



Measurements of Correlation Coefficients in Neutron Beta Decay with PERKEO and PERC

Bastian Märkisch

Physikalisches Institut
Universität Heidelberg

3rd Workshop on the Physics of Fundamental Symmetries and Interactions
at low energies and the precision frontier



Three Experiments

- Final beta asymmetry result of **PERKEO II**
- Beta asymmetry measurement with **PERKEO III**
- Status of the next generation experiment **PERC**
(Proton Electron Radiation Channel)

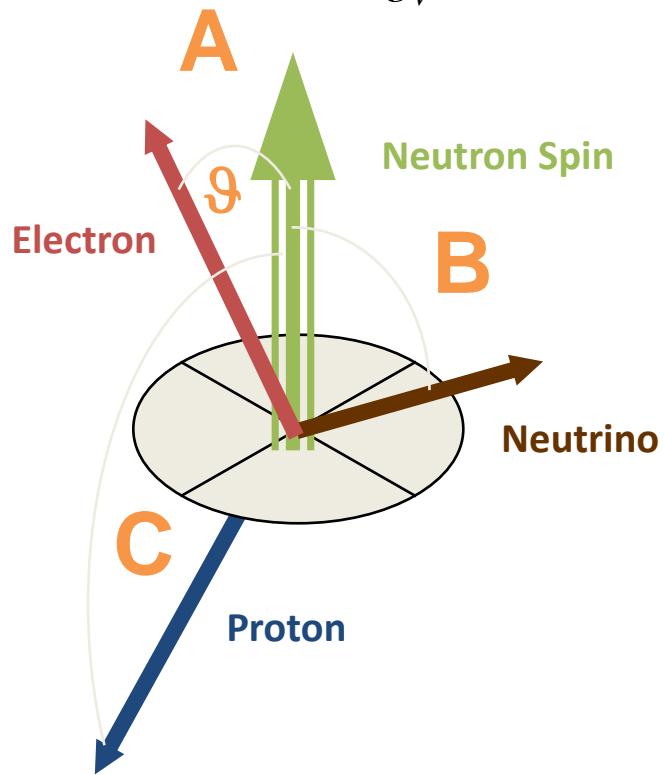




Correlations Coefficients

SM parameters:

$$\lambda = \frac{g_A}{g_V}, \quad V_{ud}$$



Unmeasured:

- Fierz interference term b
- Weak magnetism f_2
- Electron helicity h

Beta Asymmetry A

$$A \approx -12\%$$

UCNA, PRC 87 (2013) – talk by Broussard

PERKEO II, PRL 110 (2013)

PERKEO III, this talk

$$\Delta A / A = 2\%$$

Neutrino Asymmetry B

$$B \approx 98\%$$

PERKEO II, PRL 99 (2007)

$$\Delta B / B = 3\%$$

Proton Asymmetry C

$$C \approx -24\%$$

PERKEO II, PRL 100 (2008)

$$\Delta C / C = 1\%$$

Electron-Neutrino Correlation a

$$a \approx -10\%$$

Byrne et al., J. Phys. G 28 (2002)

a Spect – talk by M. Beck

aCORN – running at NIST

$$\Delta a / a = 4\%$$

Triple Coefficient D

$$D = 0$$

$$\Delta D \approx 10^{-4}$$

TRINE, PLB 581 (2004)

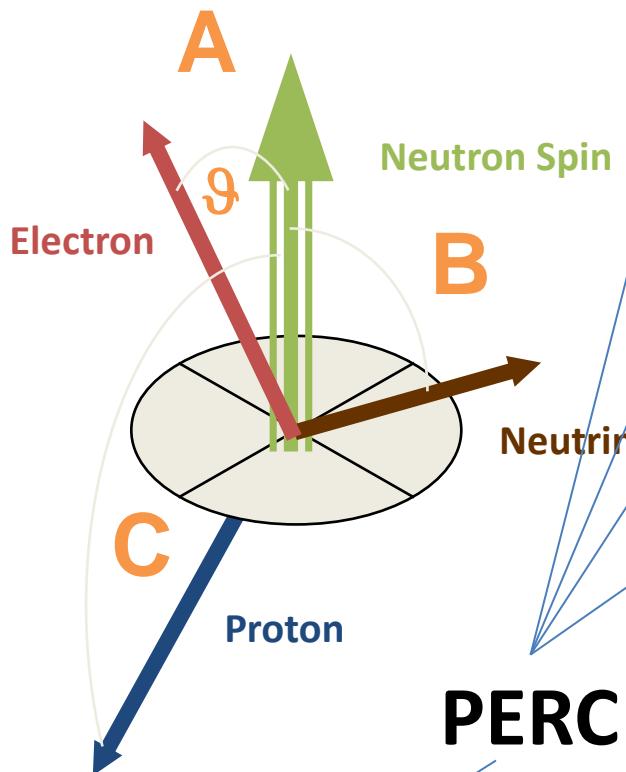
emiT, PRL 107 (2011)

Electron-spin correlations

- N
 - R
- Kozela et al., PRL 102 (2009)
- Bastian Märkisch



PERC: “Versatile”



Unmeasured:

- Fierz interference term b
- Weak magnetism f_2
- Electron helicity h

Beta Asymmetry A

$A \approx -12\%$

UCNA, PRC 87 (2013) – talk by Broussard

PERKEO II, PRL 110 (2013)

PERKEO III, this talk

Neutrino Asymmetry B

$B \approx 98\%$

PERKEO II, PRL 99 (2007)

Proton Asymmetry C

$C \approx -24\%$

PERKEO II, PRL 100 (2008)

Electron-Neutrino Correlation a

$a \approx -10\%$

Byrne et al., J. Phys. G 28 (2002)

a Spect – talk by M. Beck

aCORN – running at NIST

Triple Coefficient D

$D = 0$

TRINE, PLB 581 (2004)

emiT, PRL 107 (2011)

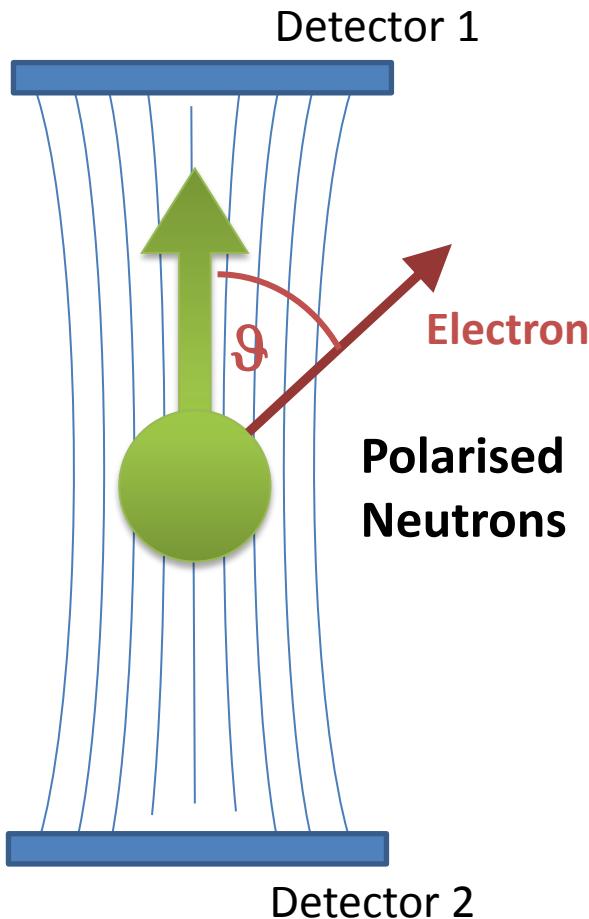
Electron-spin correlations

N } Kozela et al., PRL 102 (2009)
 R }



Measuring Beta Asymmetry

- Electron angular distribution:



$$W(\vartheta, E) = 1 + \frac{v}{c} A \cos \vartheta$$

- Within Standard Model:

$$A = -2 \frac{\lambda^2 + \lambda}{1 + 3\lambda^2} \quad \lambda = \frac{g_A}{g_V}$$

- Magnetic field to as quantisation axis
- Integration over hemispheres: $\cos \vartheta \rightarrow \frac{1}{2}$
2 × 2π detection
- Experimental asymmetry, polarisation P

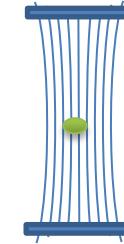
$$A_{\text{exp}} = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} = \frac{1}{2} \frac{v}{c} P A$$

Experimental Challenges



- **Electron Spectroscopy**

2 x 2π detection using strong magnetic field
time-of-flight of *backscattered* electrons:
full energy detection



$$A_{\text{exp}} = \frac{1}{2} \frac{v}{c} P A$$

- **Neutron Polarisation P**

PERKEO II: X-SM polariser geometry, $P = 99.7(1)\%$

PERKEO III: narrow wavelength band, pulsed beam

Analysis with ILL's „Magic Box“ – ${}^3\text{He}$ spin filter $\Delta P/P = 10^{-4}$

- **Counting Statistics**

Long lifetime 15 min, velocity of cold neutrons $v \sim 700 \text{ m/s}$

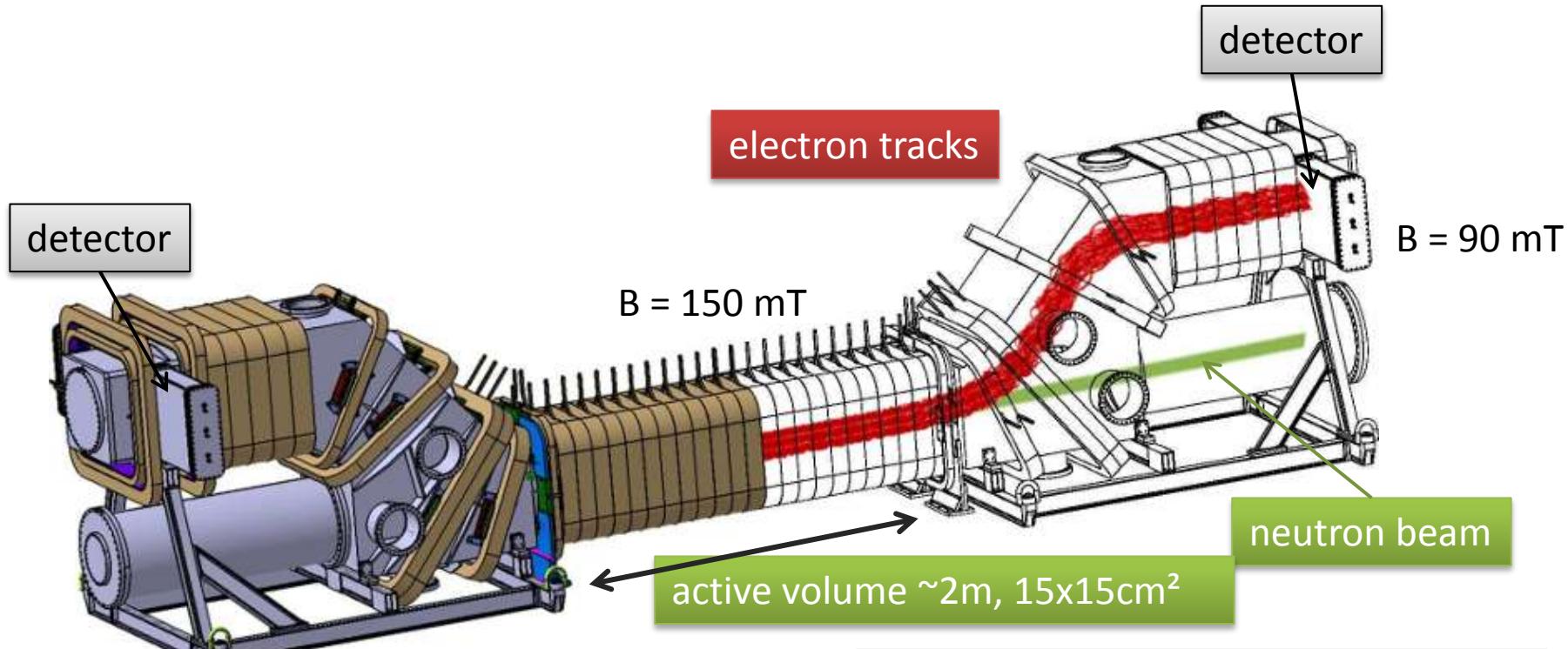
Only 1 in 10^6 neutrons decays per meter (in a cold beam)

- **Background**

Only few neutrons decay, others potentially cause background

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

Spectrometer PERKEO III



54 water-cooled copper coils

Total Weight: 8 t

Total Length: 8 m

Electric: 300 kW, 540 A

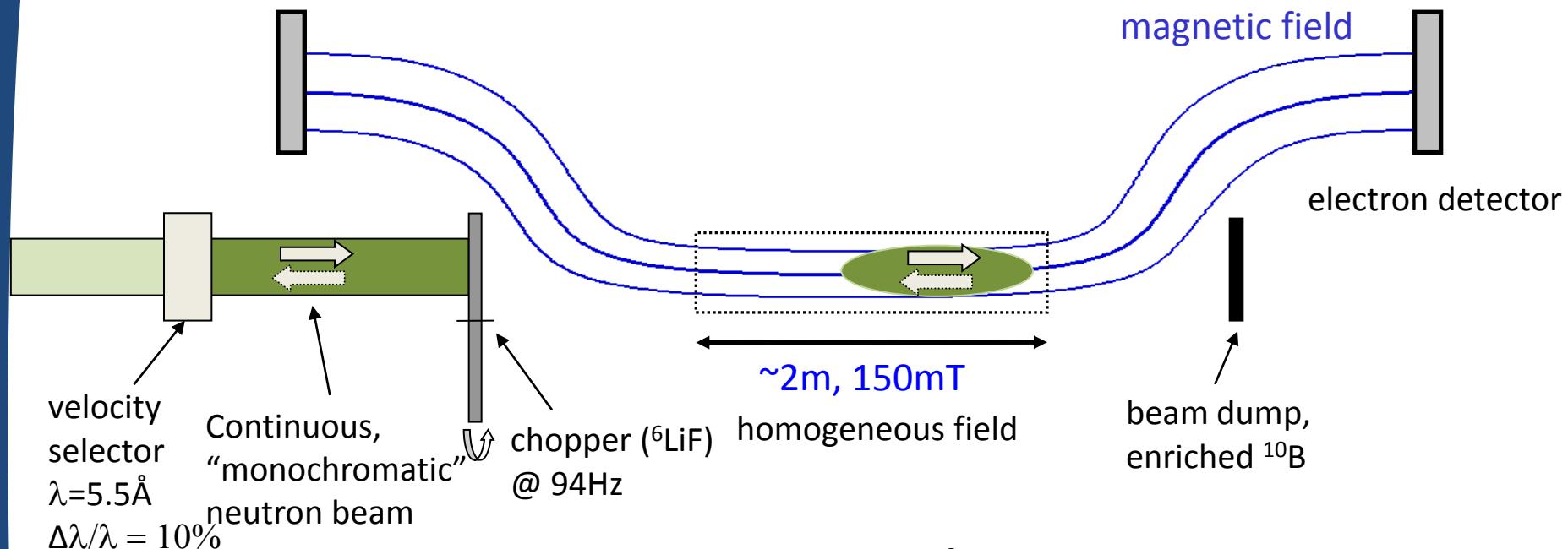
10.9.2013

Magnetic field :

- alignment of n–spin
- guide e^- , p onto detectors
⇒ $2 \times 2 \pi$ detector
- separation into hemispheres

Bastian Märk

Pulsed Cold Neutron Beam

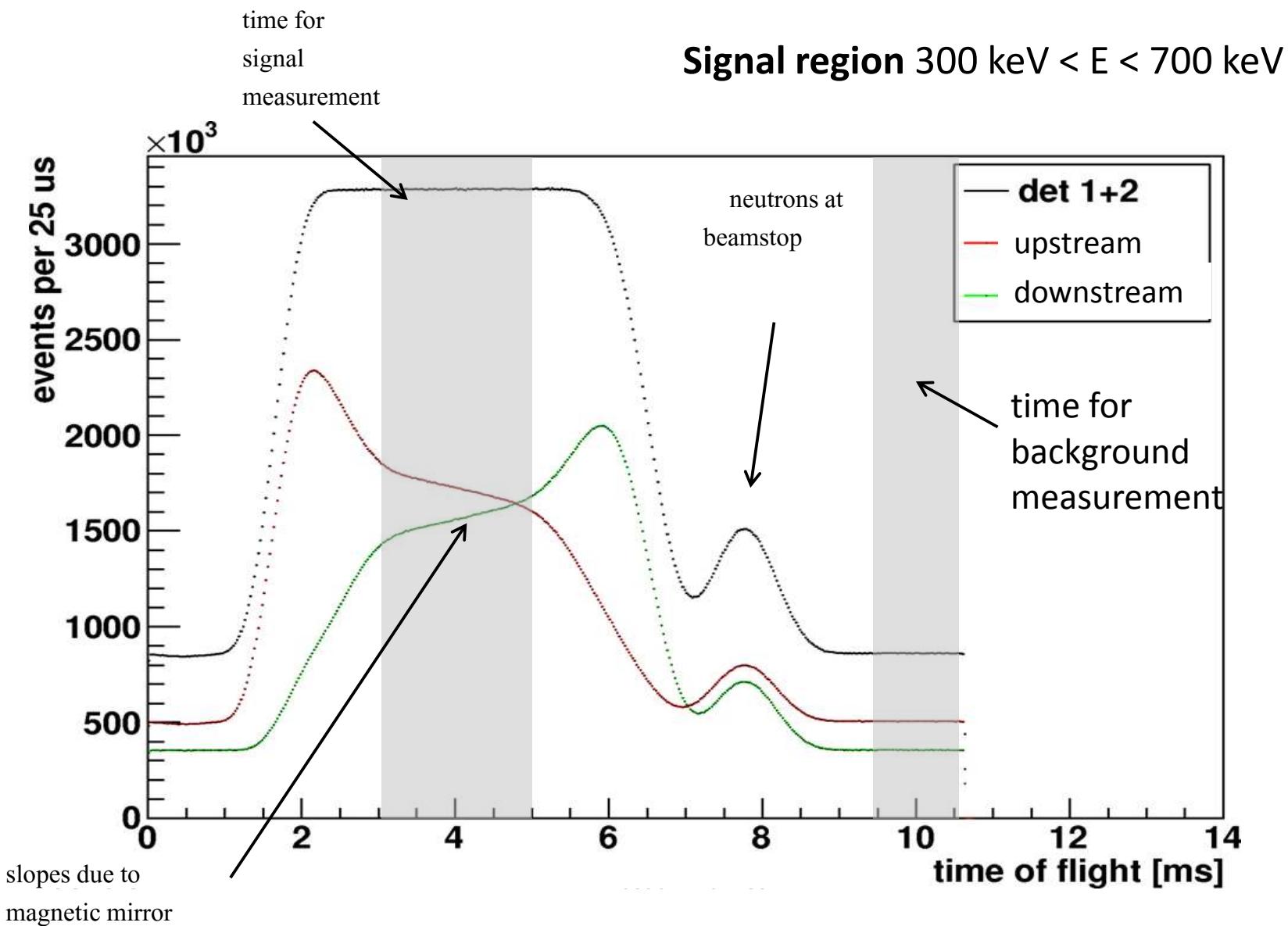


D. Werder, UHD

Benefits:

- Background can be *fully measured and subtracted*
- *Edge-free projection* onto detectors: full $2 \times 2\pi$ detection without distortions
- Magnetic mirror effect controlled

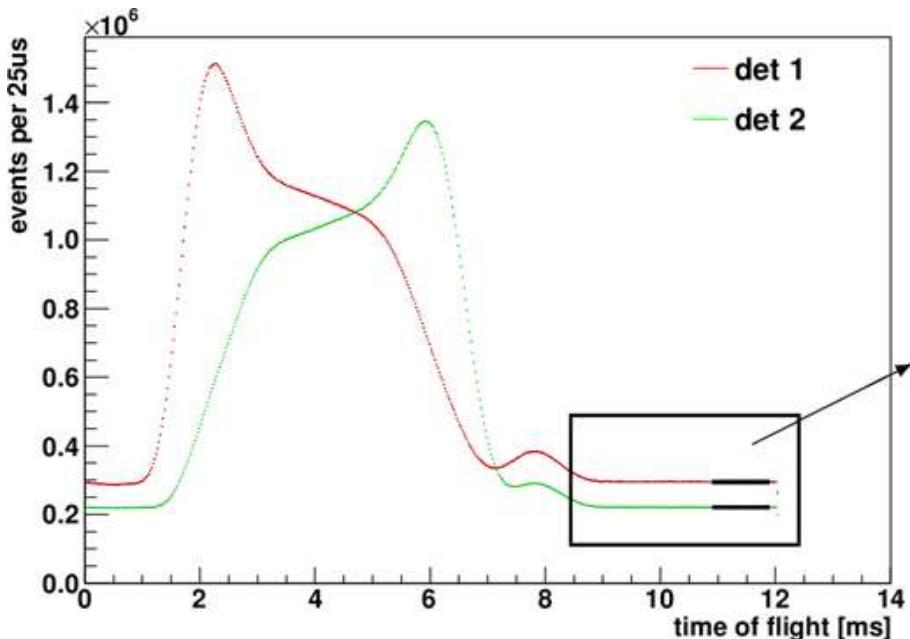
Pulsed Neutron Beam



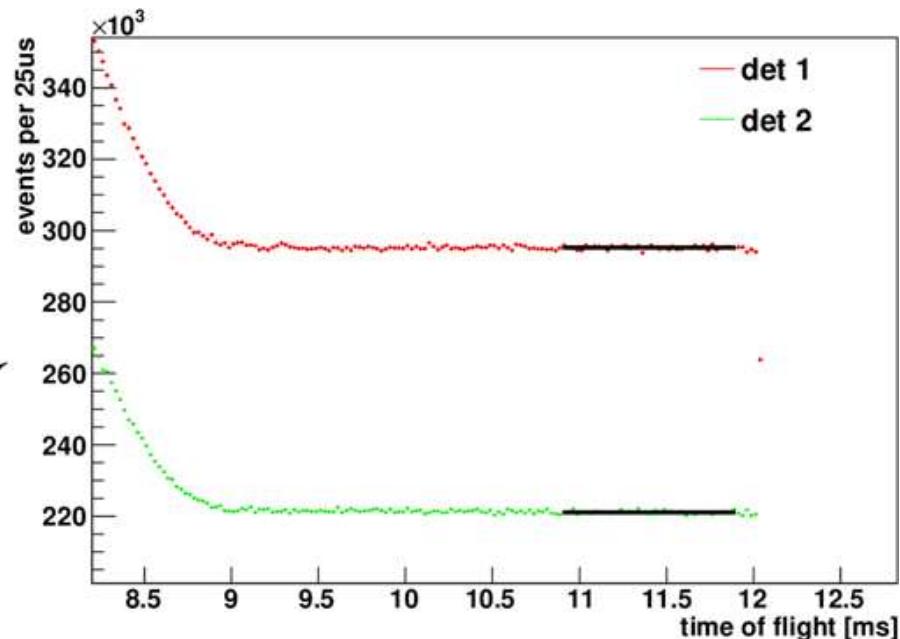
Background Subtraction



No time variation of background signal,
both detectors, chopper at 83 and 94 Hz



$$\frac{\partial Bg}{\partial t} / Bg = -0.3(1.1) \cdot 10^{-3} \text{ ms}^{-1}$$



Additional background tests:

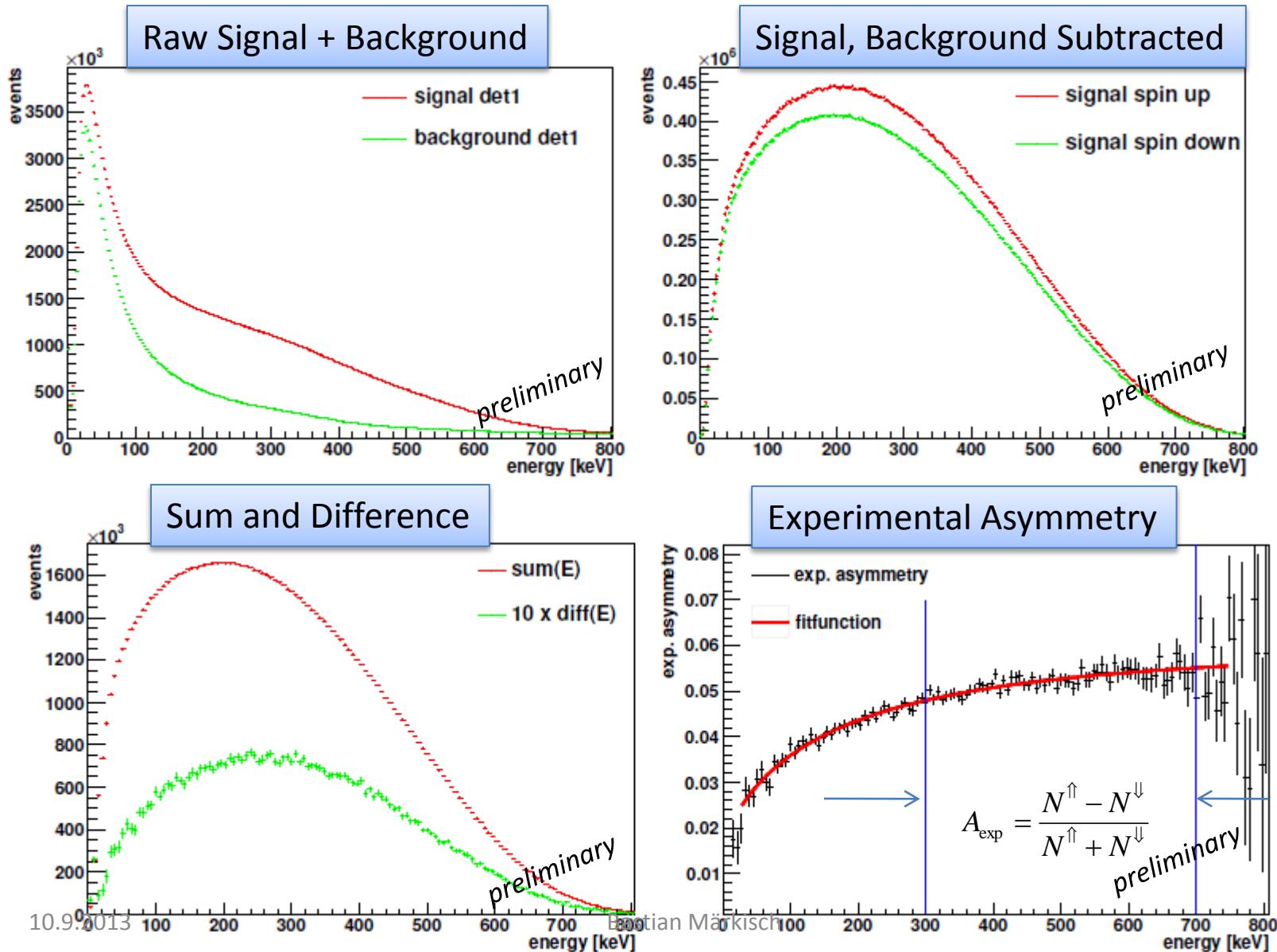
- Background monitors (NaI and He)
- Different chopper frequencies: 83 Hz, 94 Hz
- Control measurements with blocked beam

10.9.2013

Signal region $300 \text{ keV} < E < 700 \text{ keV}$

Thesis H. Mest, HD

Beta Asymmetry, Chopper 94 Hz



Error Budget, Preliminary



Effect on Asymmetry A	Relative $\Delta A / A$ Correction	Relative $\Delta A / A$ Uncertainty	
• Polarisation \mathcal{P}	separate analysis	$\leq 10 \cdot 10^{-4}$	$A = -2 \frac{\lambda^2 + \lambda}{1 + 3\lambda^2}$
• Spinflip efficiency \mathcal{F}	separate analysis	$\leq 8 \cdot 10^{-4}$	
• Magn. mirror effect			
* Background	$-2.0 \cdot 10^{-4}$	$0.9 \cdot 10^{-4}$	
* Deadtime	$-5.0 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	
* Detector drift		$4 \cdot 10^{-4}$	
* Detector calibration		$5 \cdot 10^{-4}$	
* Short gate time		$1.4 \cdot 10^{-4}$	
• Systematics	to be finalised	$\leq 14.6 \cdot 10^{-4}$	
[†] Ext. radiative corr.	$9 \cdot 10^{-4}$	$5 \cdot 10^{-4}$	
* Statistics		$13.7 \cdot 10^{-4}$	
Total	O(1%)	$\leq 2.1 \cdot 10^{-3}$	

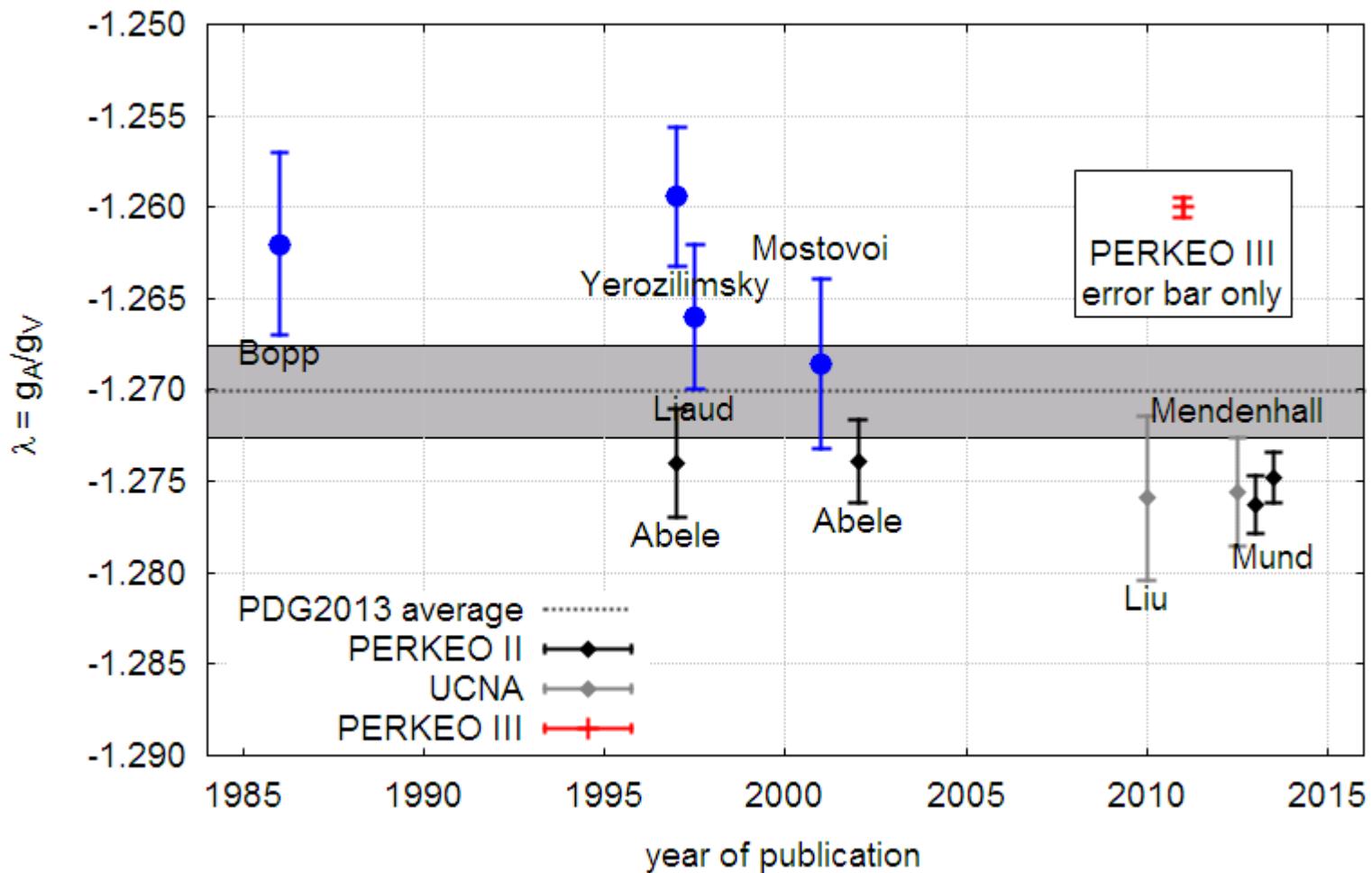
Preliminary Result:

$$\frac{\Delta A}{A} = 2.1 \cdot 10^{-3}$$

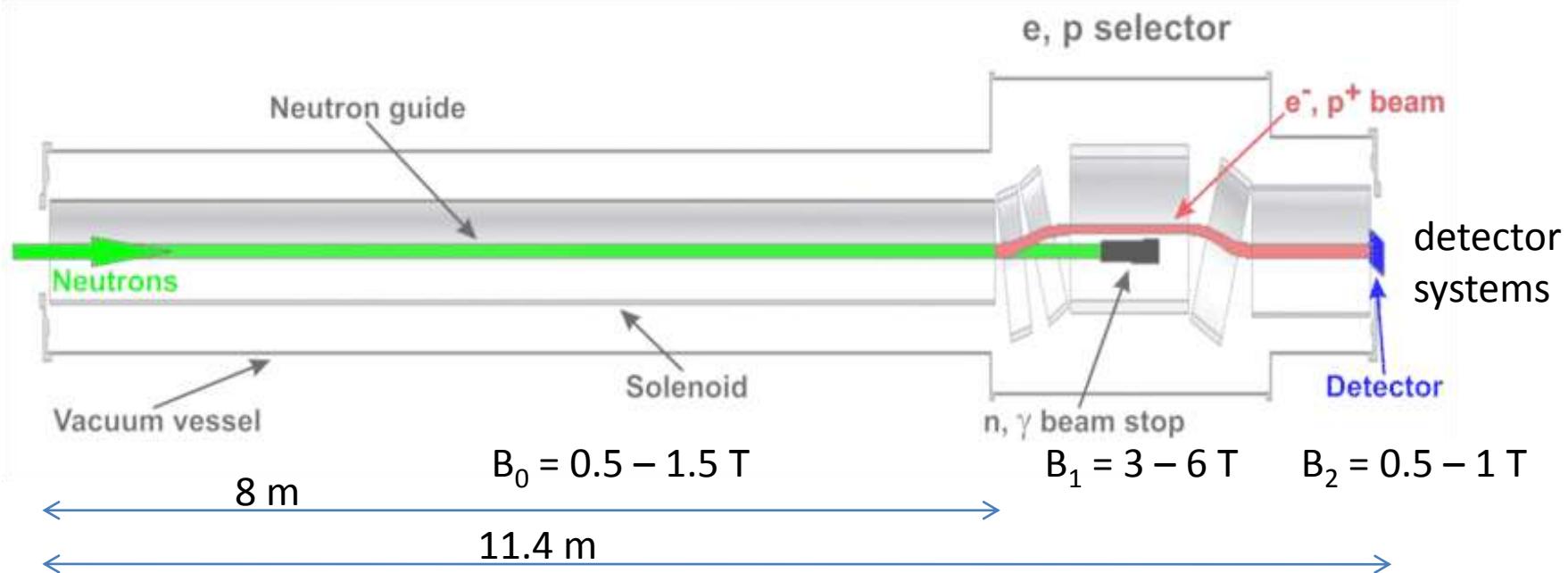
$$\frac{\Delta \lambda}{\lambda} = 5.3 \cdot 10^{-4}$$

Thesis
Holger Mest, HD

Status of g_A



Additional input expected from “ a ”: a Spect, a CORN, (Nab, PERC (A, a))



- No local field minima
- B_1 homogeneity 10^{-4} in e/p beam
- Filter variable over wide range to control systematic effects: $B_1/\nu = 2 \dots 12$



Heidelberg



TU Wien



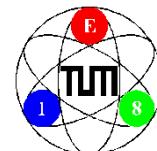
Grenoble



FRM II, München

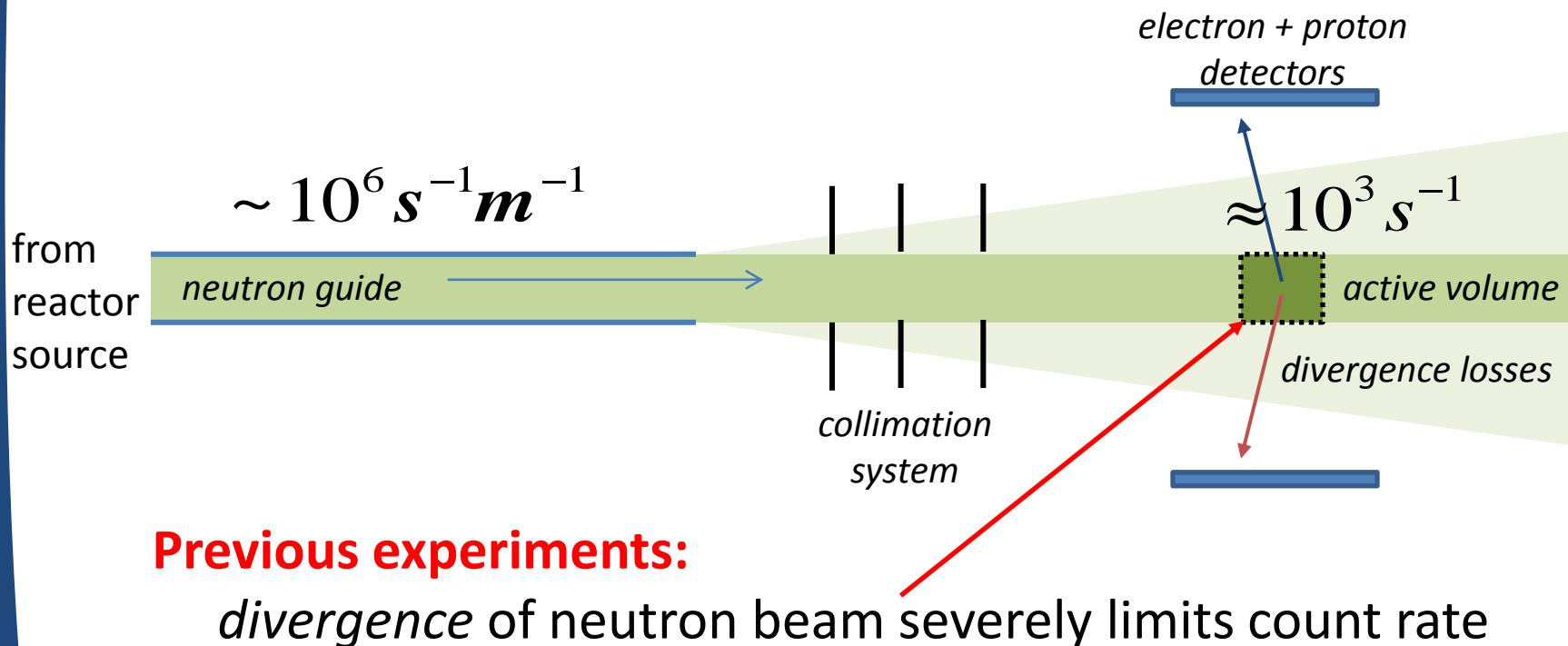


JOHANNES GUTENBERG
UNIVERSITÄT MAINZ



TU München

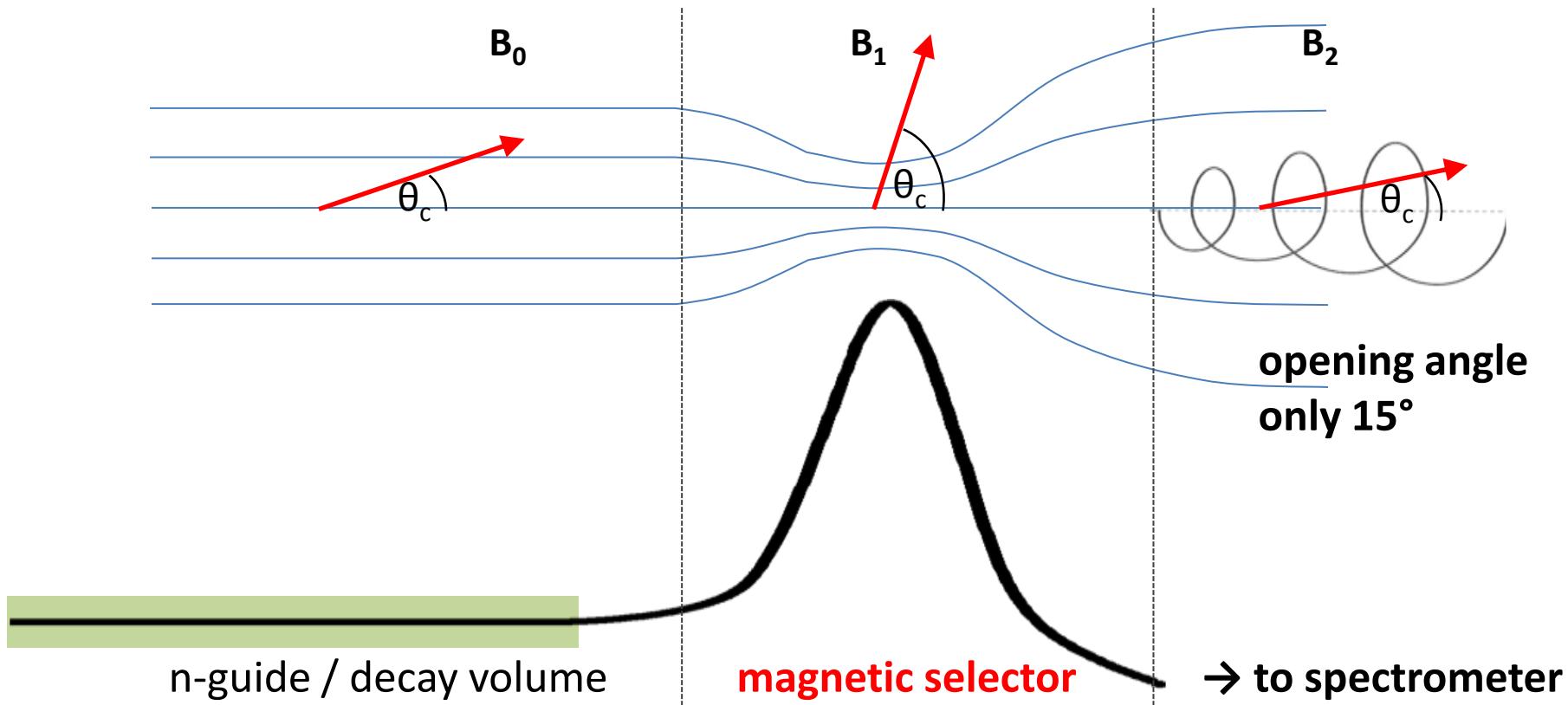
Use the **inside of an 8 m long neutron guide** as active volume:
maximal neutron phase space



Previous experiments:

divergence of neutron beam severely limits count rate

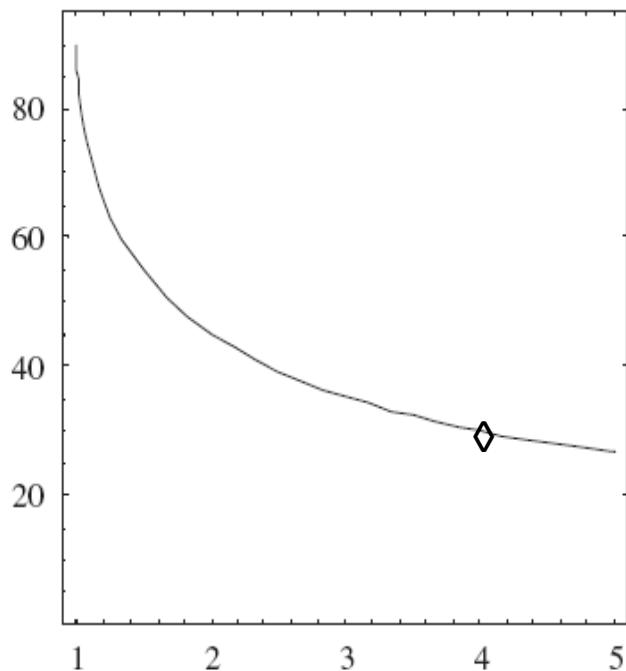
Magnetic Barrier: “Clean”



Magnetic field	$B_0 = 1.5 \text{ T}$	$B_1 = 6 \text{ T}$	$B_2 = 0.375 \text{ T}$
Radius of gyration	< 1 mm	< .5 mm	< 2 mm
Opening angle θ_c	30°	90°	15°
Beam size	5 cm	2.5 cm	10 cm

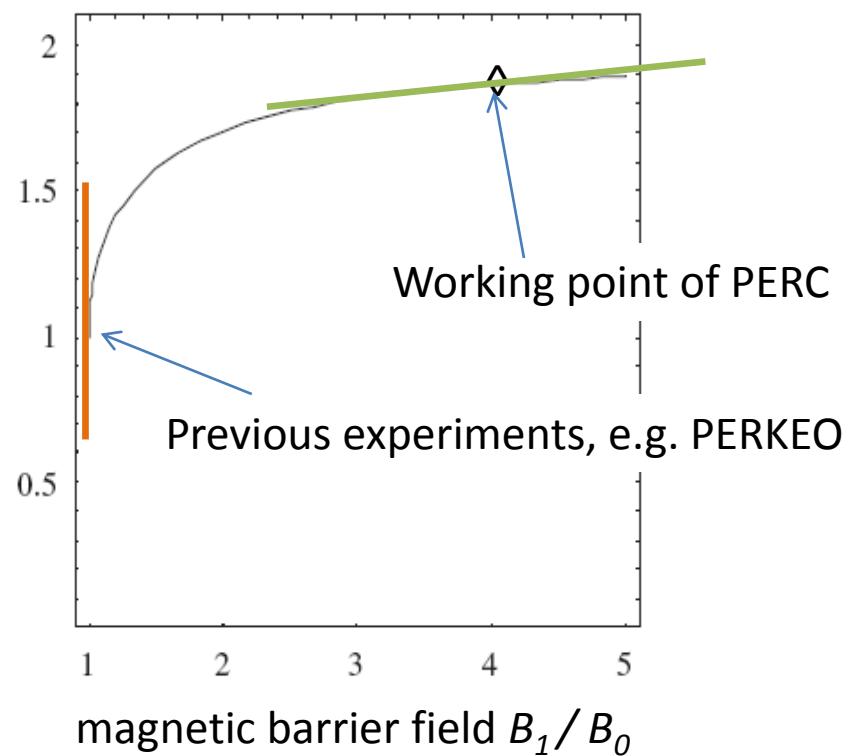
Errors due to non-uniform magnetic field are strongly suppressed

critical angle θ_c



magnetic barrier filter B_1/B_0

asymmetry A

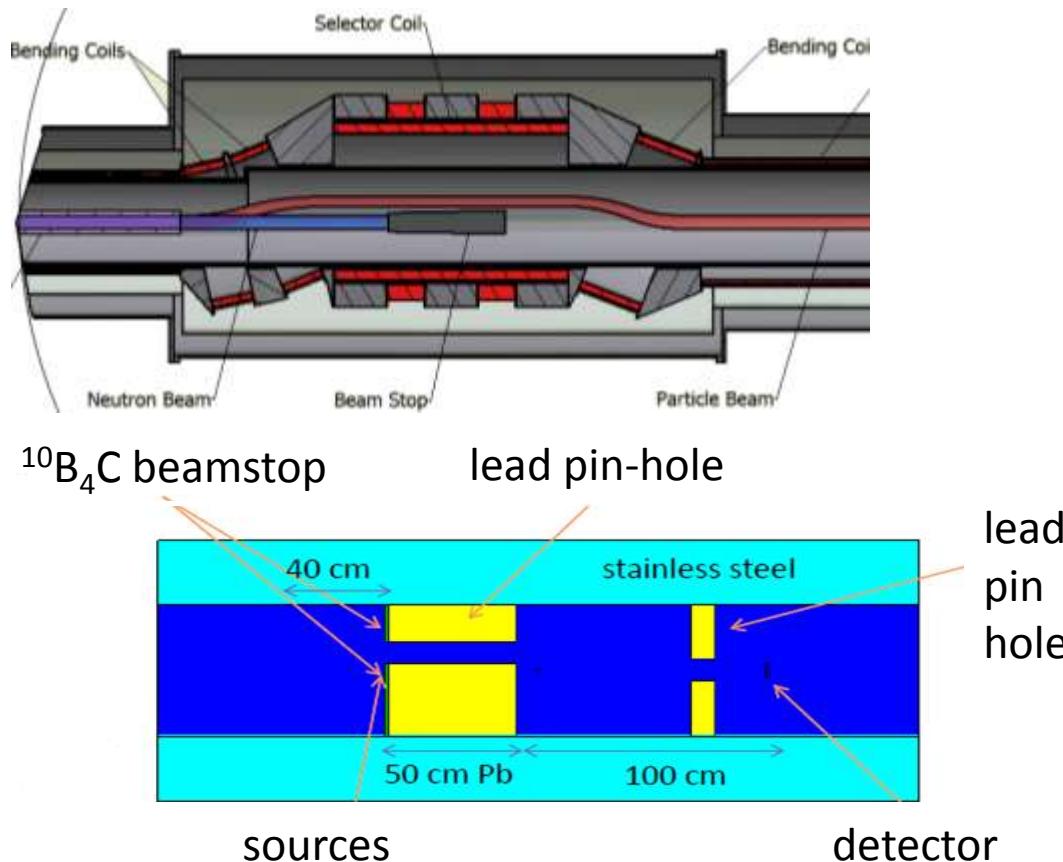


magnetic barrier field B_1/B_0

D. Dubbers *et al.*, *Nucl. Instr. Meth. A* **596** (2008) 238 and arXiv:0709.4440

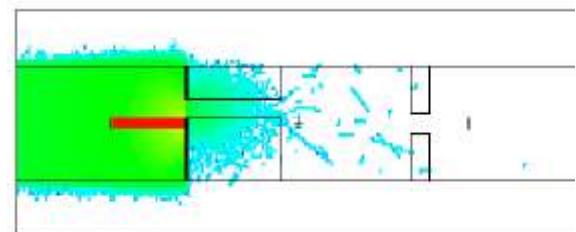
Shielding Concept: 2 Pin-holes - MCNP simulations

C. Gösselsberger,
E. Jericha (ATI)

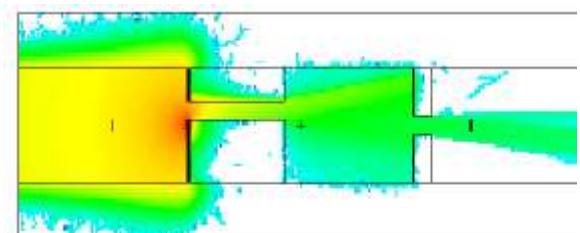


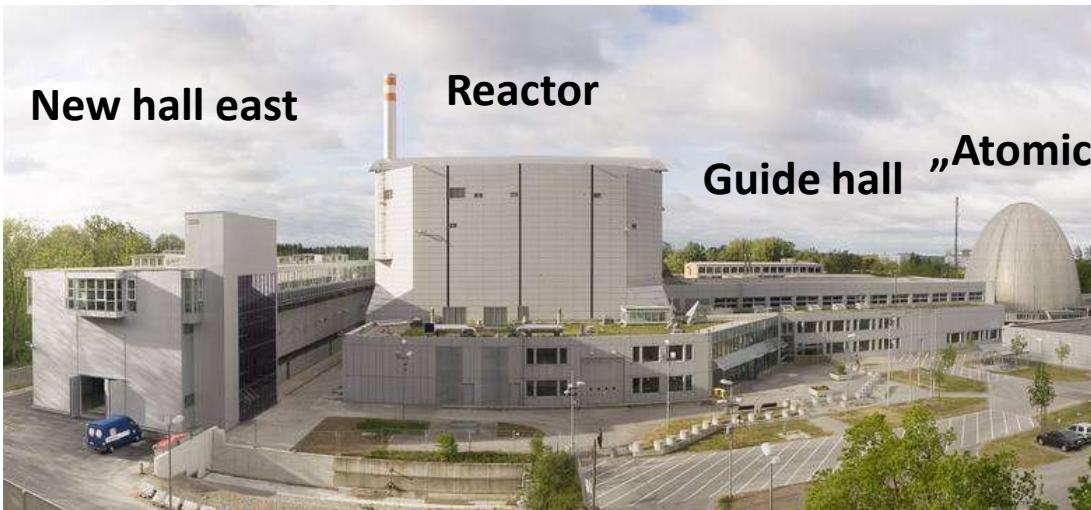
Simulate 10^{10} n/s on beamstop

Fast neutrons: 0 s^{-1}

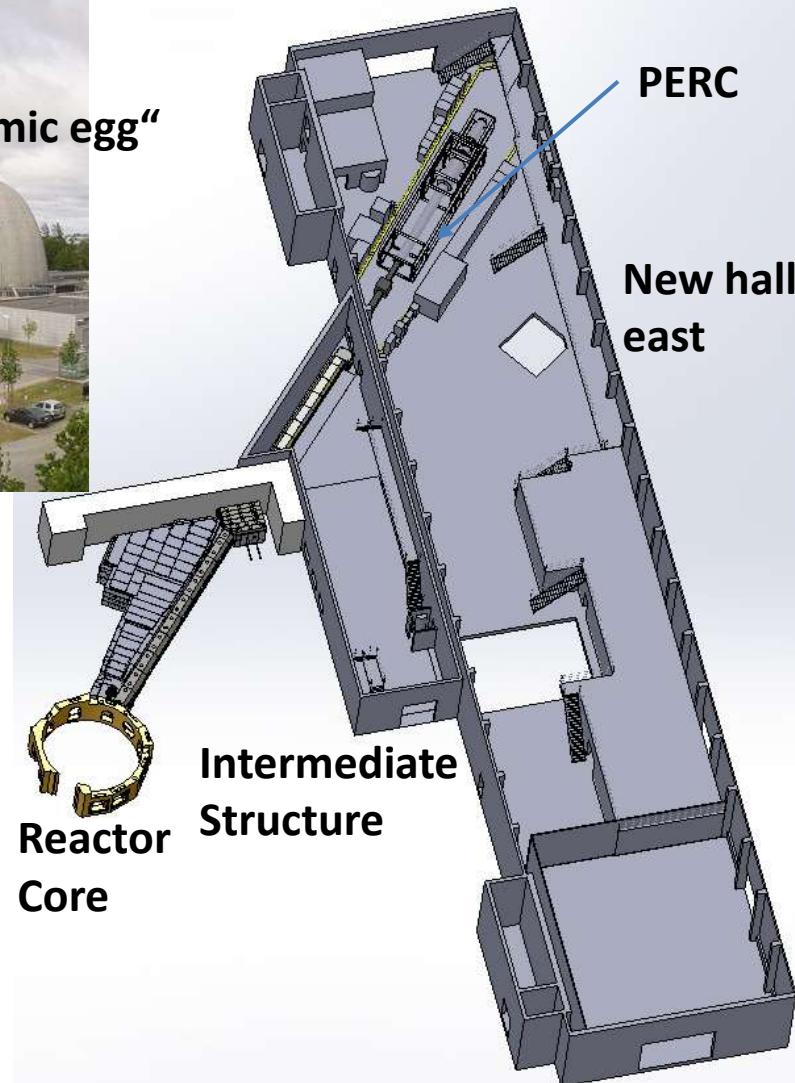


Gamma: 35 s^{-1}





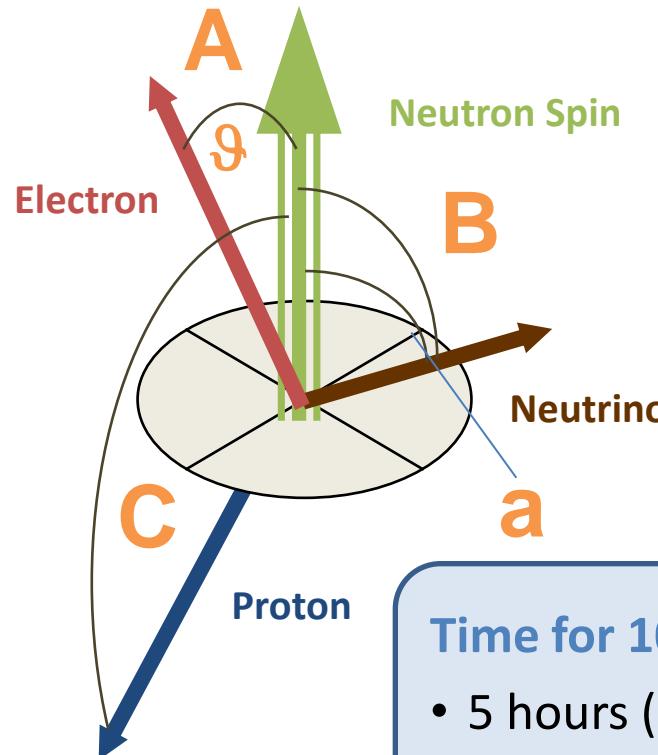
- “Empty” new hall
- Neutron guide:
length 40 m, $R = 3000$ m, $m = 2.5$
- Expected intensity equal to PF1B at ILL
- Only very few neighbours:
low background
- Easy ground level access



Focus on *non-coincident* measurements due to high count rates:

Polarised neutrons

- β -asymmetry **A**
- Proton asymmetry **C**
Neutrino asymmetry **B**
- Weak magnetism f_{WM}
from β -asymmetry or
polarised spectra



Unpolarised neutrons

- Correlation **a**
from proton spectrum
- Fierz coefficient **b**
from electron spectrum or
 β -asymmetry
- Electron helicity **h**

Time for 10^9 events

- 5 hours (unpolarised)
- 1 day polarised 98%
- 2 days polarised 99.7%
- $\times 25$ for pulsed mode

- **PERKEO II:** Most precise result on *axial-vector constant* (so far), Mund et al. PRL 110 $\frac{\Delta\lambda}{\lambda} = 11 \cdot 10^{-4}$
 $\lambda = -1.2748(^{+13}_{-14})$
- **PERKEO III:** First measurement of beta asymmetry $\frac{\Delta A}{A} = 2.1 \cdot 10^{-3}$ with pulsed cold neutron beam:
background measureable, edge effect eliminated, magnetic mirror effect controllable $\frac{\Delta\lambda}{\lambda} = 5.3 \cdot 10^{-4}$ preliminary
- Concept of **PERC** is *unique*: a clean, bright, and versatile source of neutron decay products
 - Maximum phase space
 - Clean systematics: all uncertainties $\Delta A/A \leq O(10^{-4})$
 - Wide range of observables accessible: $A, B, C, a; b, f_{WM}$

PERKEO III Collaboration



University of Heidelberg

D. Dubbers, B. Märkisch, H. Mest, C. Roick, D. Werder

TU Vienna, TU Munich

H. Abele, H. Saul, X. Wang

Institut Laue Langevin, Grenoble

T. Soldner, A. Petoukhov



B. Märkisch

U. Schmidt

D. Dubbers

L. Raffelt

C. Roick

N. Rebrova

C. Ziener

R. Maix

B. Windelband

T. Soldner

O. Zimmer

C. Klauser

W. Heil

M. Beck



Heidelberg



Vienna



NEUTRONS
FOR SCIENCE

Grenoble



JOHANNES GUTENBERG
UNIVERSITÄT MAINZ



FRM II, Munich

H. Abele

E. Jericha

G. Konrad

J. Erhart

C. Gösselsberger

X. Wang

H. Fillunger

M. Horvath

R. Maix

J. Klenke

T. Lauer

H. Saul

K. Lehmann