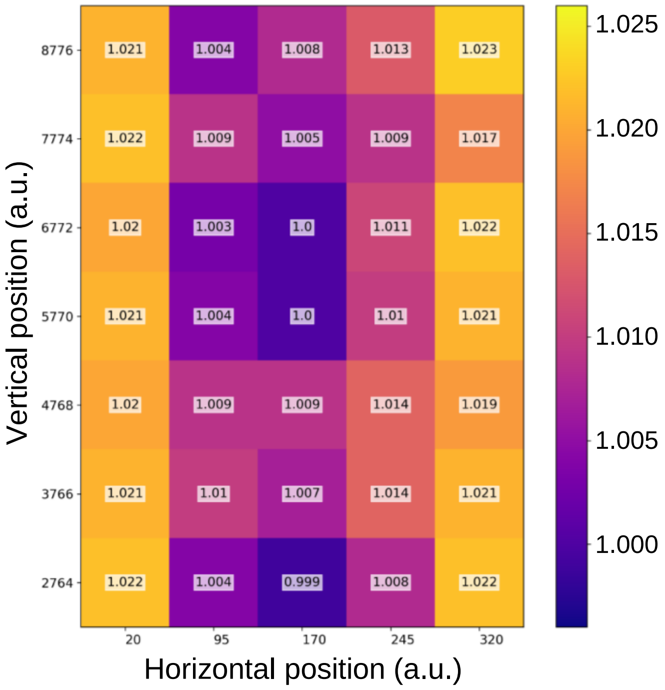
Improving systematics: Detector

New detectors optimized for uniformity (~2%) and light output

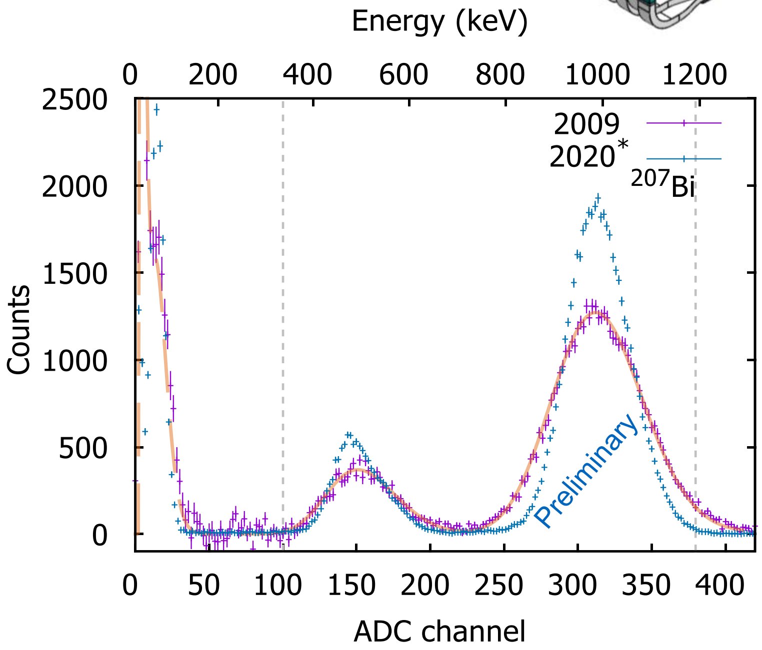


Lightguides manufactured by Martin Aigner

2D response (optimized)



Lamparth *et al.*, arXiv:2205.07625



Factor of two increase in light output gives higher energy resolution!

Master Thesis K. Bernert 2019
Bachelor Thesis M. Anthony 2019

Improving systematics: Cooling

Shifts in temperature lead to shifts in PMT gain → Hourly drift measurements needed

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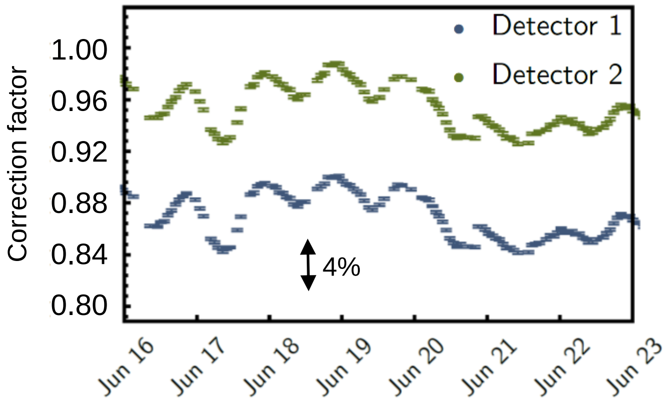
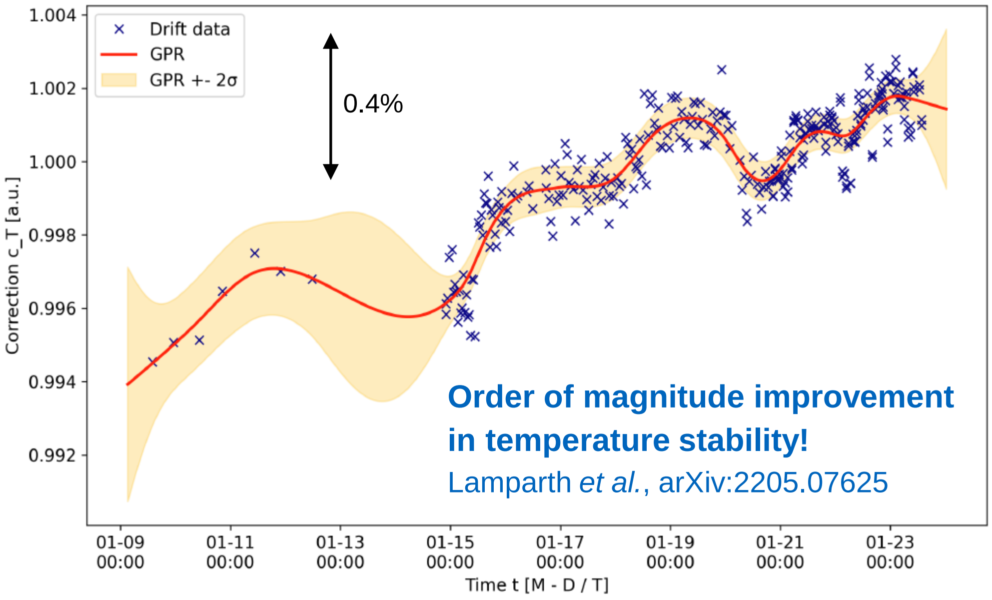
Beta Asymmetry measurement in 2009



PhD Thesis, H. Saul (2018)

Fierz term measurement in 2019/20



Order of magnitude improvement in temperature stability!

Lamparth *et al.*, arXiv:2205.07625

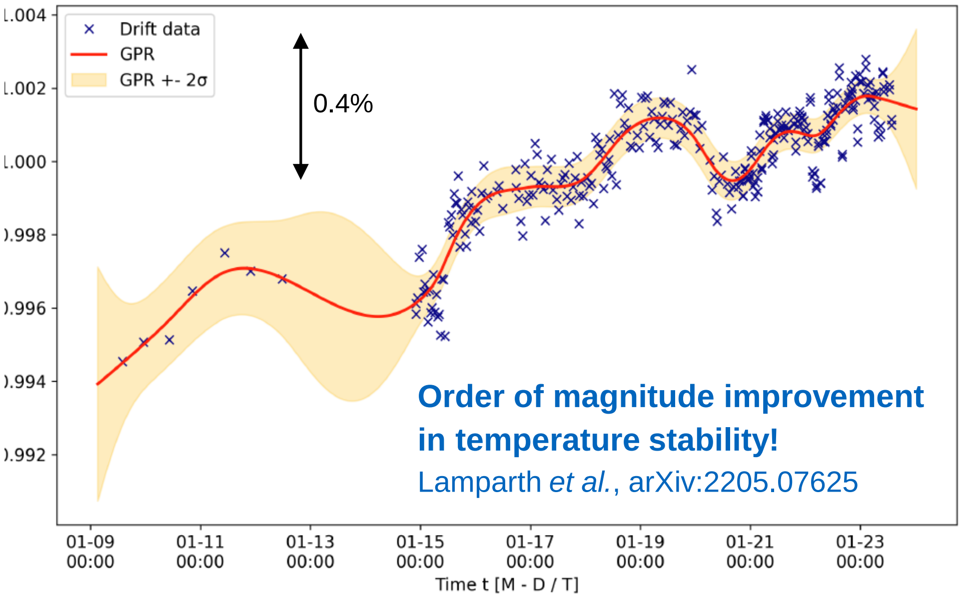
Improving systematics: Cooling

Shifts in temperature lead to shifts in PMT gain → Hourly drift measurements needed

New magnet cooling system helps to limit drift*

Measuring in the winter was helpful too ;)

Fierz term measurement in 2019/20



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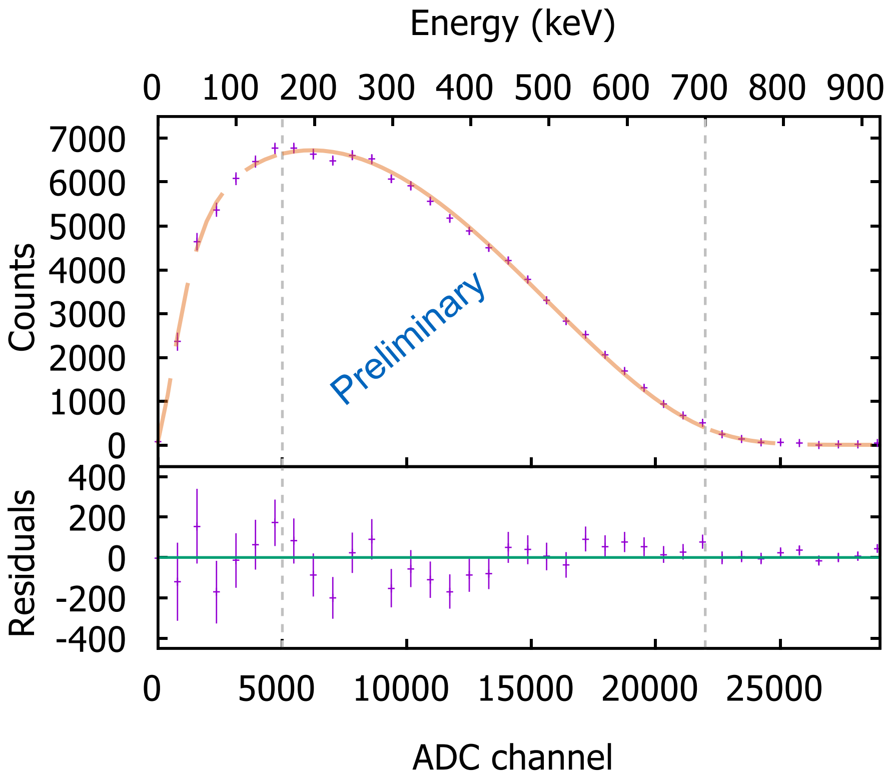
* Dr. Jens Klenke, FRM II

A taste of the data…

5 min run



Outlook

Analysis ongoing…

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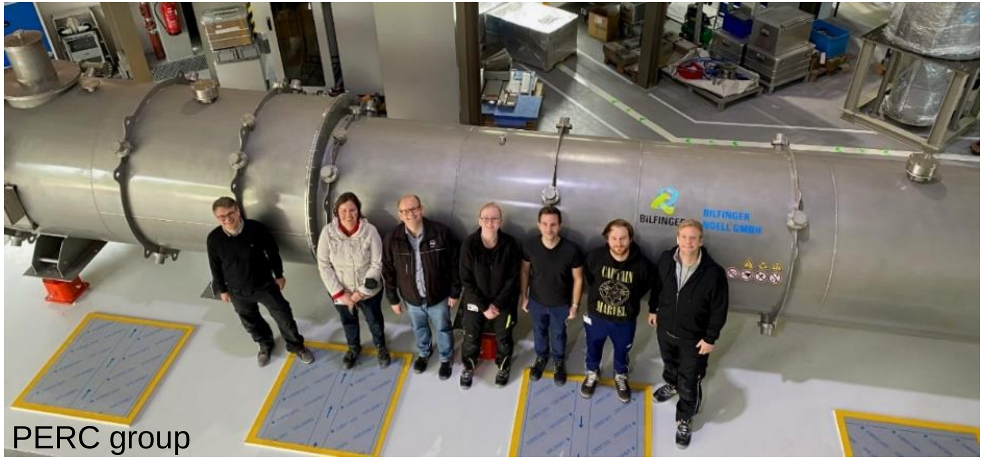
Next generation experiment is already under construction at the FRM II



PERC group

PERC (Proton Electron Radiation Channel)

- Longer decay volume → higher event rate
- Magnetic filter for phase space selection
- Aims to improve measurements of A, C, a, b