W. Heil

Neutron lifetime experiments - status and future

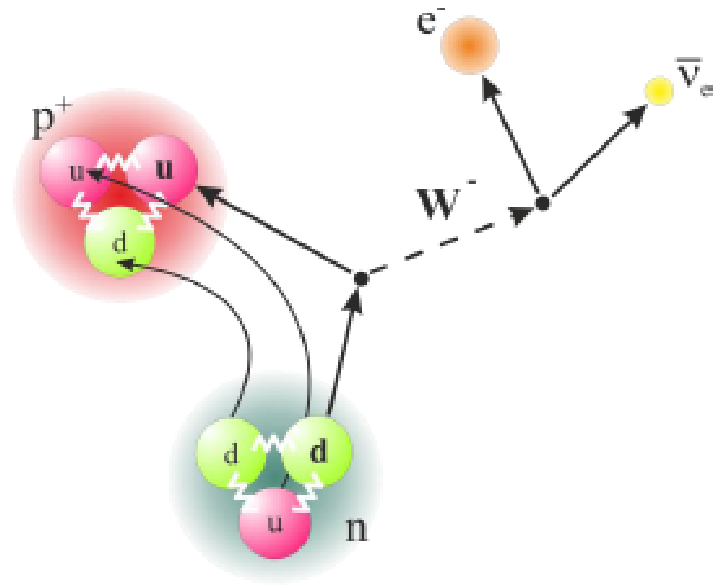
Outline

- Impact of neutron lifetime experiments
- Overview on „beam“ and „bottle“ type experiments
- τSPECT experiment at Mainz

Bridging the Standard Model to New Physics with the Parity Violation Program at MESA

from 23 April 2018 to 4 May 2018   MITP, JGU Mainz

Neutron Beta-Decay



Low energy

$E_{p,max}$ = 752 eV $E_{e,max}$ = 782 keV

Long lifetime

τ = 880.3(1.1) s

$$\tau^{-1} = G_F^2 \left|V_{ud}\right|^2 (1+3\lambda^2) \frac{f^R m_e^5 c^4}{2\pi^3 \hbar^7}$$

Only small, precisely known radiative corrections

Two free parameters within SM (G_F from muon decay)

Ratio of coupling constants

Axial-vector g_A und vector g_V

$$\lambda = \frac{g_A}{g_V}$$

Quark mixing

Cabibbo-Kobayashi-Maskawa matrix element

$$V_{ud}$$

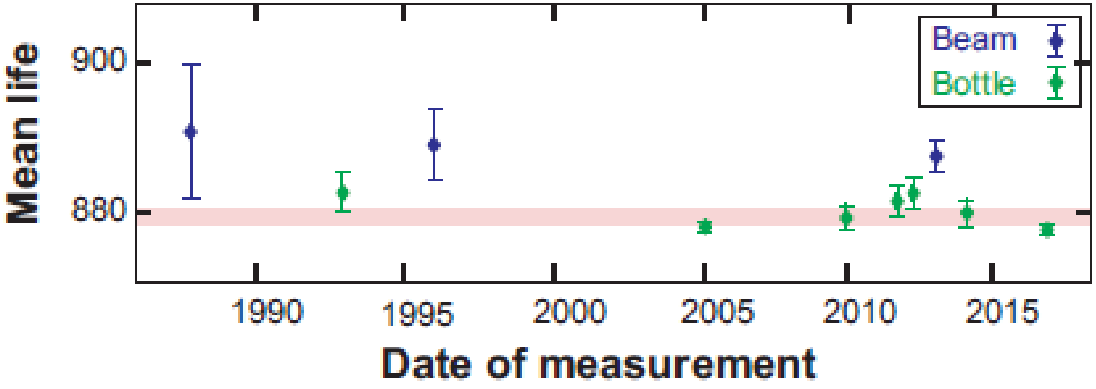
V_{ud} via neutron decay data 2017

Mean life:

$\tau = 879.4 \pm 0.9$ s

$\chi^2/N = 4.2$

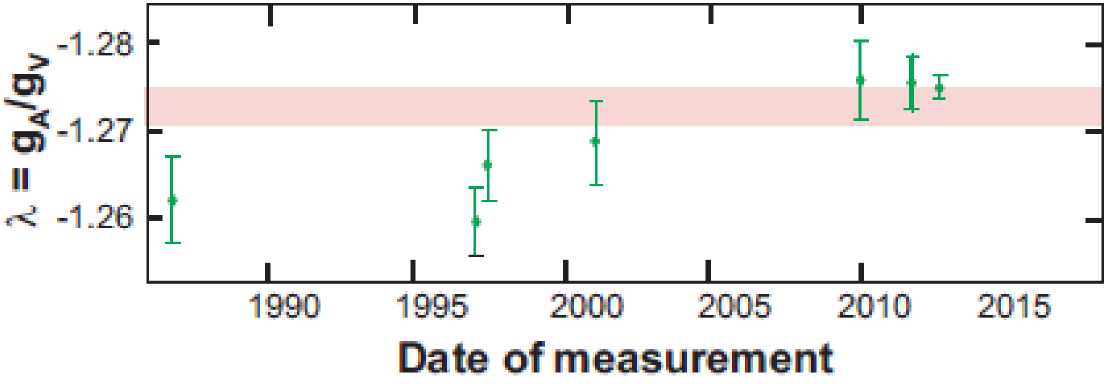
Beam: 888.1 ± 2.0 s
Bottle: 878.9 ± 0.6 s



β asymmetry:

$\lambda = -1.2725 \pm 0.0020$

$\chi^2/N = 4.1$



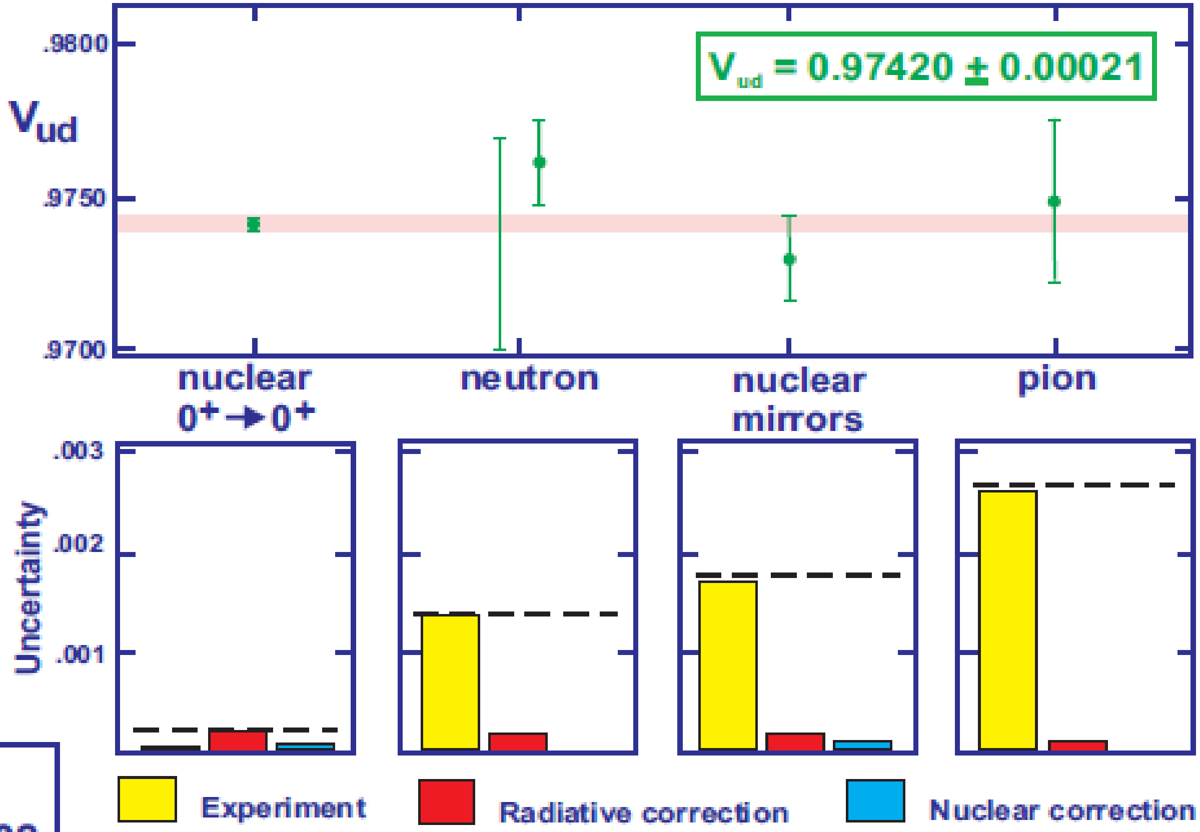
$V_{ud} = 0.9762 \pm 0.0014$

Beam-bottle span
$0.9700 \leq V_{ud} \leq 0.9770$

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

Marciano , Sirlin PRL 96 (2006)

CURRENT STATUS OF V_{ud} AND CKM UNITARITY



nuclear $0^+ \rightarrow 0^+$

$V_{ud} = 0.9742 \pm 0.0002$

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 0.99962 \pm 0.00049$$

V_{ud}^2 nuclear decays
muon decay
0.94906 ± 0.00041

V_{us}^2 PDG
kaon decays
0.05054 ± 0.00027

V_{ub}^2 B decays
0.00002

Courtesy of J. Hardy

The Neutron Alphabet

$$\frac{d^3\Gamma}{dE_e\,d\Omega_e\,d\Omega_\nu} = \frac{1}{2(2\pi)^5}\overbrace{G_F^2\left|V_{ud}\right|^2\left(1+3\left|\lambda\right|^2\right)}^{\propto\,\tau_n^{-1}} p_e E_e\left(E_0-E_e\right)^2$$
$$\times\left[1 + a\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_eE_\nu} + b\frac{m_e}{E_e} + \frac{\langle\vec{\sigma}_n\rangle}{\vec{\sigma}_n}\cdot\left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e\times\vec{p}_\nu}{E_eE_\nu}\right)\right]$$

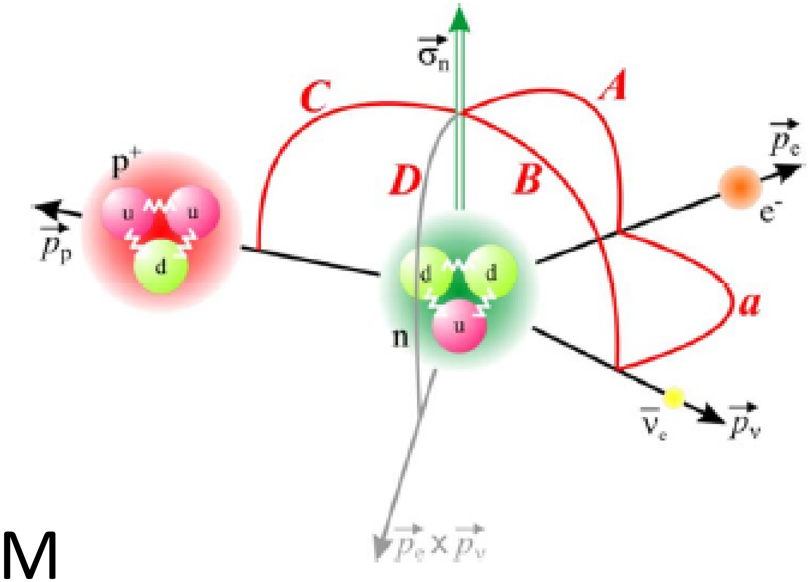
J.D. Jackson *et al.*, PR 106, 517 (1957)

- 3 unknown parameters

  G_F, V_{ud}, $\lambda = g_A/g_V$
- 20 or more observables

  τ_n, a, b, A, B, C, D, …
- yet unmeasured

  b



Symmetry tests beyond SM

Is the electroweak interaction purely V-A ?

- scalar (S) and tensor (T) admixtures
- right handed (V+A) currents

Standard Model: $L_V=1$; $L_A=\lambda$; $L_S= L_T= R_V= R_A= R_S= R_T=0$

Neutron lifetime: $\tau_n^{-1} \propto \left(|L_V|^2 + 3|L_A|^2\right) + \left(|L_S|^2 + 3|L_T|^2 + |R_V|^2 + 3|R_A|^2 + |R_S|^2 + 3|R_T|^2\right)$

SM: $\propto \;(\mathbf{1+3|\lambda|^2})$

$\bar{\upsilon}_e - e$ Correlation:

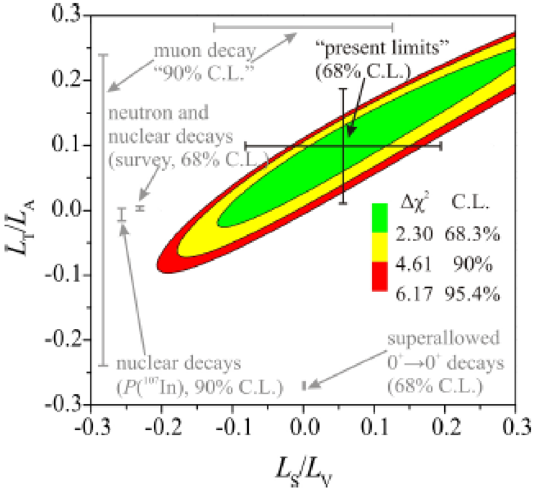
$$a = \frac{|L_V|^2 - |L_A|^2 - |L_S|^2 + |L_T|^2 + |R_V|^2 - |R_A|^2 - |R_S|^2 + |R_T|^2}{|L_V|^2 + 3|L_A|^2 + |L_S|^2 + 3|L_T|^2 + |R_V|^2 + 3|R_A|^2 + |R_S|^2 + 3|R_T|^2}$$

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

Beta Asymmetry:

$$A = \frac{2\cdot \Re e\left(-|L_A|^2 - L_V L_A^* + |L_T|^2 + L_S L_T^* + |R_A|^2 + R_V R_A^* - |R_T|^2 - R_S R_T^*\right)}{|L_V|^2 + 3|L_A|^2 + |L_S|^2 + 3|L_T|^2 + |R_V|^2 + 3|R_A|^2 + |R_S|^2 + 3|R_T|^2}$$

SM: $A = \mathbf{-2}\,\frac{\mathbf{|\lambda|^2 + |\lambda|}}{\mathbf{1+3|\lambda|^2}}$



<u>Present limits from neutron decay (only a, A, and B)</u>

Typical current relative precision: $O(10^{-2} - 10^{-3})$

Goal of next generation: $O(10^{-3} - 10^{-4})$

for some observables

The Parameters of Big Bang Nucleosynthesis

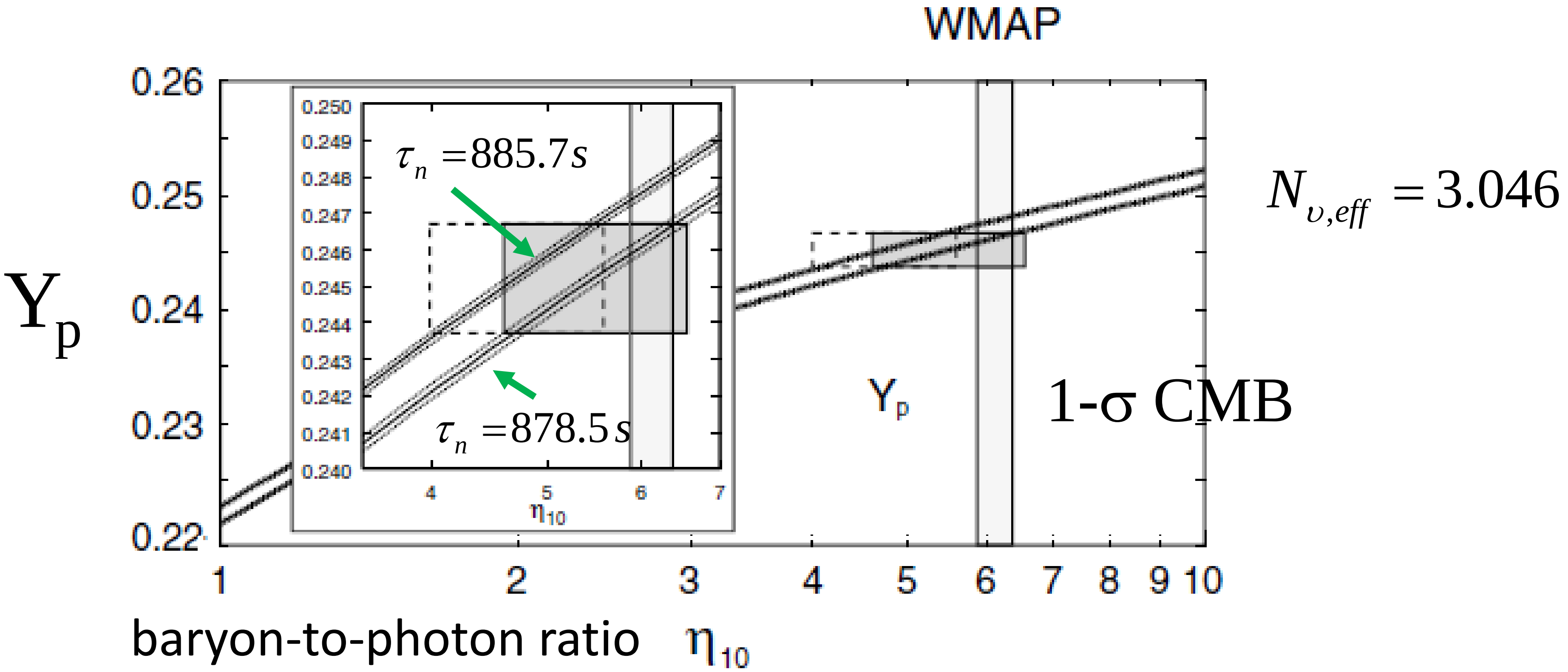
$$\boxed{Y_p} = 0.228 + 0.023 \log \boxed{\eta_{10}} + 0.012 \boxed{N_\nu} + 0.018(\boxed{\tau_n} - 10.28)$$

Cosmic Helium Abundance

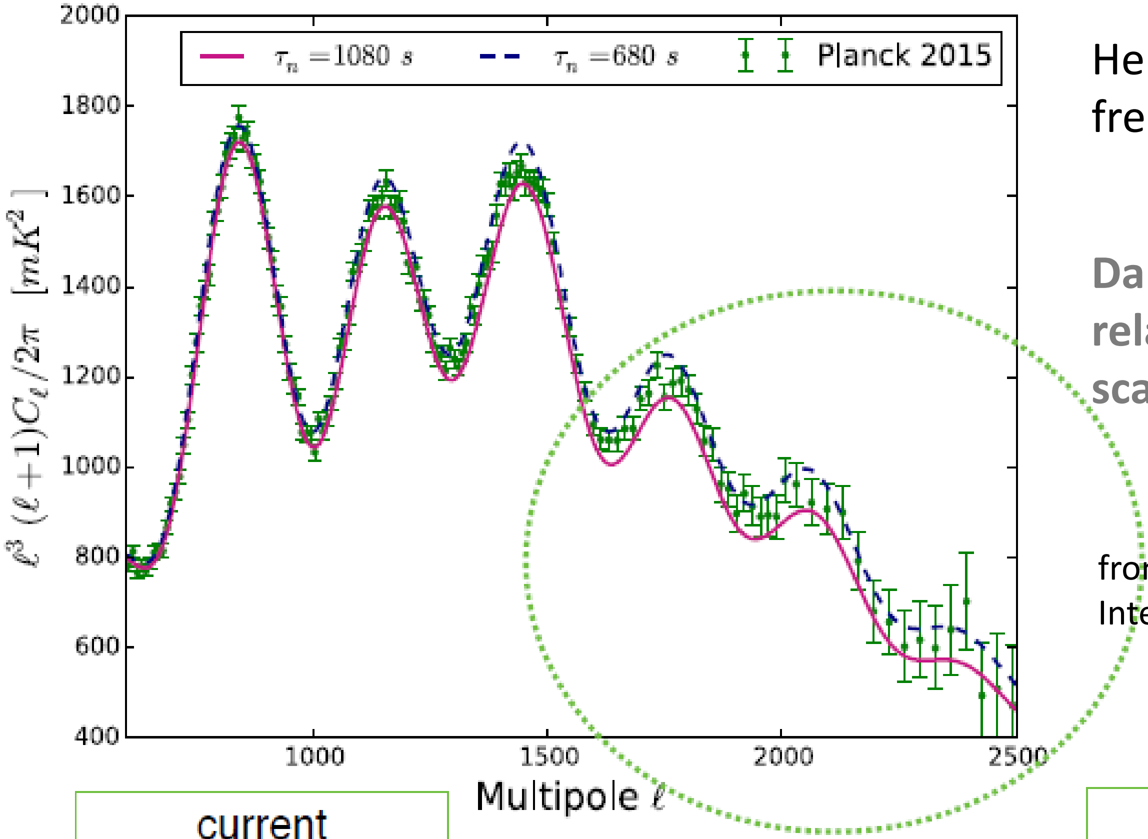
Cosmic Baryon Density

Number of Neutrino Flavors

Neutron Lifetime in Minutes



Cosmological constrains on neutron lifetime



Big Bang nucleosynthesis

Helium recombination affects free electrons fraction

Damping tail of CMB spectrum related to the thickness of the last scattering of photon with electron

from: Laura Salvati,
International UCN Workshop @ Mainz 2016

Journal of Cosmology
and Astroparticle Physics, 2016 (2016)

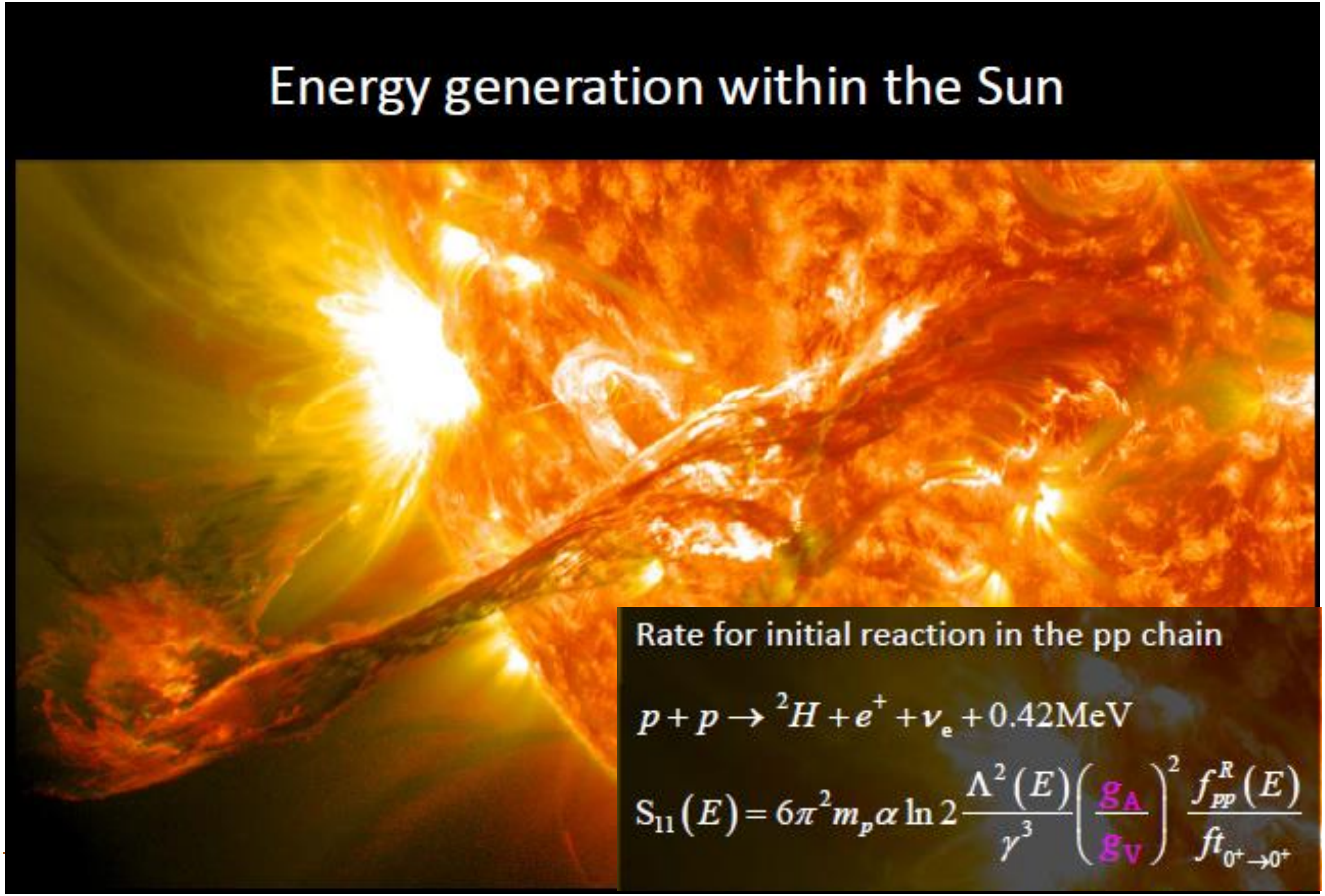
current
cosmological and
astrophysical data

$\sigma_{\tau_n} \simeq 15\,\mathrm{s}$

future
cosmological and
astrophysical data

$\sigma_{\tau_n} \sim\ \mathrm{s}$

Important Processes with the same Feynman Diagram as Neutron Decay



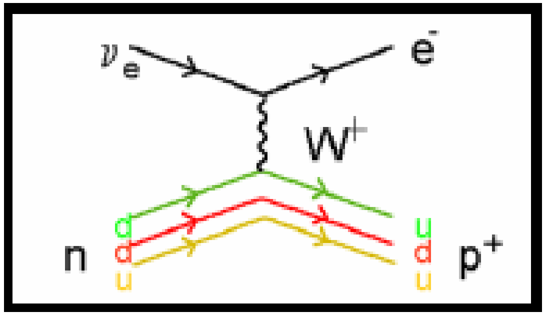
Energy generation within the Sun

Rate for initial reaction in the pp chain

$$p + p \rightarrow {}^2H + e^+ + \nu_e + 0.42\mathrm{MeV}$$

$$\mathrm{S}_{11}(E) = 6\pi^2 m_p \alpha \ln 2 \frac{\Lambda^2(E)}{\gamma^3}\left(\frac{g_A}{g_V}\right)^2 \frac{f_{pp}^R(E)}{ft_{0^+\to 0^+}}$$

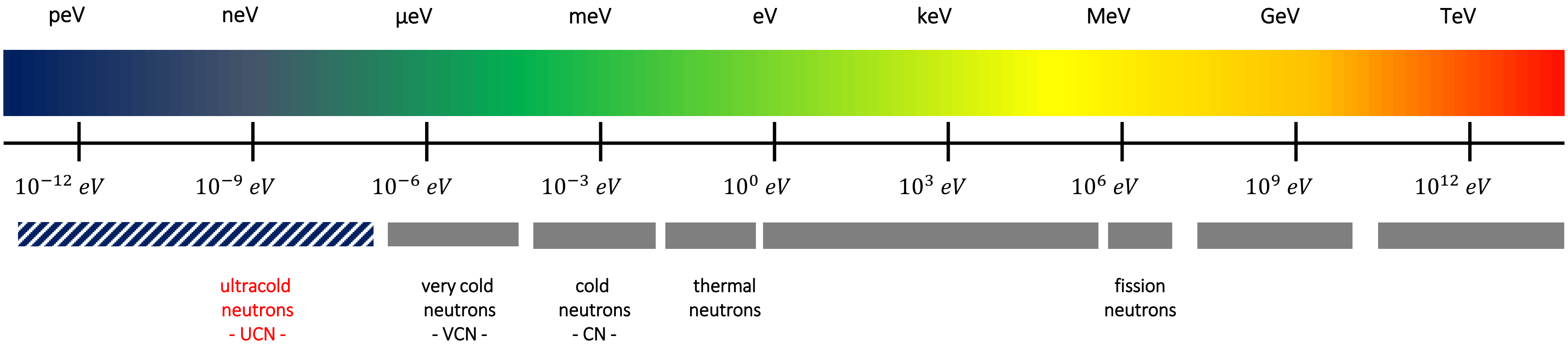
Important Processes with the same Feynman Diagram as Neutron Decay



Primordial element formation	$n + e^+ \longleftrightarrow p + \nu_e$
	$p + e^- \longleftrightarrow n + \nu_e$
	$n \longrightarrow p + e^- + \overline{\nu}_e$
Solar cycle	$p + p \longrightarrow {}^2H + e^+ + \nu_e$
	$p + p + e^- \longrightarrow {}^2H + \nu_e$ etc.
Neutron star formation	$p + e^- \longrightarrow n + \nu_e$
Pion decay	$\pi^- \longrightarrow \pi^0 + e^- + \overline{\nu}_e$
Neutrino detectors	$\nu_e' + p \longrightarrow e^+ + n$
Neutrino forward scattering	$\nu_e + n \longrightarrow e^- + p$ etc.

After D.Dubbers

Neutron Energy Spectrum



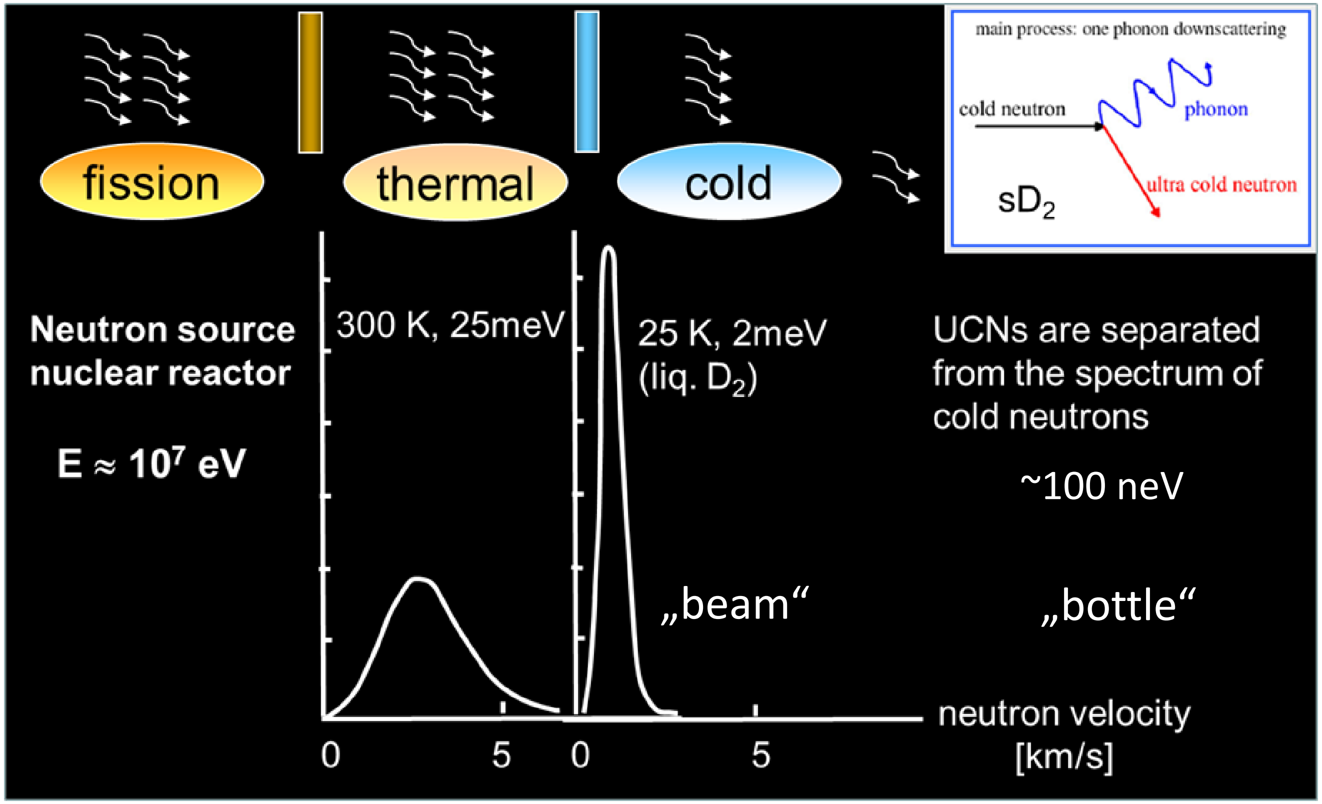
ultracold neutrons
- UCN -

very cold neutrons
- VCN -

cold neutrons
- CN -

thermal neutrons

fission neutrons



Neutron source nuclear reactor

$E \approx 10^7$ eV

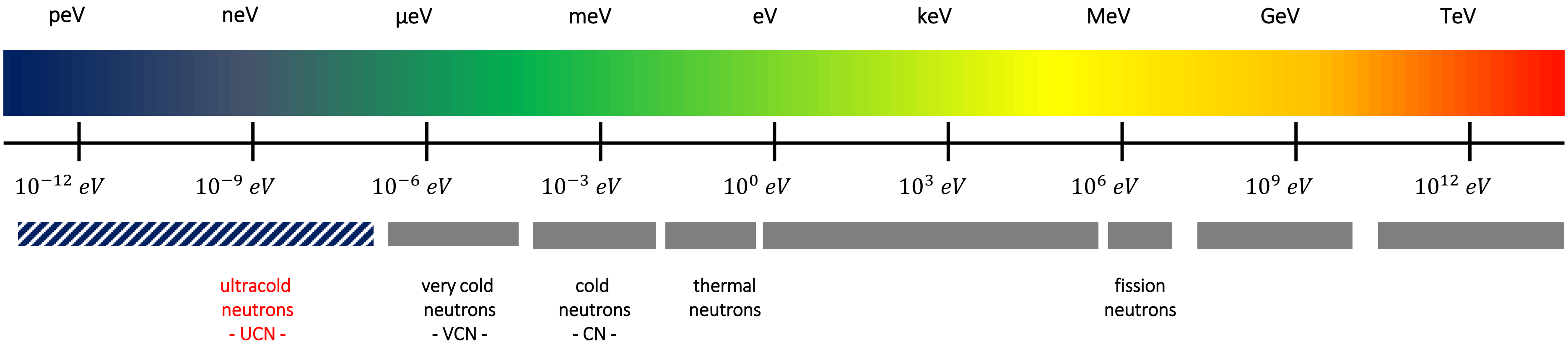
„beam“

UCNs are separated from the spectrum of cold neutrons

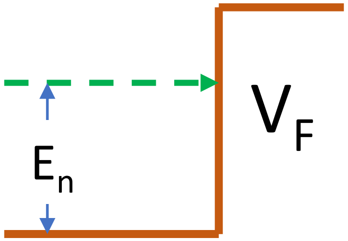
~100 neV

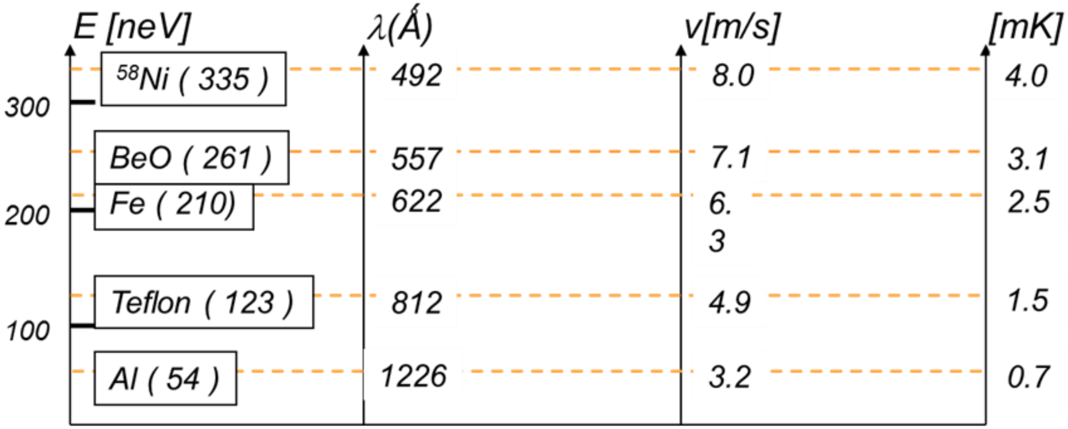
„bottle“

Neutron Energy Spectrum



UCN: storable neutrons

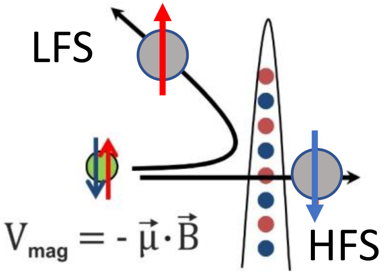




E [neV]	λ(Å)	v[m/s]	[mK]
^{58}Ni (335)	492	8.0	4.0
BeO (261)	557	7.1	3.1
Fe (210)	622	6. 3	2.5
Teflon (123)	812	4.9	1.5
Al (54)	1226	3.2	0.7

<ins>magnetic energy</ins>:

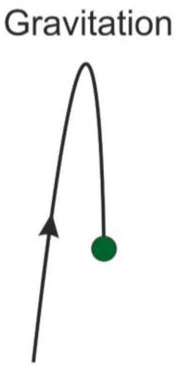
$$E_{mag} = -\vec{\mu}_n \cdot \vec{B} \approx 60\,neV\ @\ B = 1\,Tesla$$



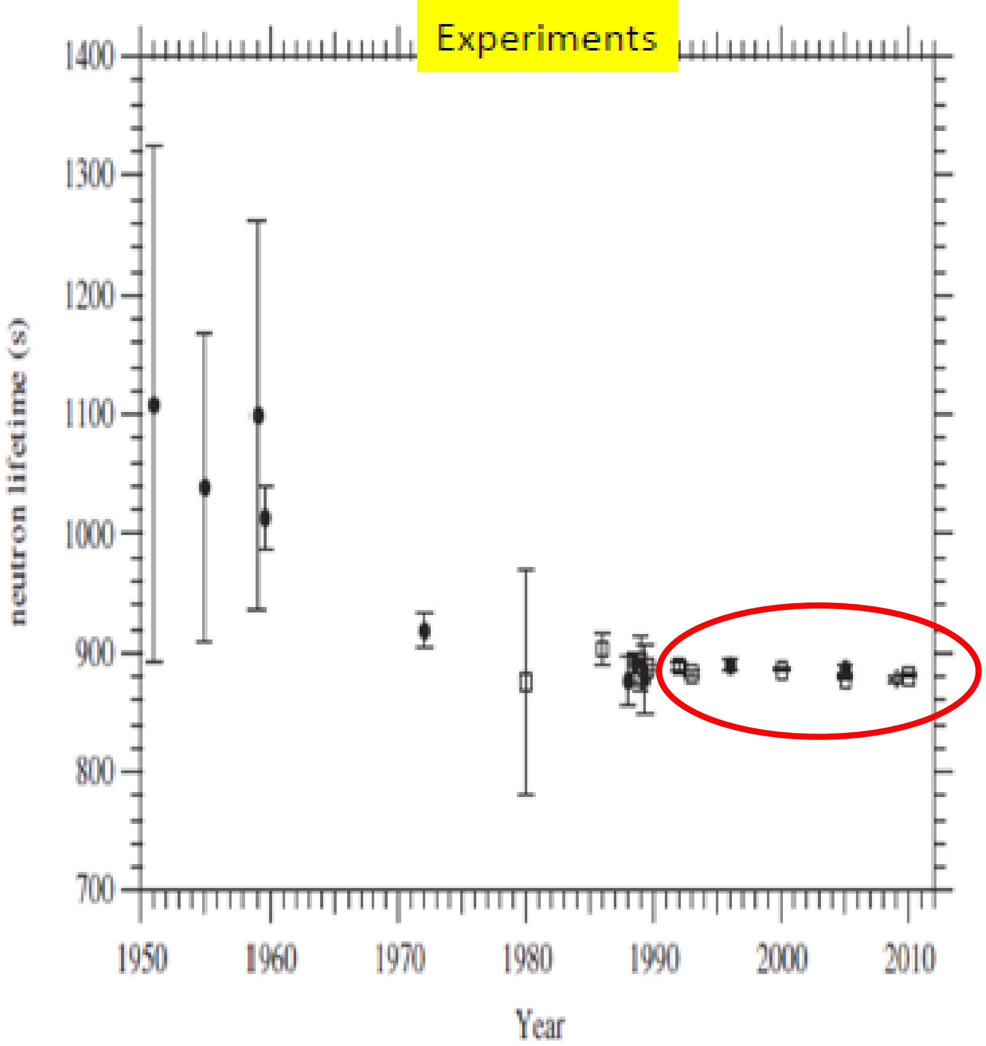
$$V_{mag} = -\vec{\mu} \cdot \vec{B}$$

<ins>gravitational energy</ins>:

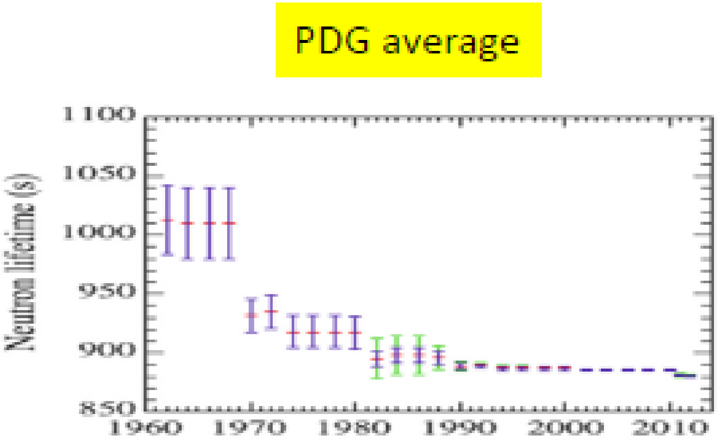
$$E_{pot} = m_n \cdot g \cdot h \approx 100\,neV\ @\ h = 1m$$



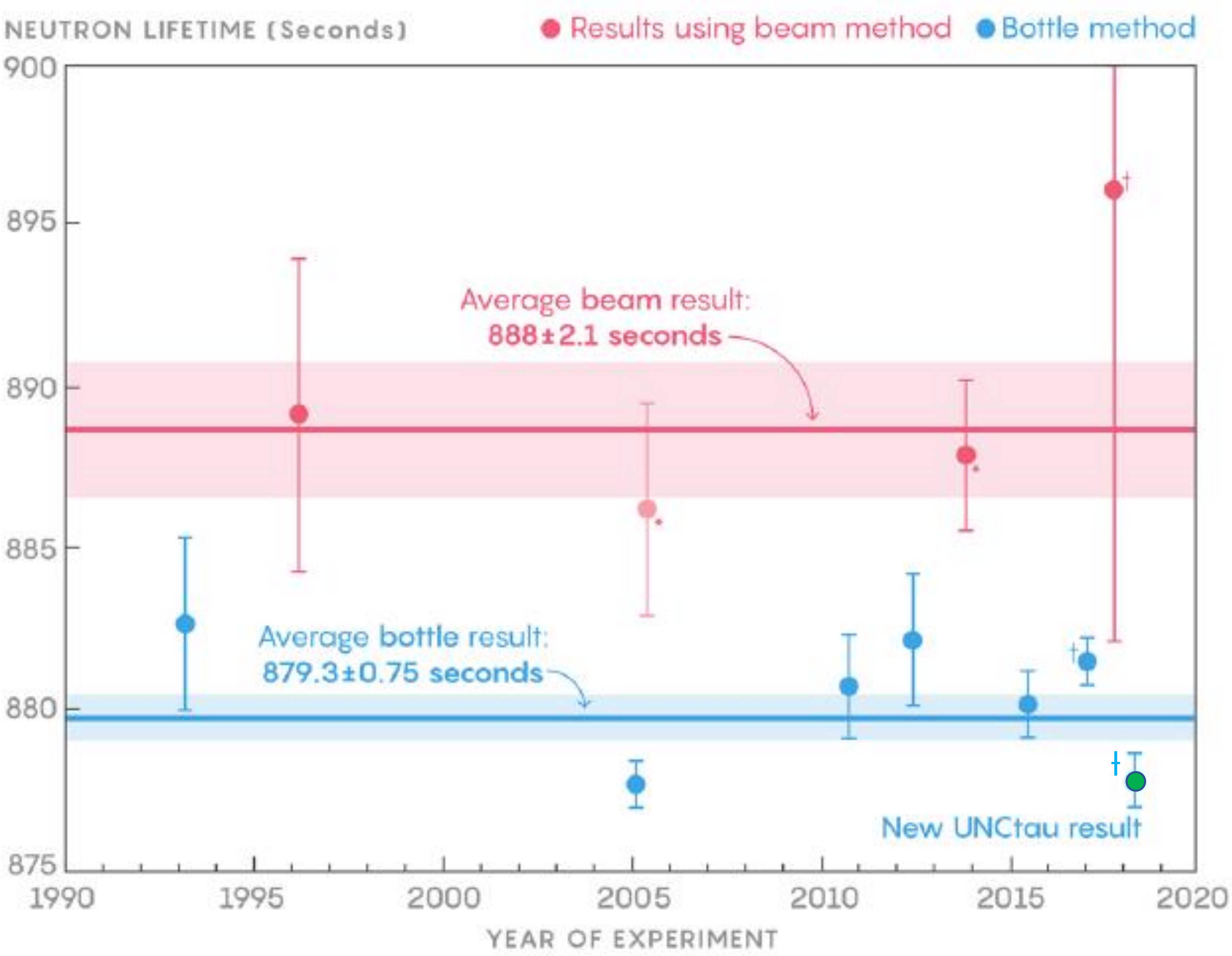
The History of Neutron Lifetime: PDG compilation



Solid circle: beam
Open square: bottle



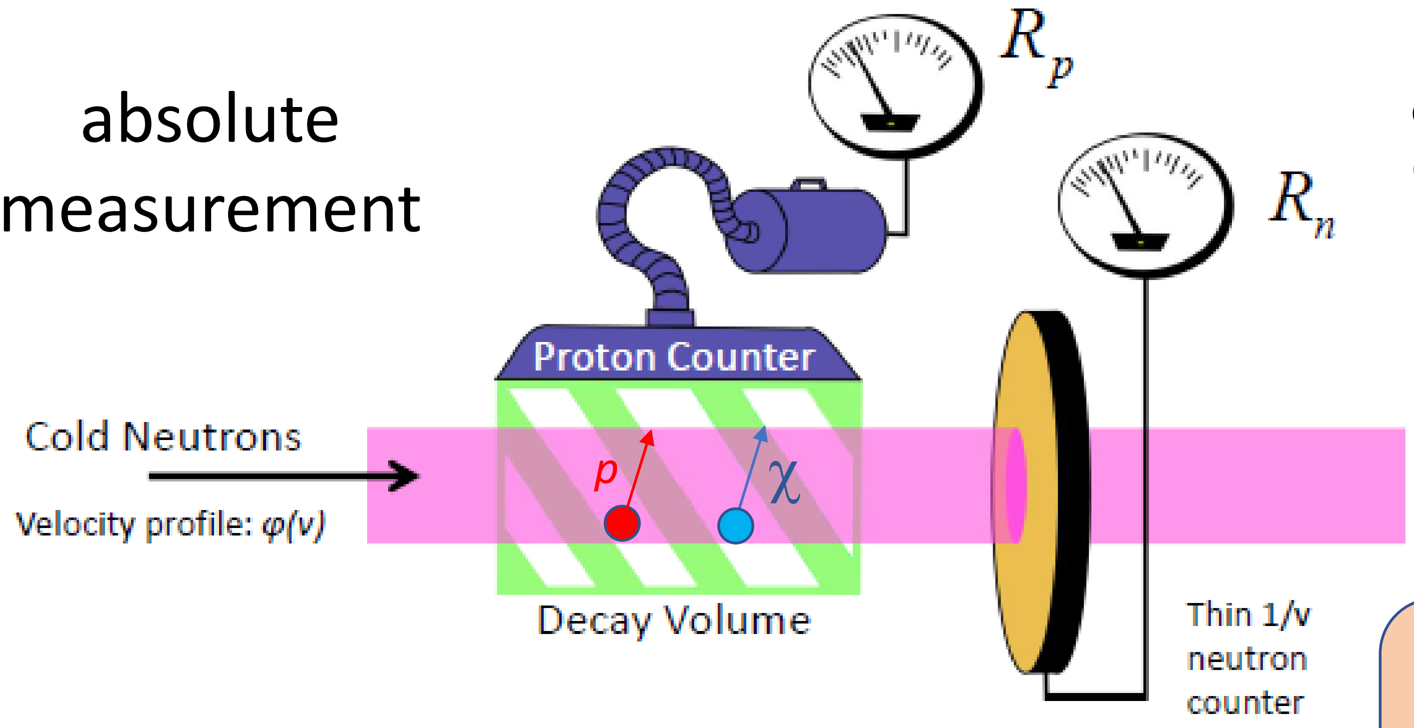
PDG 2004-2010: 885.7 ± 0.8 s
PDG 2011: 881.0 ± 1.5 s
PDG 2013: 880.0 ± 0.9 s
PDG 2014: 880.3 ± 1.1 s



Source: pre-2017,PDG; Serebrov 2017, arXiv:1712.05663; Pattie,2018, arXiv:1707.01817

How to Measure τ_n in a Beam

absolute measurement



$$R_p = \varepsilon_p \cdot \frac{dN}{dt} = \varepsilon_p \cdot \frac{(A_{beam} \cdot L)}{\tau_n} \cdot \rho_n$$

$$R_n = \varepsilon_{th} \cdot A_{beam} \cdot v_{th} \cdot \rho_n$$

$$\boxed{\tau_n^{(p)} = \frac{R_n \varepsilon_p L}{R_p \varepsilon_{th} v_{th}}}$$

FM absorbs neutrons as 1/v
So it's calibrated at thermal velocity

exotic decay channels (DM particles: χ, ϕ)

B. Fornal et al. arXiv:1801.01124v2, 2018

$$n \to \chi + \phi$$

$$n \to \chi + \gamma$$

$$\boxed{\frac{1}{\tau_n} = \frac{1}{\tau_n^{(p)}} + \frac{1}{\tau_n^{DM}} + \ldots}$$

$$\to \tau_n < \tau_n^{(p)}$$

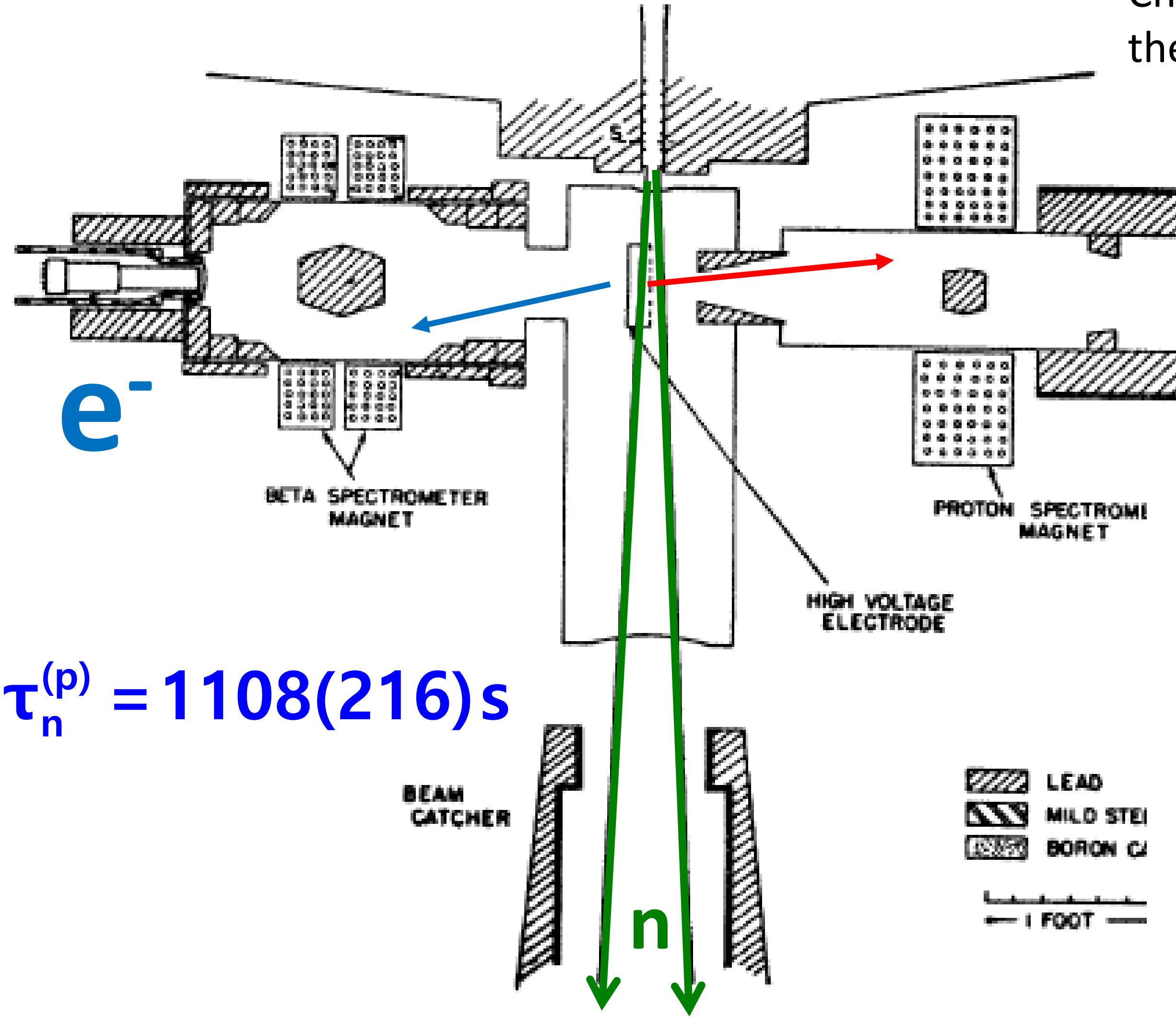
Z. Tang, et al., arXiv:1802.01595

$n \to \chi + photon$ ruled out

Note: $n \to H + \bar{\upsilon}_e$ (BR: ~4x10^{-6}) exists

1^{st} precise lifetime experiment: Robson et al., 1951

Chalk River reactor
thermal n-beam: 2×10^9 n/cm^2/s



$$\tau_n^{(p)} = 1108(216)\,\text{s}$$

Fig. 1. Plan view of the apparatus mounted ou the main shield of the pile.

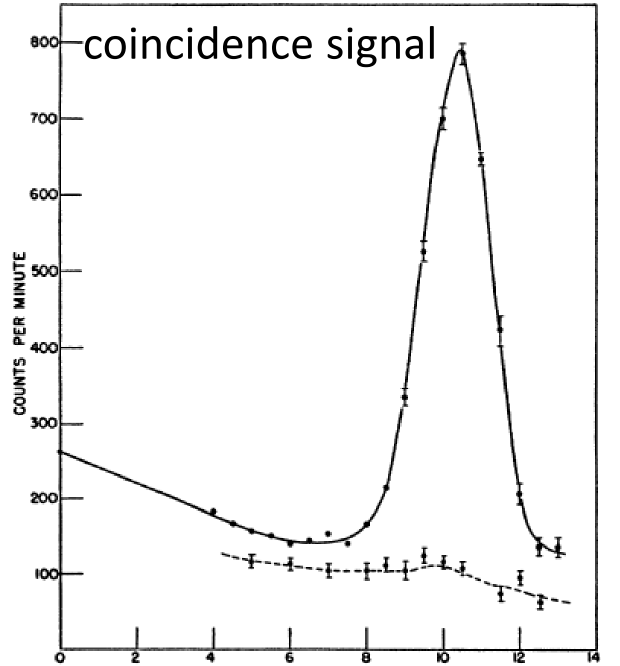
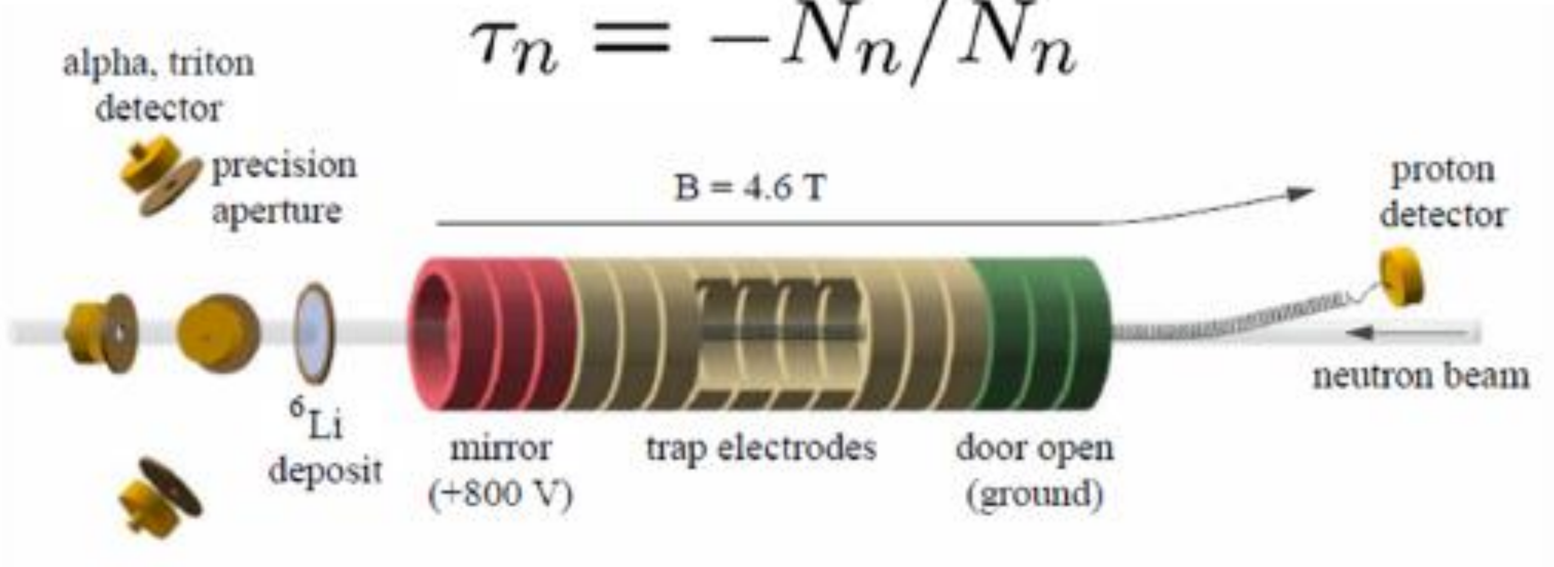


Fig. 4. Counting rate of the electron multiplier plotted against current through the proton spectrometer magnet.

The NIST Beam Lifetime Experiment (BL1, BL2)

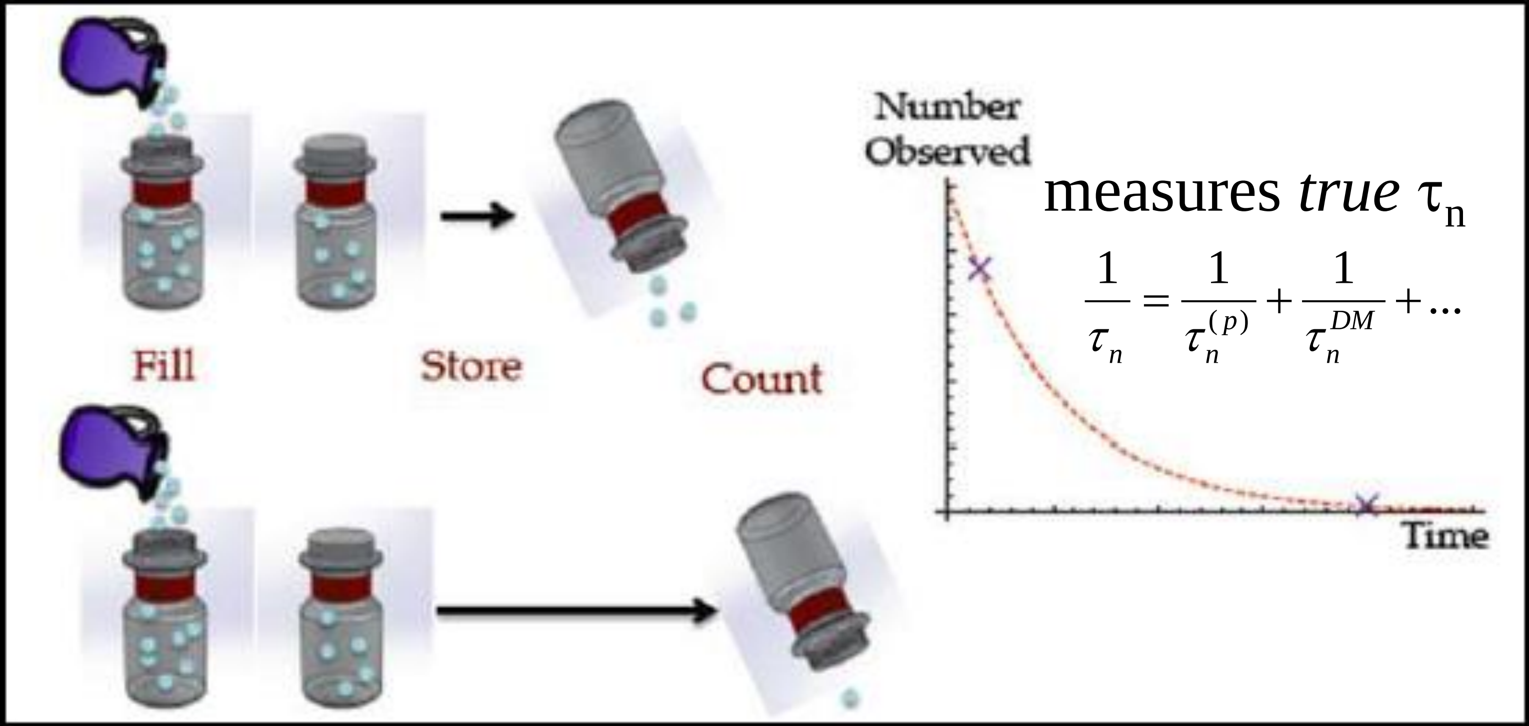
$$\tau_n = -\bar{N}_n/\dot{N}_n$$



Yue et al., Phys. Rev. Lett. 111, 222501 (2013)

- A quasi-penning trap electrostatically traps decay protons, which are guided to detector via a B field, when the door electrodes are lowered to the ground potential.
- Neutron monitor measures incident neutron rate by counting n+^{6}Li→ α+t.

The Bottle Method: *fill-store-count*



measures *true* τ_n

$$\frac{1}{\tau_n} = \frac{1}{\tau_n^{(p)}} + \frac{1}{\tau_n^{DM}} + \ldots$$

Measures the Storage Time

relative measurement

$$\frac{1}{\tau_{mea}} = \frac{1}{\tau_{\beta}} + \frac{1}{\tau_{ab}} + \frac{1}{\tau_{up}} + \frac{1}{\tau_{sf}} + \frac{1}{\tau_{heat}} + \frac{1}{\tau_{qb}} + \ \ldots$$

The first neutron lifetime experiment with UCN
(V.I. Morozov's group at SM-2 reactor Dimitrovgrad, Russia)

Yu. Yu. Kosvintsev, Yu. A. Kushnir, V. I. Morozov, and G. I. Terekhov

Pis'ma Zh. Eksp. Teor. Fiz. **31**, No. 4, 257–261 (20 February 1980)

$$\boxed{\tau_p = 875 \pm 95 \text{ сек.}}$$

Pis'ma Zh. Eksp. Teor. Fiz. **44**, No. 10, 444–446 (25 November 1986)

$$\boxed{\tau_\beta = 903 \pm 13 \text{ s}}$$

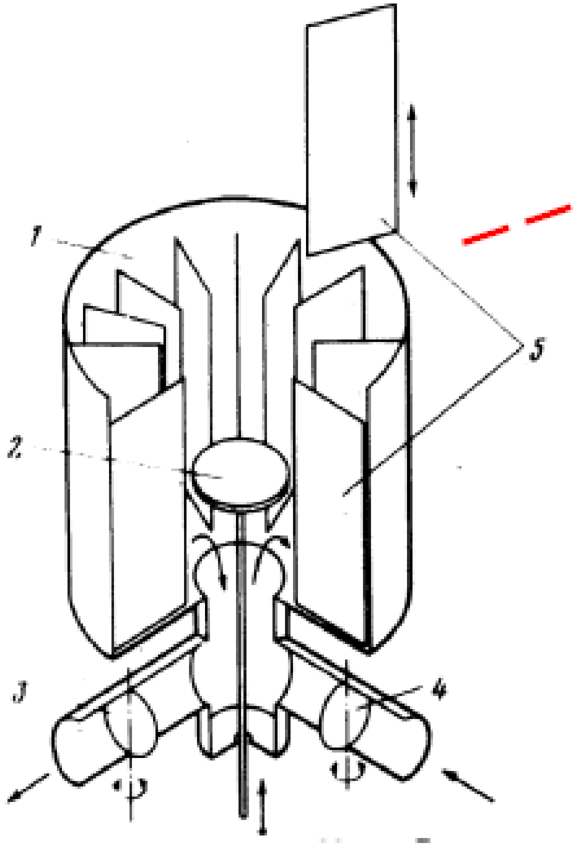
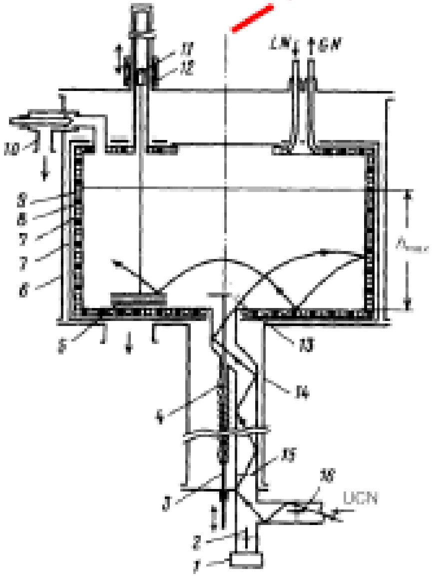


FIG. 1. Storage container for UCN: 1, cylindrical container; 2, disk shutter; 3, output shutter.



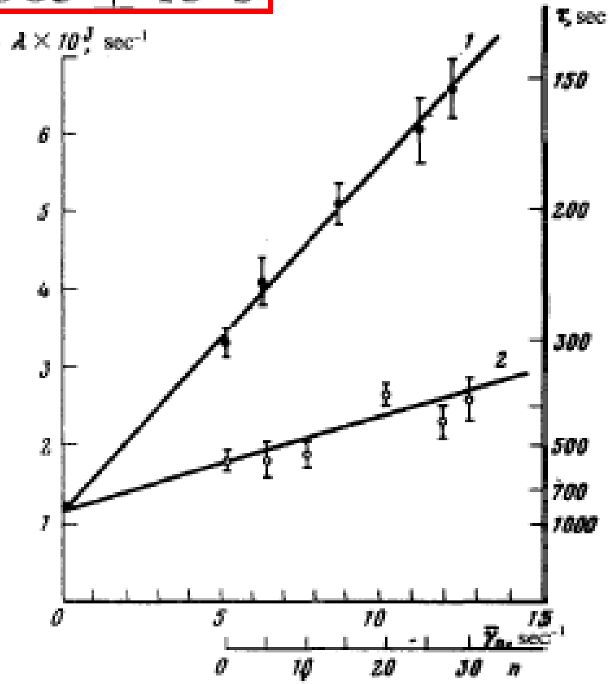
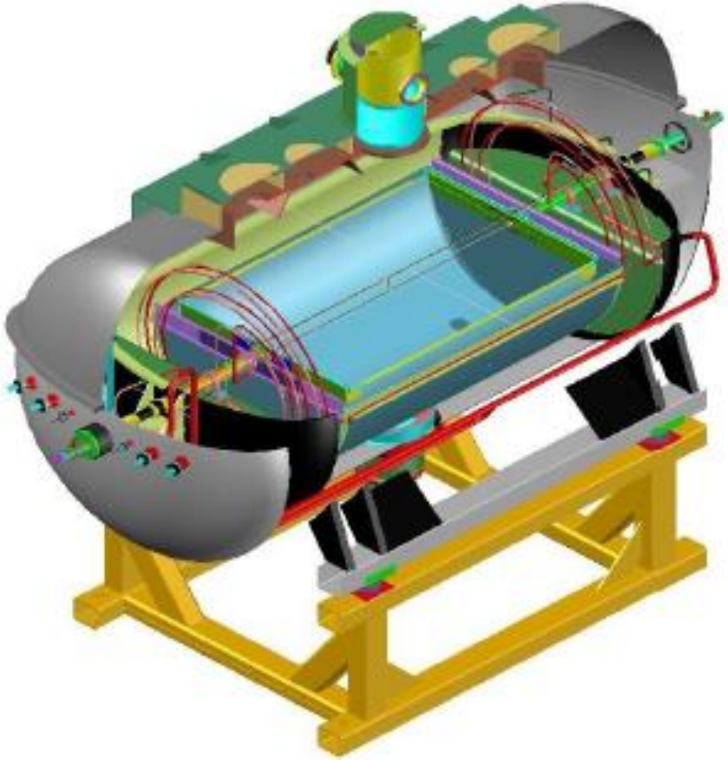
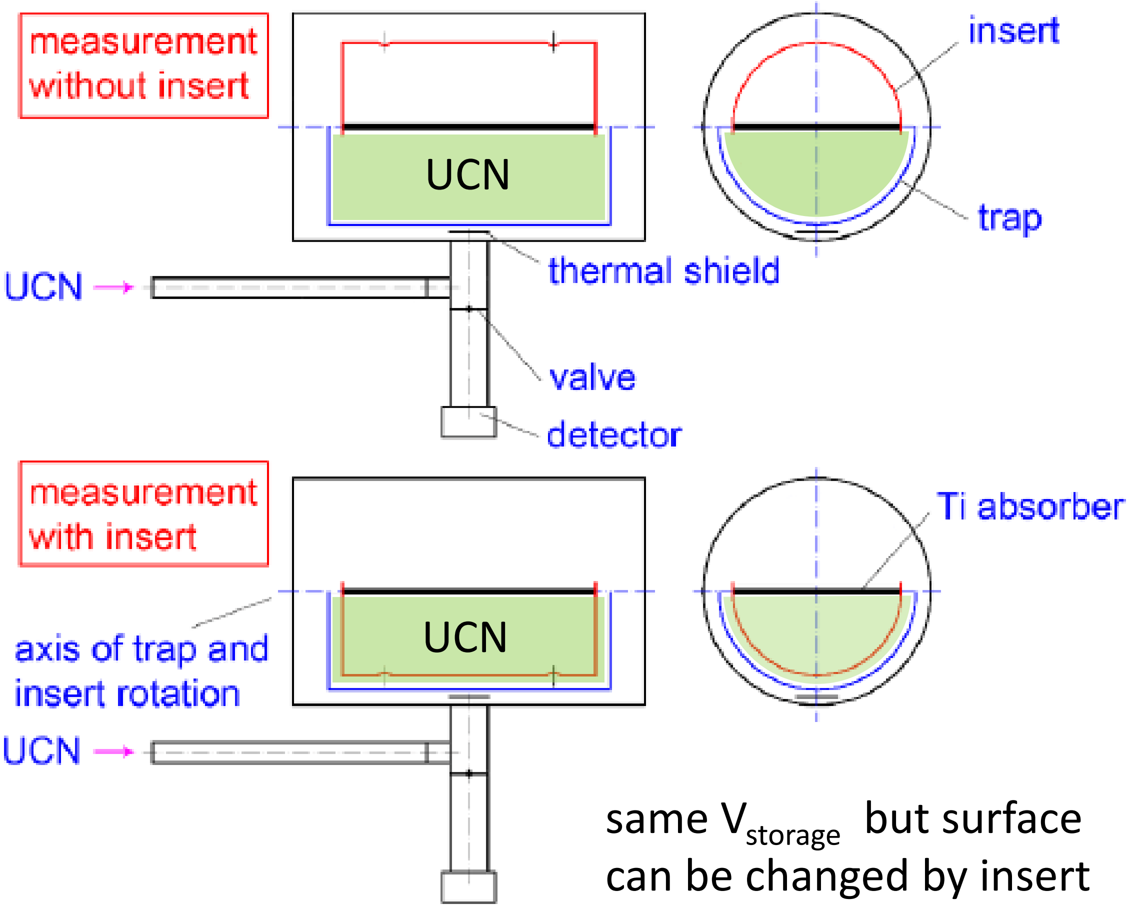


FIG. 3. Experimental dependeces of λ_{exp} on $\bar{\gamma}_n$:1, first series of measurements; 2, second series of measurements.

The Big Gravitational Trap
with Fomblin grease coating

PNPI – ILL collaboration





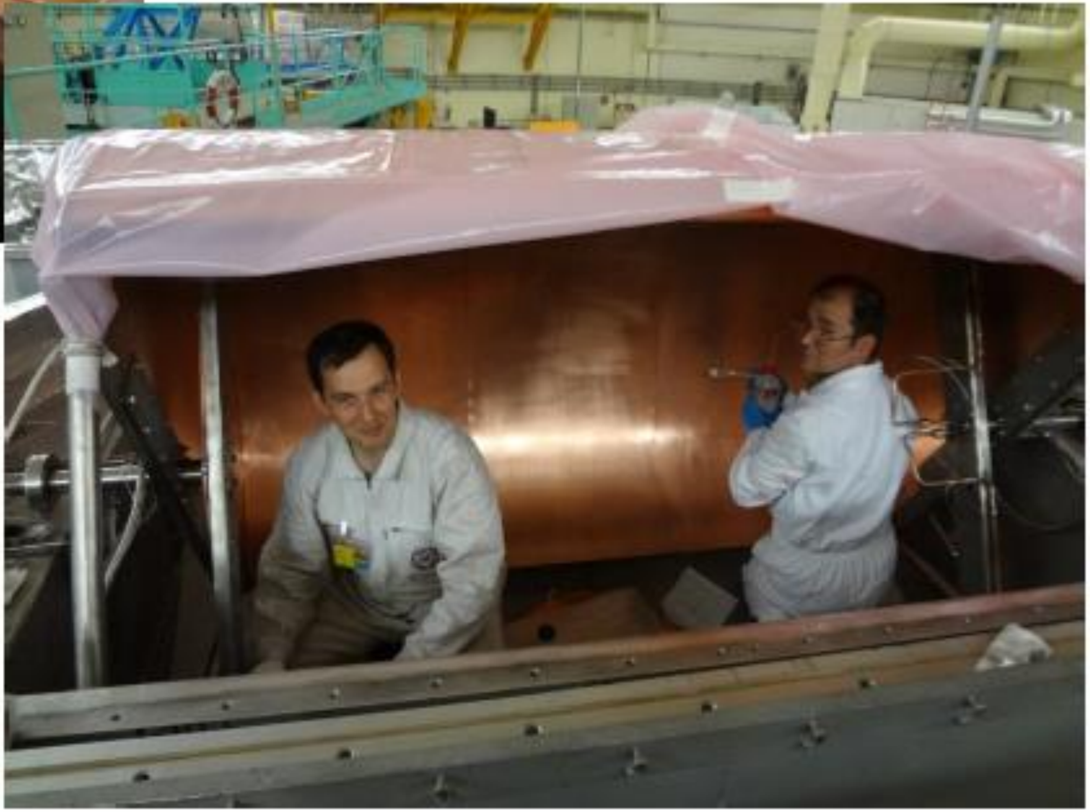
same $V_{storage}$ but surface can be changed by insert

Installation of Big Gravitrap on ILL reactor (August 2014)

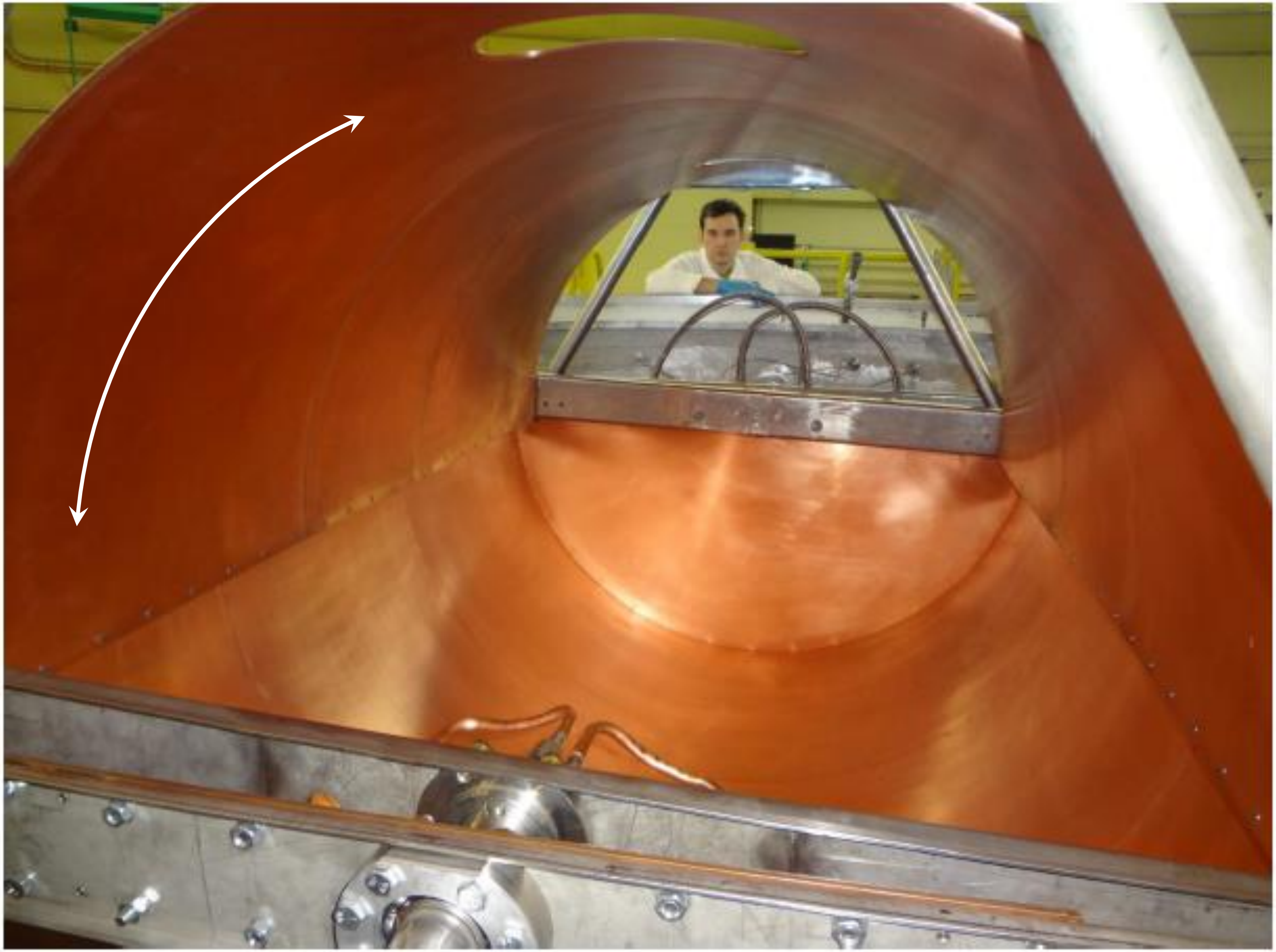
Cleaning of Cu Trap and

coating by Fomblin grease

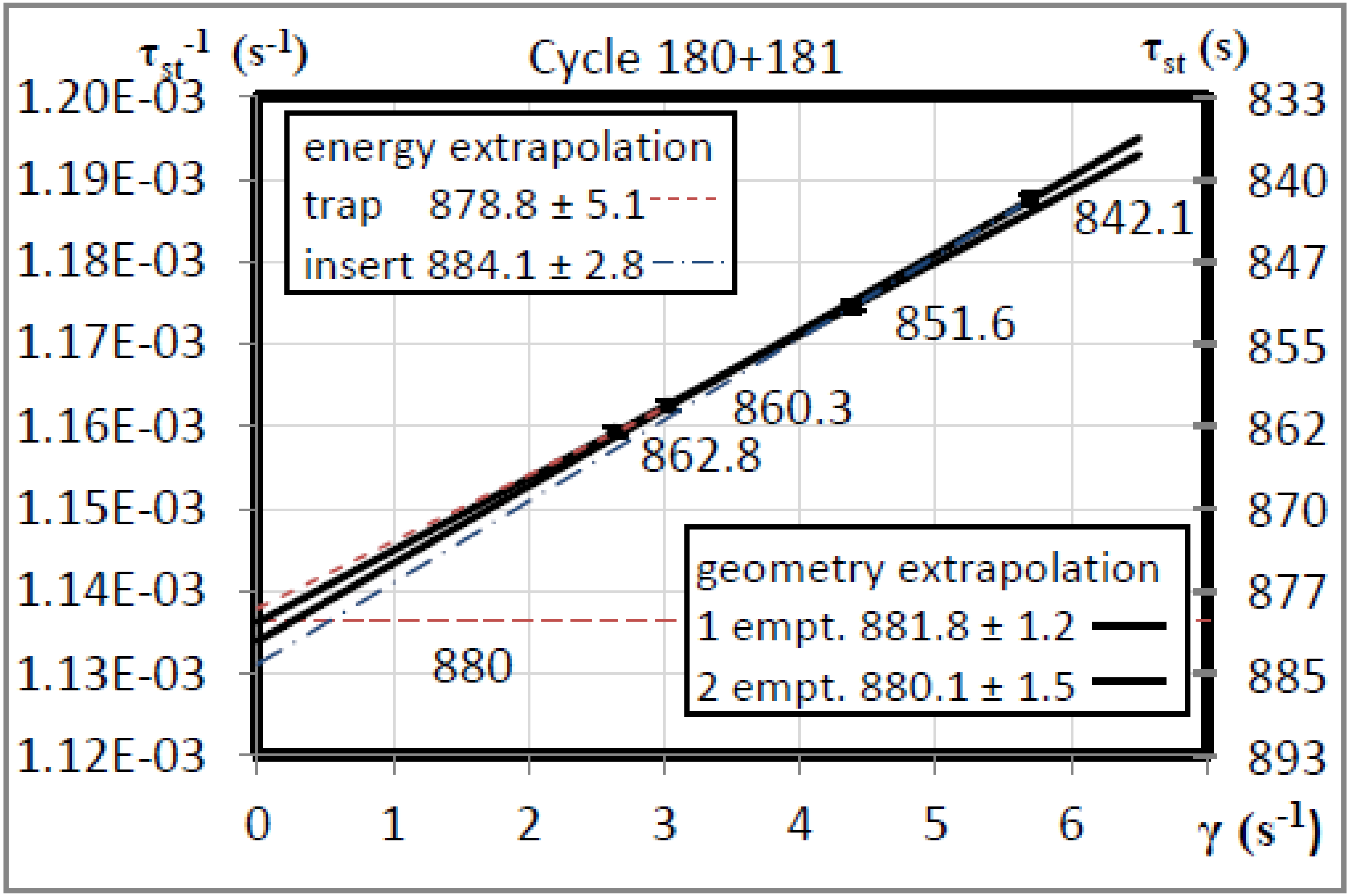
(fluorinated lubricant)



Cu Trap coated by Fomblin grease



(Serebrov et al., arXiv:1712.05663, 2017) $\tau_n = (881.5 \pm 0.7_{stat} \pm 0.6_{syst})\,s$



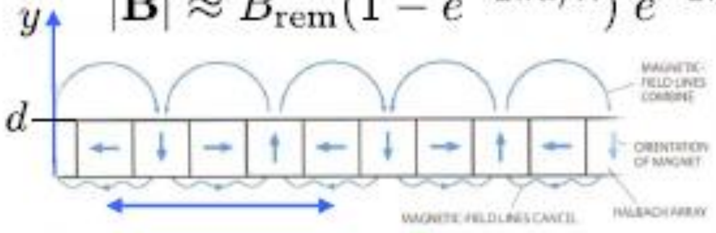
Loss rate due to Fomblin grease : ~1/40000 s^{-1}

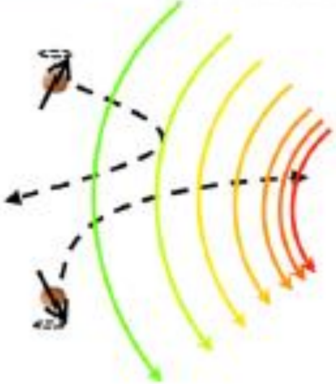
UCNτ Magneto-gravitational trap

Operated at LANL

~5500 permanent magnets

$$|\mathbf{B}| \approx B_{\text{rem}}\left(1 - e^{-2\pi d/\lambda}\right) e^{-2\pi y/\lambda}$$





advantage of magnetic storage:
control of „magnetic wall“ losses

Material: C.-Y. Liu
EXA2017

Probability of depolarization

- Precession of magnetic moment

$$\frac{d\vec{\mu}}{dt} = \gamma_n \vec{\mu} \times \vec{B}$$

$$\gamma_n = 1.83 \cdot 10^8 s^{-1} T^{-1}$$

- Adiabatic condition

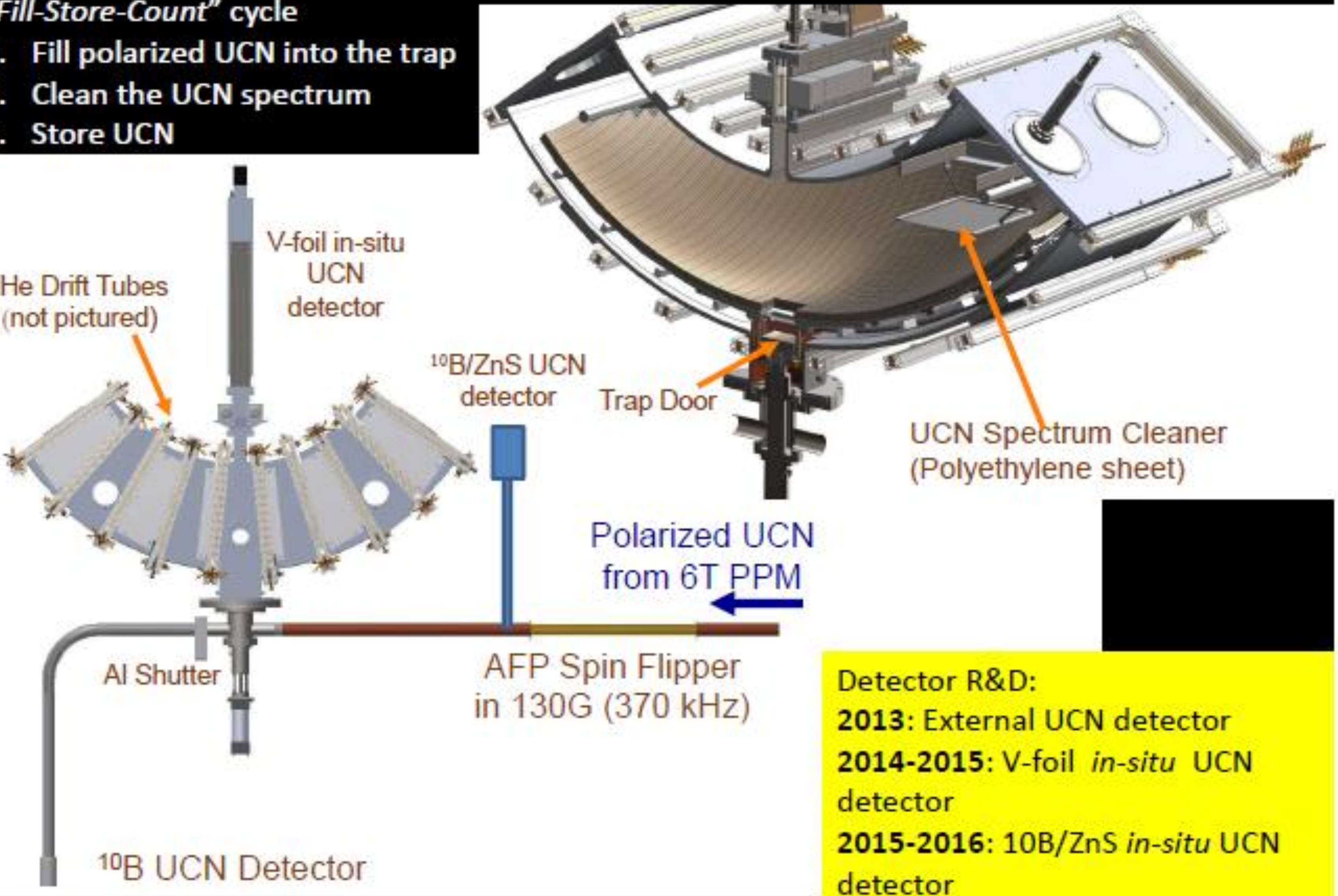
$$\gamma_n B >> \left(dB/dt\right)/B = v \cdot \nabla |B| / B$$

- (v-- is the velocity of neutron)
- For case of strong field
- (B = 1T), ∇B = 1T/mm and velocity v = 3.4 m/s one can receive next relation for adiabatic condition:
- $1.83 \cdot 10^8 >> 3.4 \cdot 10^3$.

Operation of the UCNτ Experiment

"Fill-Store-Count" cycle

1. Fill polarized UCN into the trap
2. Clean the UCN spectrum
3. Store UCN



^{3}He Drift Tubes (not pictured)

V-foil in-situ UCN detector

^{10}B/ZnS UCN detector

Trap Door

UCN Spectrum Cleaner (Polyethylene sheet)

Polarized UCN from 6T PPM

Al Shutter

AFP Spin Flipper in 130G (370 kHz)

^{10}B UCN Detector

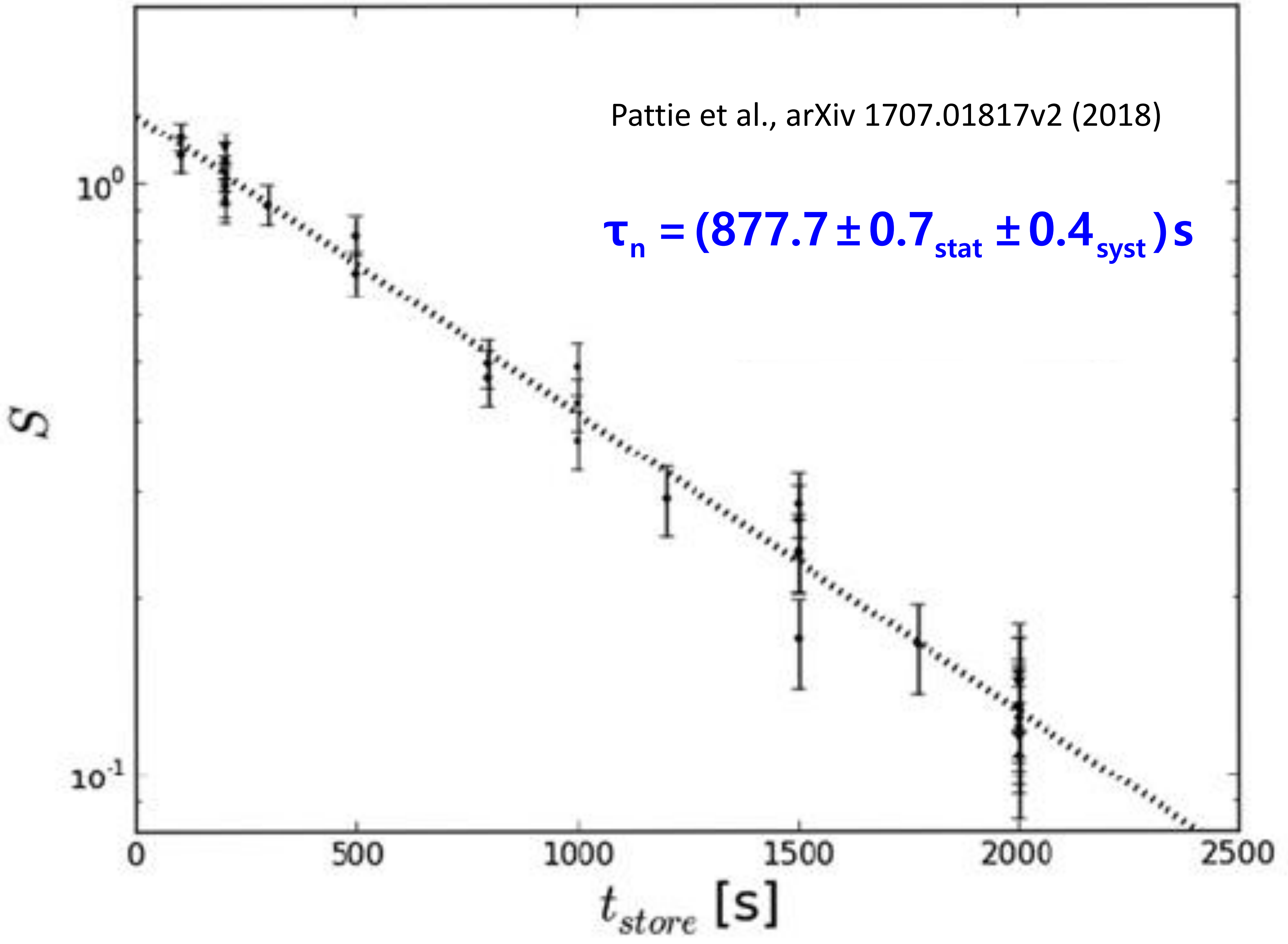
Detector R&D:

2013: External UCN detector

2014-2015: V-foil *in-situ* UCN detector

2015-2016: 10B/ZnS *in-situ* UCN detector

UCNτ apparatus installed at the LANSCE UCN facility: Feb. 2013



Pattie et al., arXiv 1707.01817v2 (2018)

$$\tau_n = (877.7 \pm 0.7_{stat} \pm 0.4_{syst})\,s$$

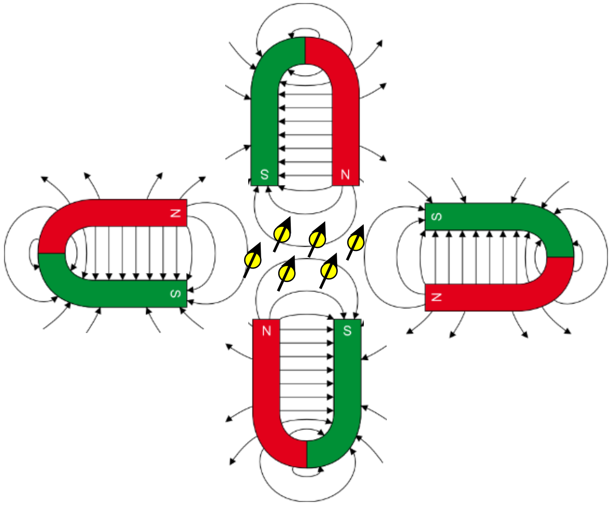
τSPECT

the neutron lifetime experiment at TRIGA Mainz

aim: $\Delta\tau_n \lesssim 0.3\ s$

S.Dewey et al., NIST [7]	In beam experiment	< 1s
K. Mishima et al., J-PARC **NIM A 799, 187 (2015)**	In beam experiment	1s
A. Steyerl et al., URI (ILL) [9]	Material bottle	~ 1 s
V. Morozov et al., KI (ILL)	Material bottle (Teflon+LTF)	~ 1s
A. Serebrov et al., PNPI (ILL)	LTF coated large gravitational tap	~ 0.2 s
P. Huffman NSCN (NIST/SNS) **NIM A 611, 171 (2009)**	Magnetic bottle, SC, sfHe, decay	< 2.4 s
S. Paul TUM (FRM-II) **NIM A 611, 176 (2009)**	Magnetic bottle, SC, decay PENeLOPE	~ 0.1 s
Y. Masuda, KEK (RCNP,J-Parc)	Magnetic bottle, SC, decay	~0.1 s
O. Zimmer, ILL **NIM A 611, 181 (2009)**	Magnetic bottle, permanent H.O.PE	~ 0.3s
V. Ezhov, PNPI (ILL) [17]	Magnetic bottle, permanent	0.2-0.3 s
D. Bowman, LANL, UCNt **Phys. Rev. C 89, 052501(R) (2014)**	Magnetic bottle, permanent	~ 0.1 s

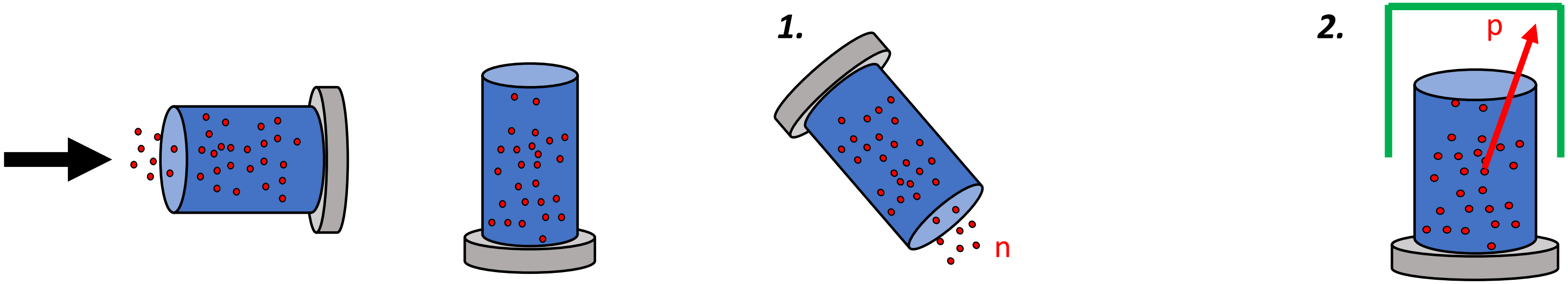
Concept of τSPECT



- **3D magnetic storage of UCN**

- **Measurement of τ_n via**

  1. ***Detection of the „survivors“***
  2. ***in-situ detection of the decay protons***



filling

storage

$$\frac{dn}{dt} \propto \frac{1}{\tau_n}$$

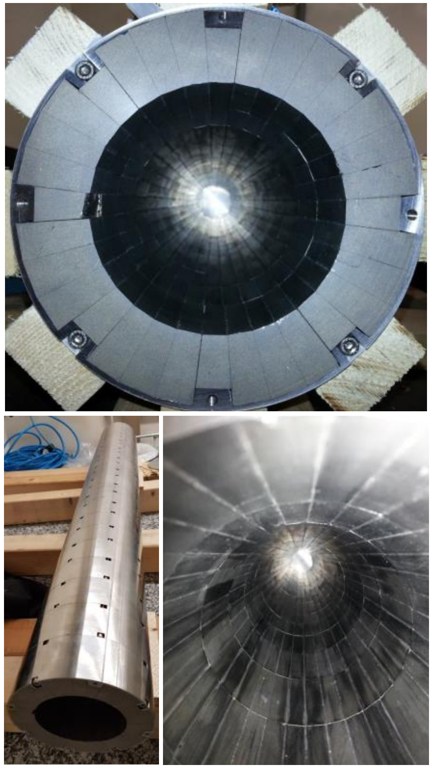
counting

$$\frac{dp}{dt} \propto \frac{1}{\tau_n}$$

3D- magnetic storage

Octupole magnet
Halbach-configuration

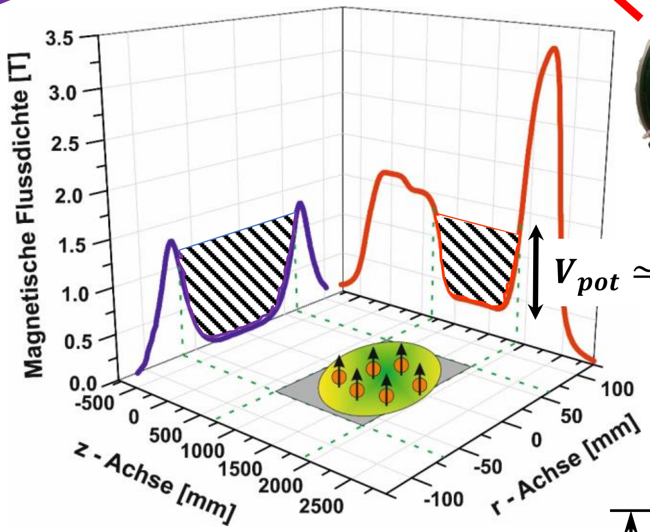
aSPECT superconducting
magnet



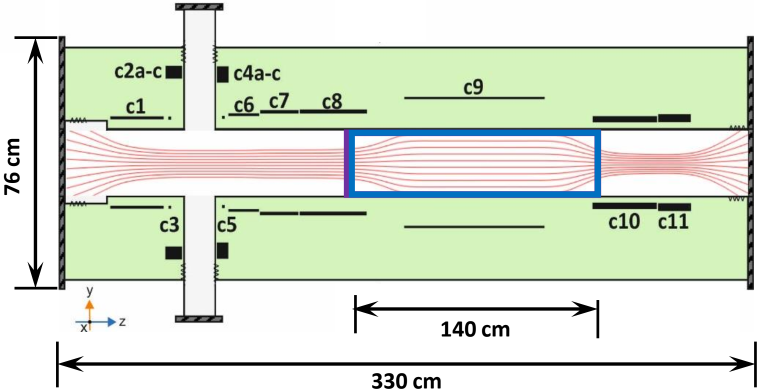
permanent magnets Sm_2Co_{17}

radial

axial

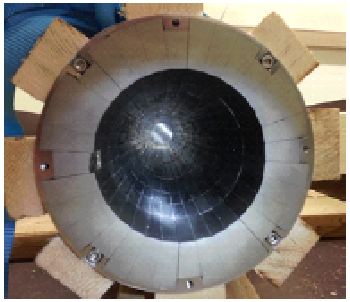


$V_{pot} \simeq 50\ neV$

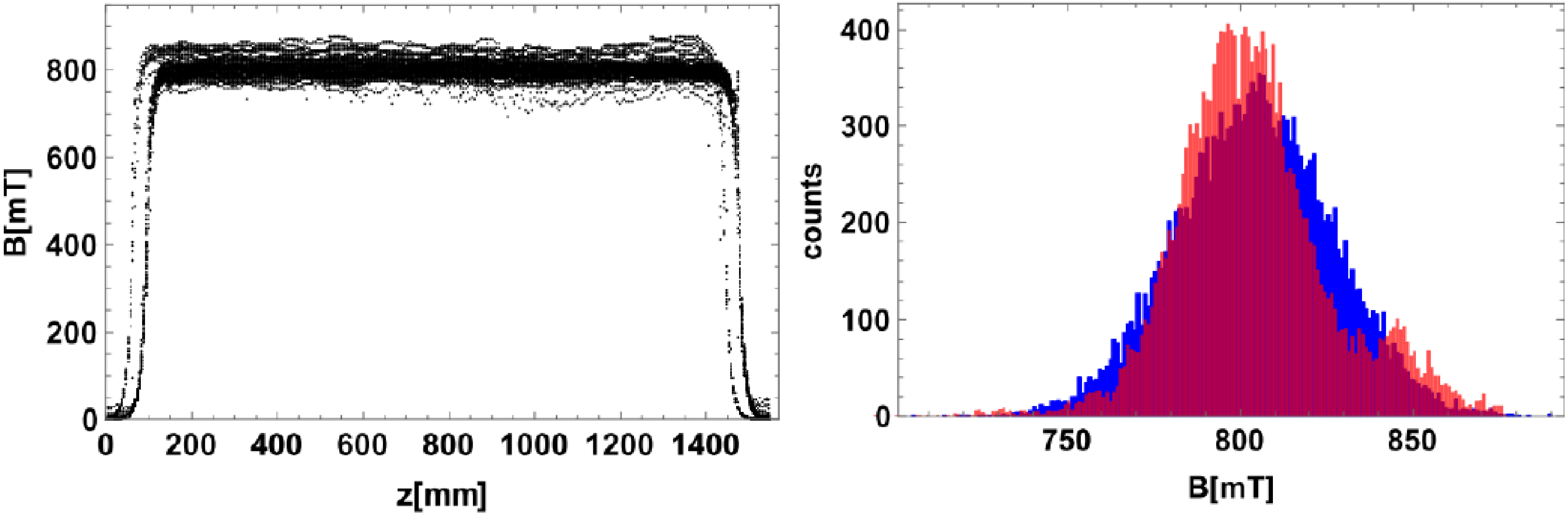


The magnetic octupole

Characterization of the
Halbach-type magnetic octupole

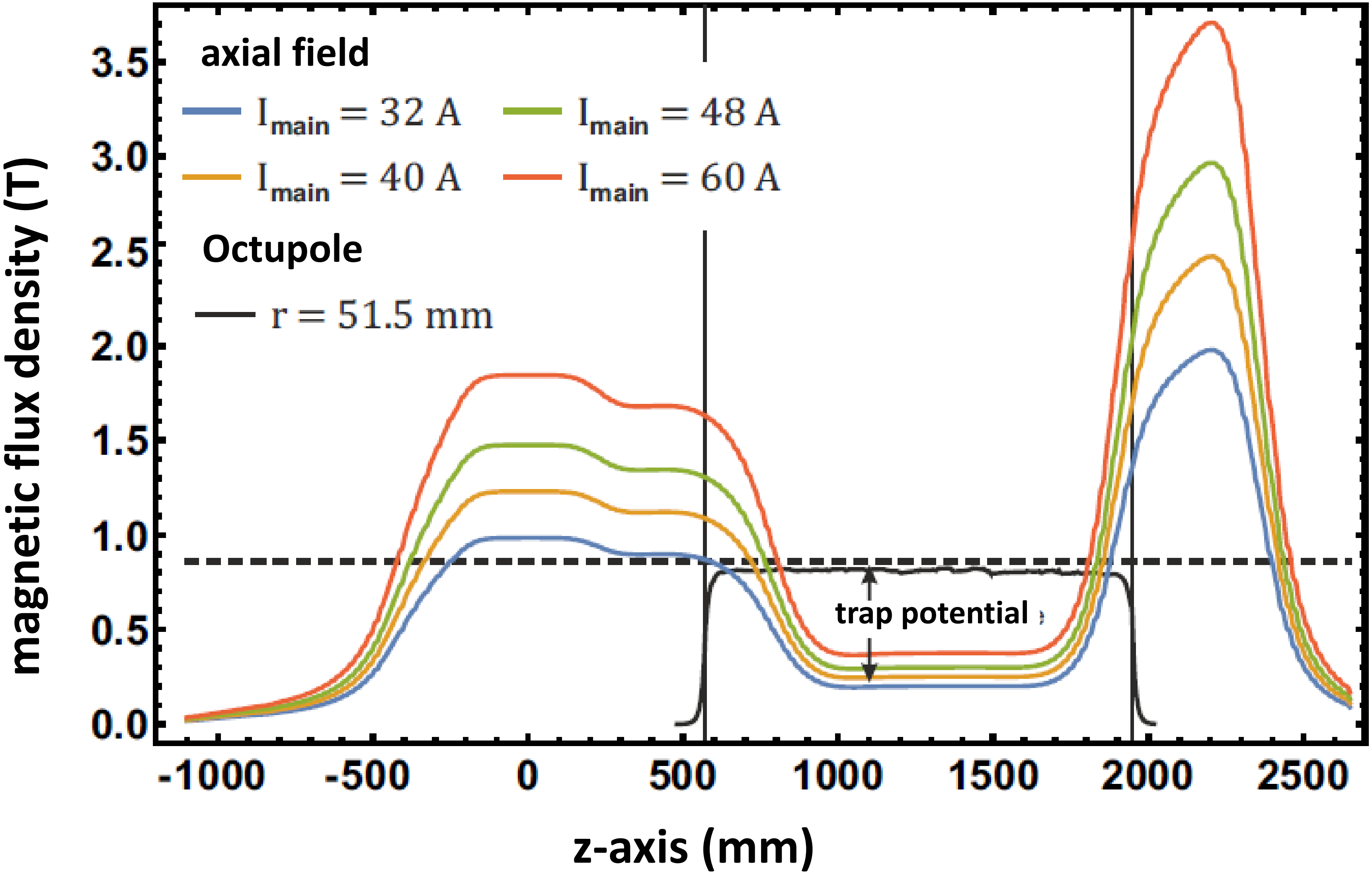


Scan of the total B-field,
2.5 mm from the magnet surface



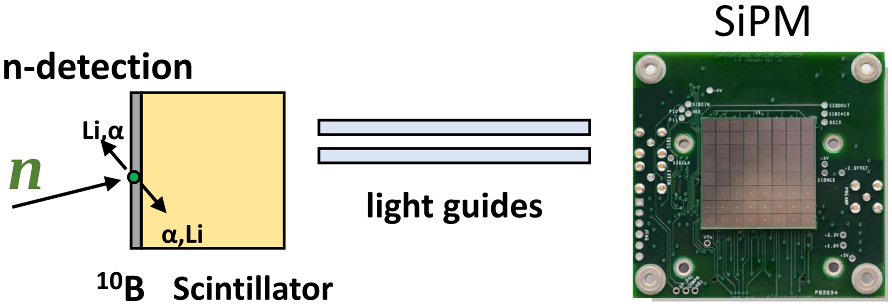
⇒ No significant holes in the magnetic wall!

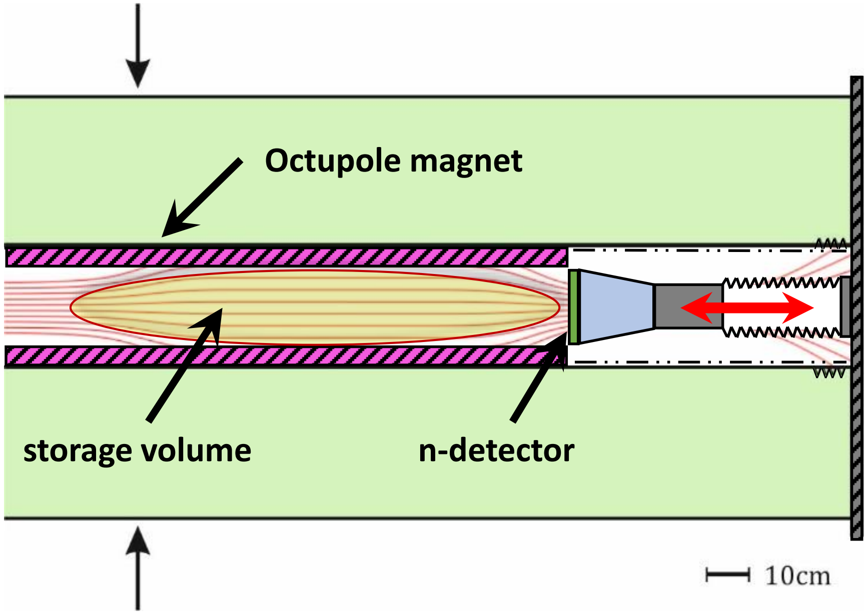
Investigation of systematic effects

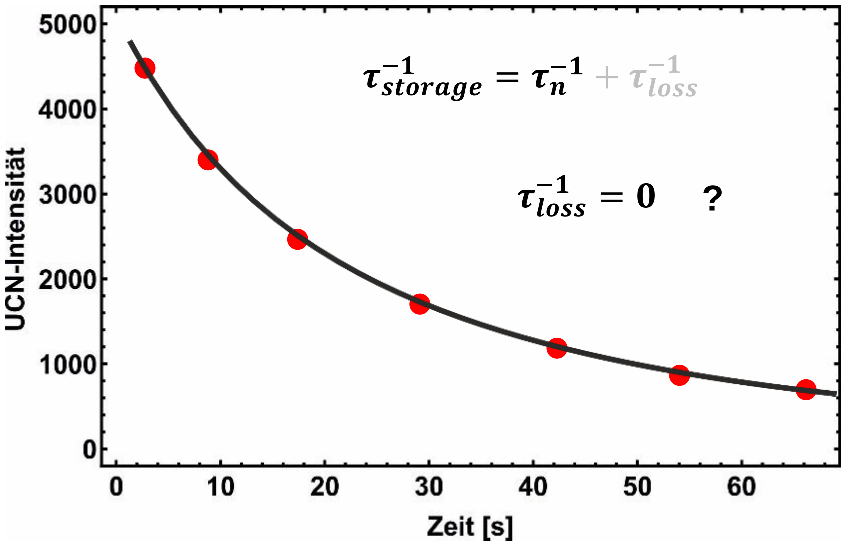


Detection

1. **„counting the survivors“ (neutrons)**

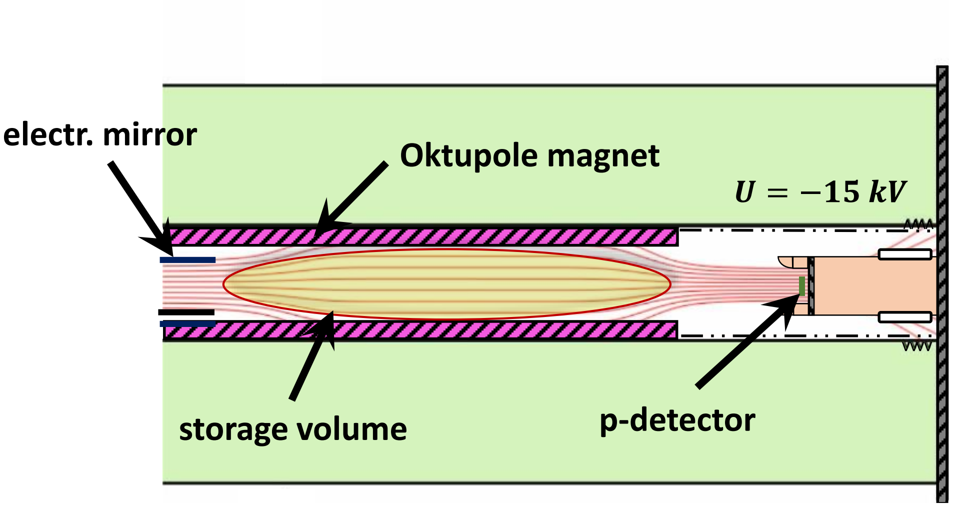


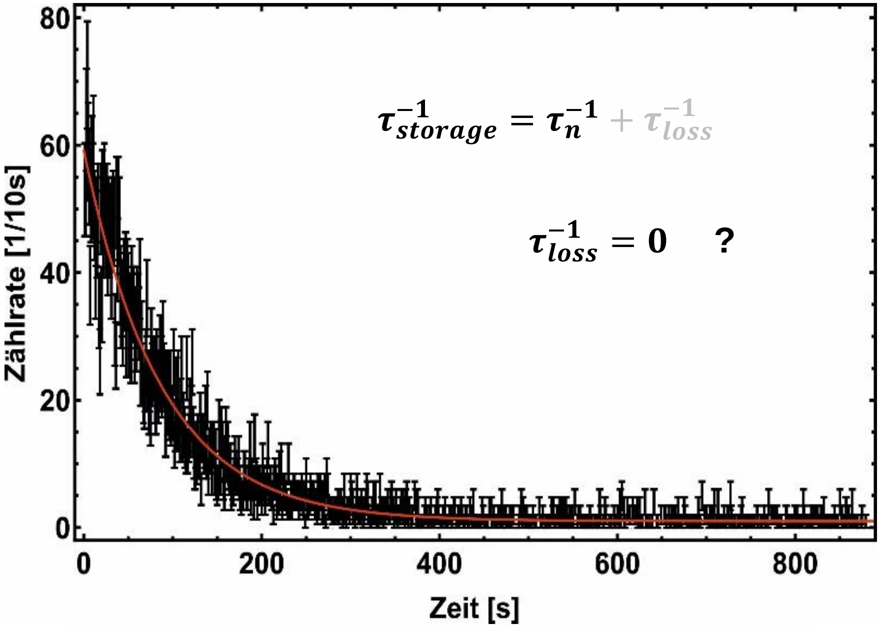




Detection

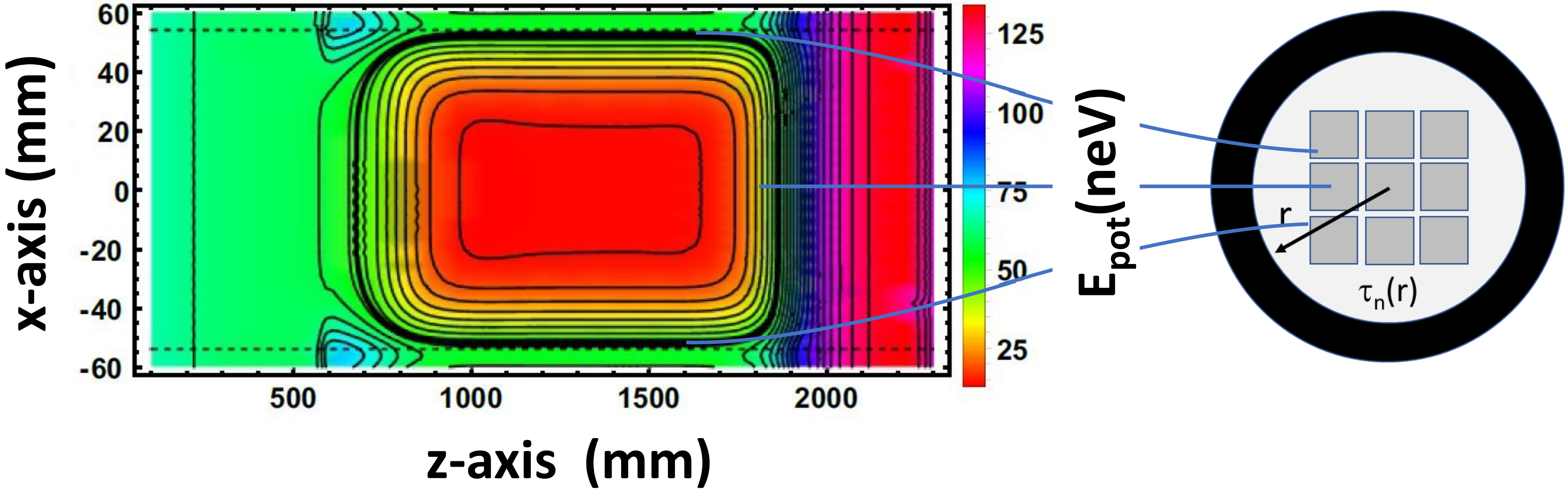
2. „counting the protons“



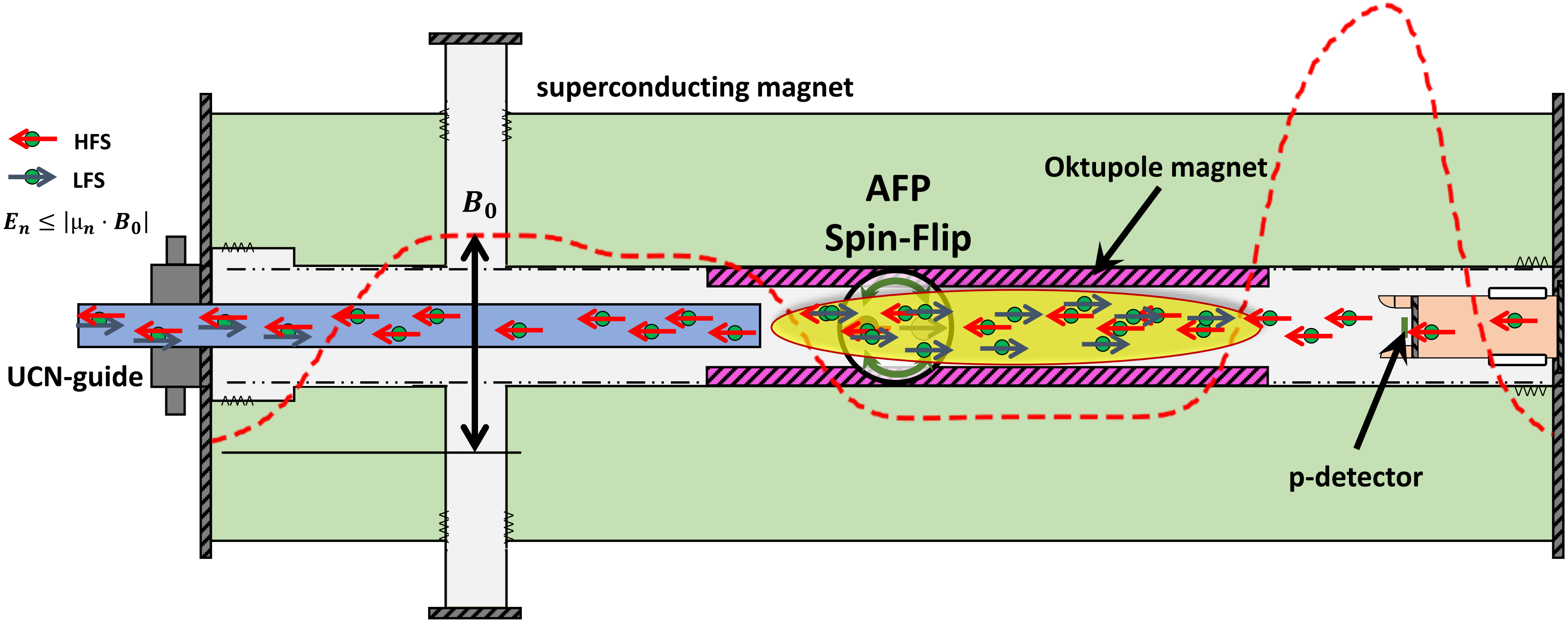


$$\tau_{storage}^{-1} = \tau_n^{-1} + \tau_{loss}^{-1}$$

$$\tau_{loss}^{-1} = 0 \quad ?$$

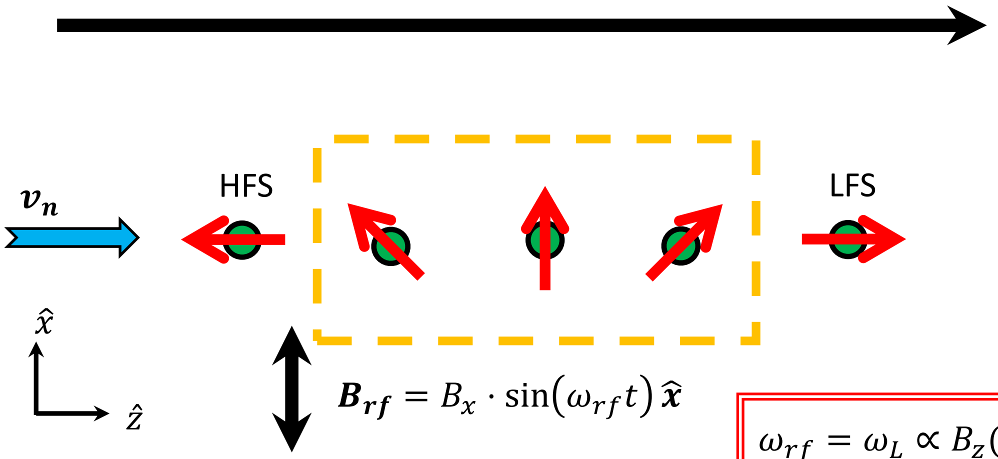


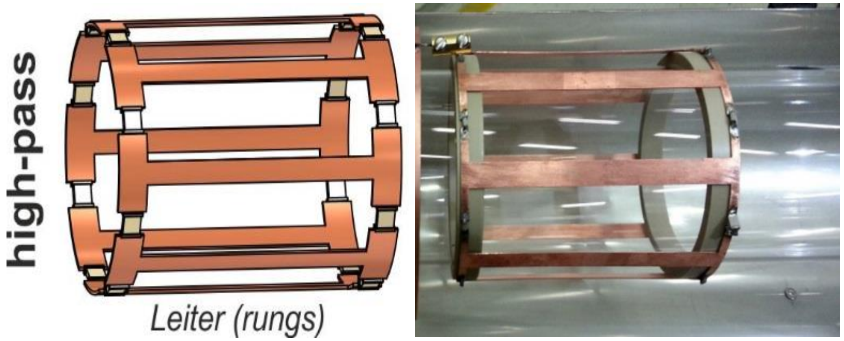
Filling the magnetic storage trap



Adiabatic Fast Passage (AFP)

$\boldsymbol{B_0} = B_z(z)\hat{\boldsymbol{z}}$ mit $\frac{\partial B_z(z)}{\partial z} \simeq 1\ G/cm$

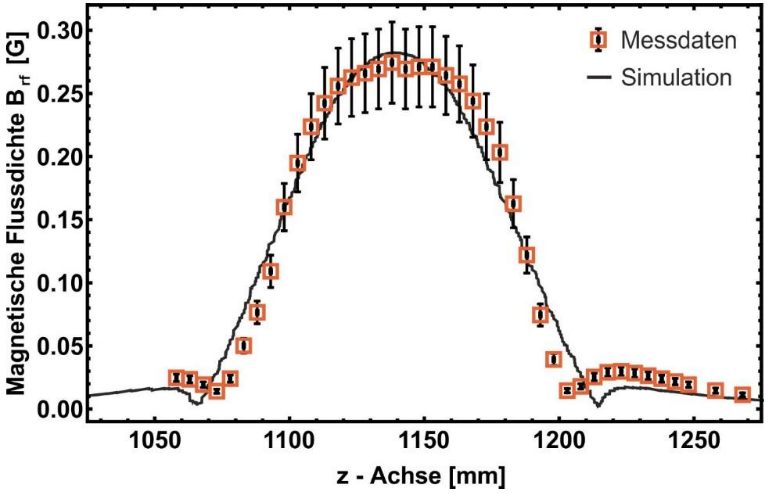


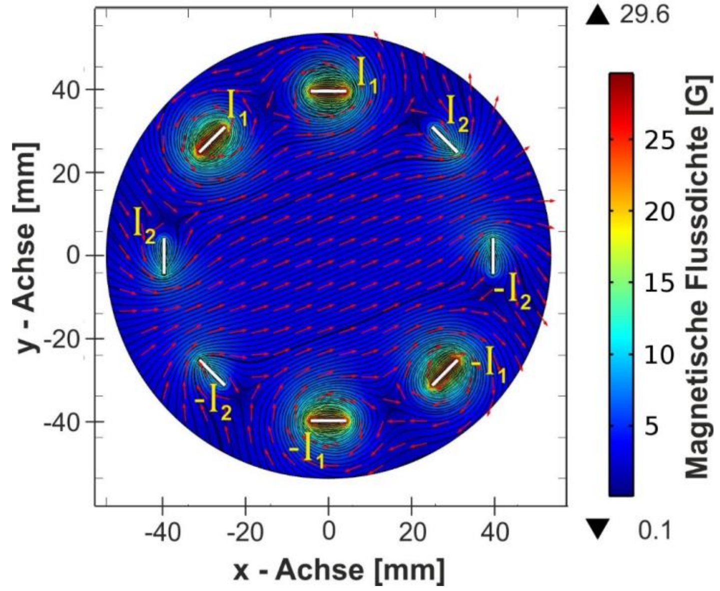


$$\epsilon > 1 - \frac{(\nabla_z B_0)^2 v_n^2}{(\nabla_z B_0^2)^2 v_n^2 + \gamma^2 B_1^4},$$

$\boldsymbol{B_{rf}} = B_x \cdot \sin(\omega_{rf} t)\,\hat{\boldsymbol{x}}$

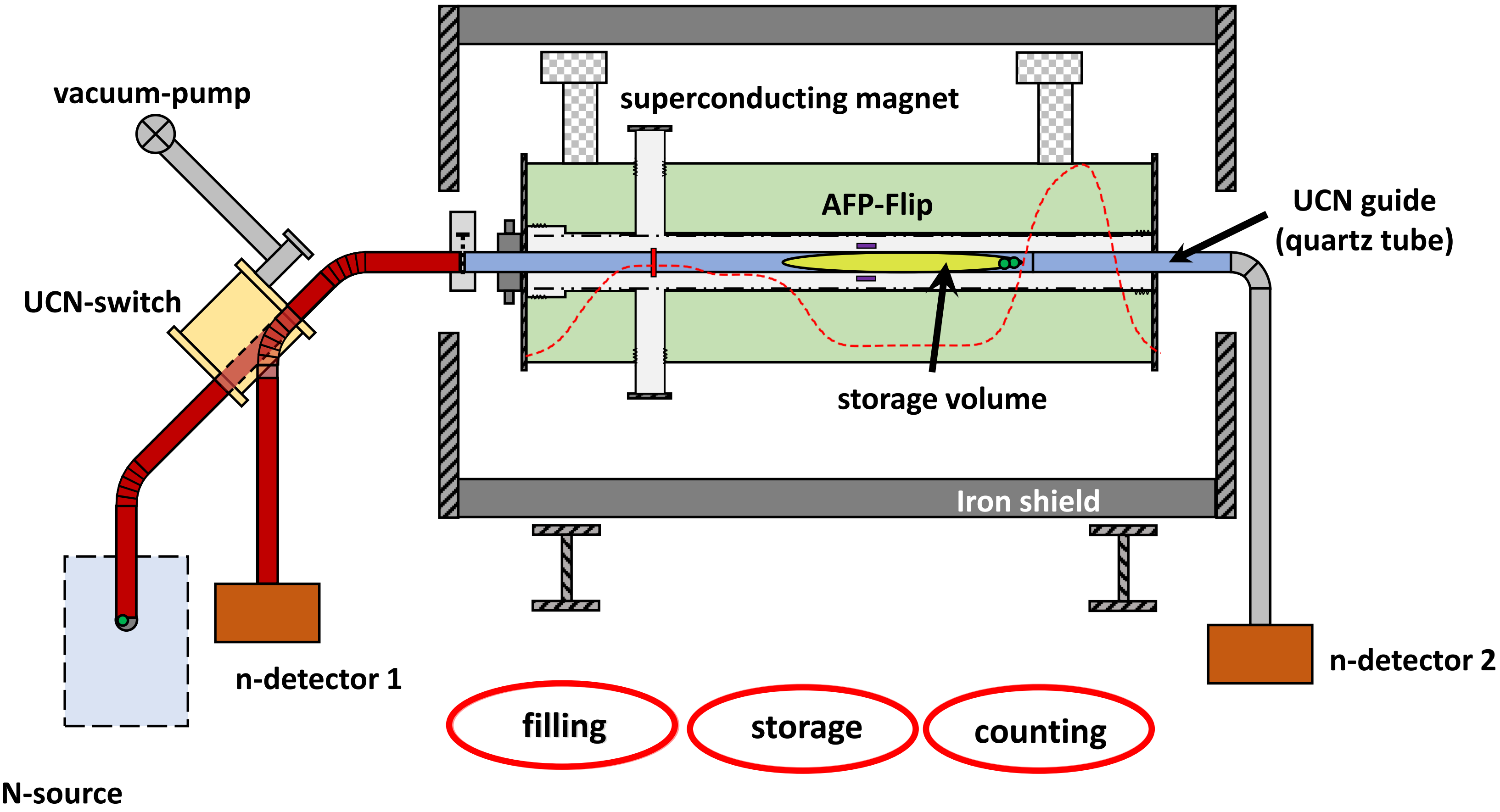
$$\boxed{\omega_{rf} = \omega_L \propto B_z(z_0)}$$



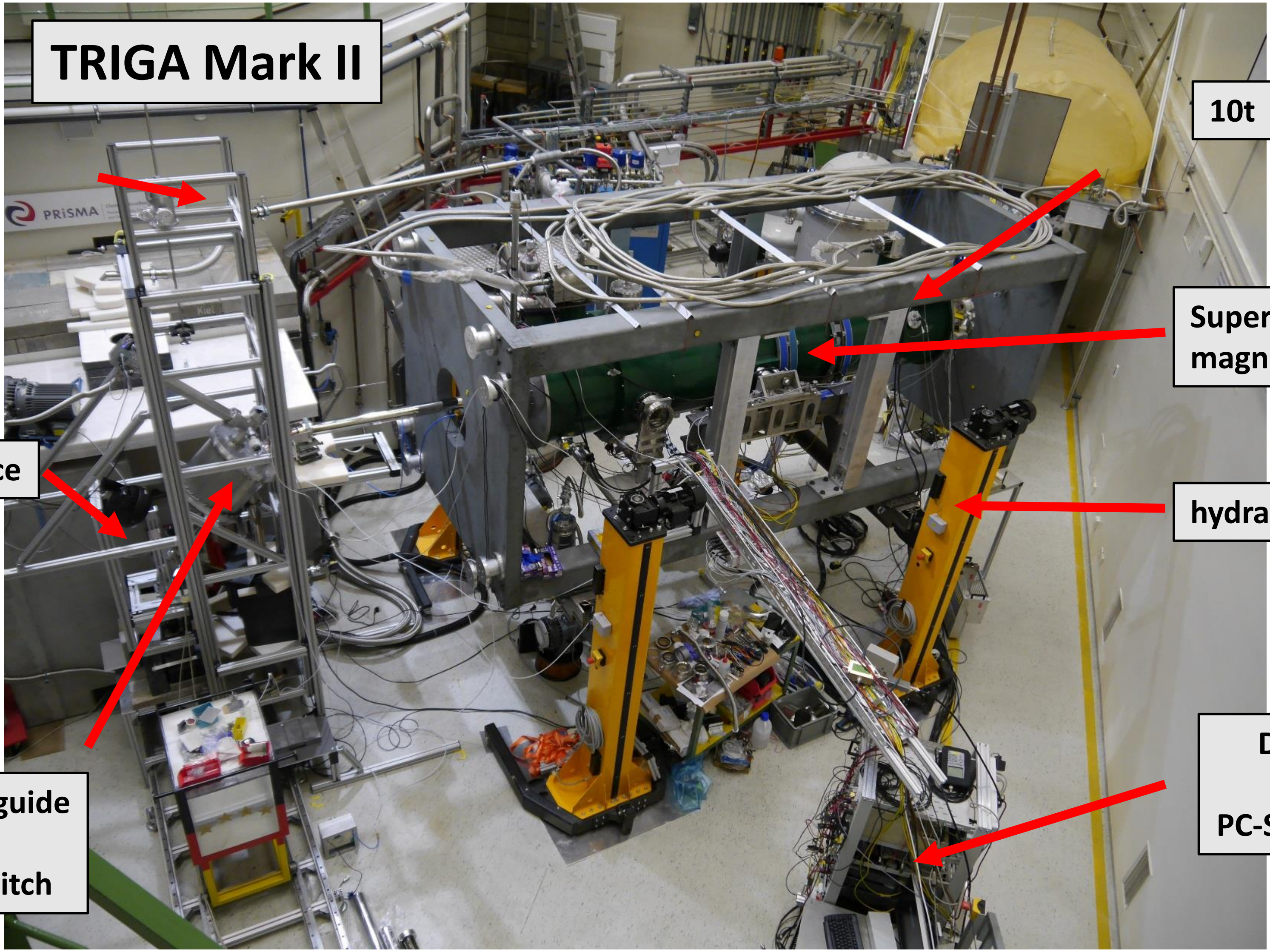


Phase I of τSPECT: Proof of Principle (2016)

PhD thesis: Jan Karch



τSPECT



TRIGA Mark II

10t iron shield

Superconducting magnet

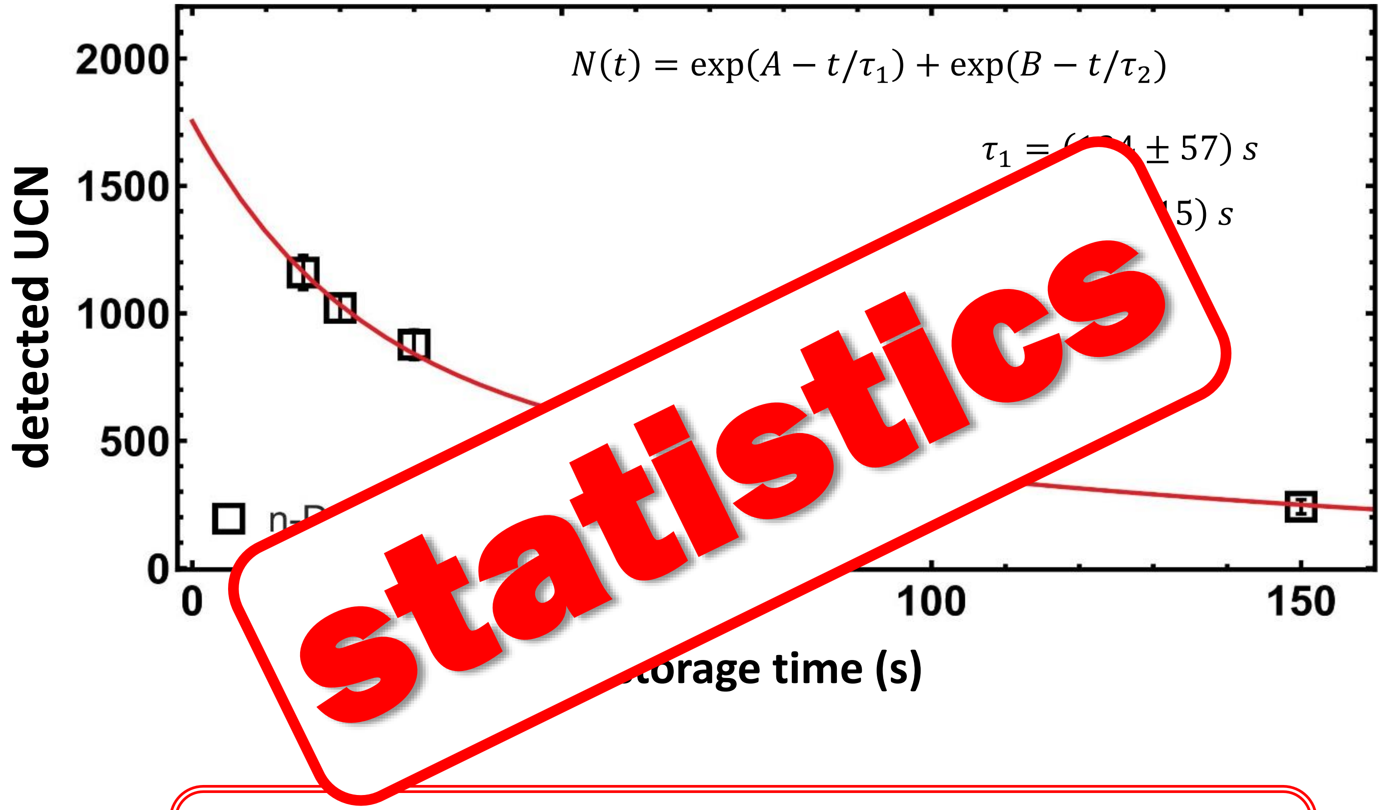
UCN-source

hydraulic ramp

neutron guide
&
UCN-switch

DAQ
&
PC-System

Phase I of τSPECT: Proof of Principle (2016)

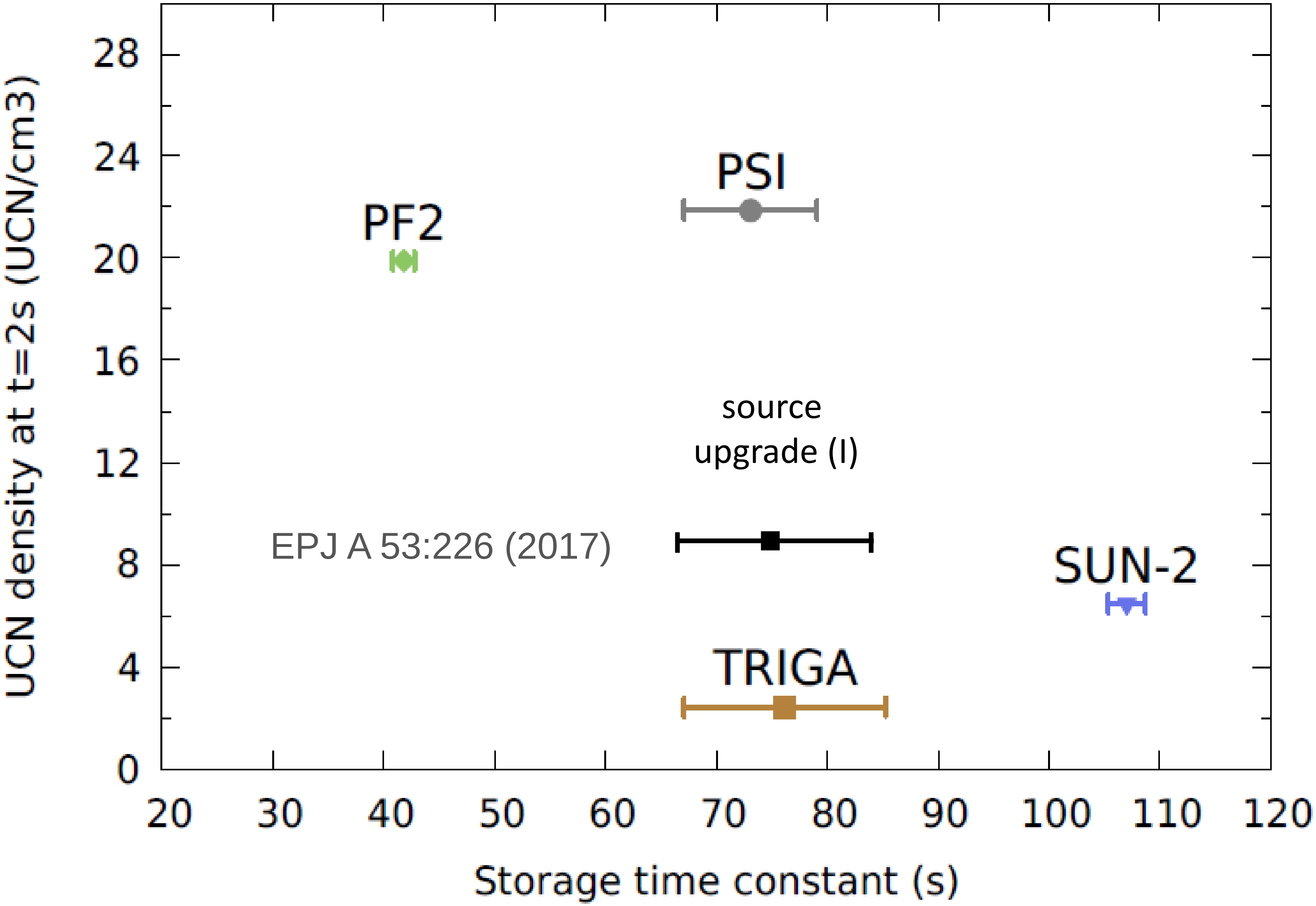


extraction efficiency ~ 18%

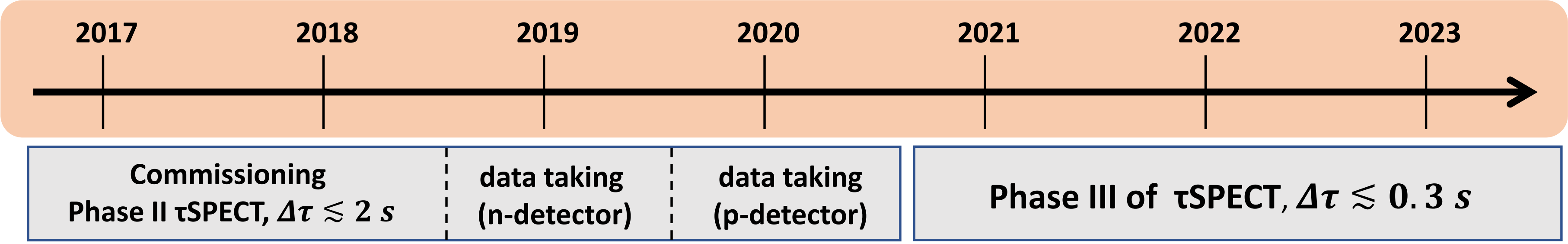
11 000 stored UCN

UCN densities (comparison) in standard storage bottle of 32 liter

G. Bison et al., Phys. Rev. C 95 (2017) 045503



- **Road map**



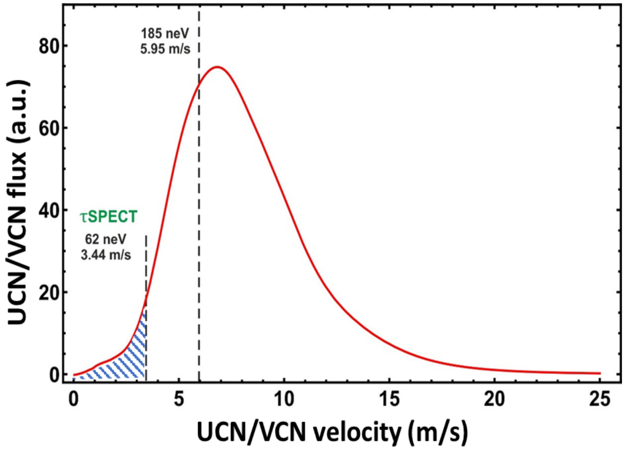
Commissioning
Phase II τSPECT, $\Delta\tau \lesssim 2\ s$

data taking
(n-detector)

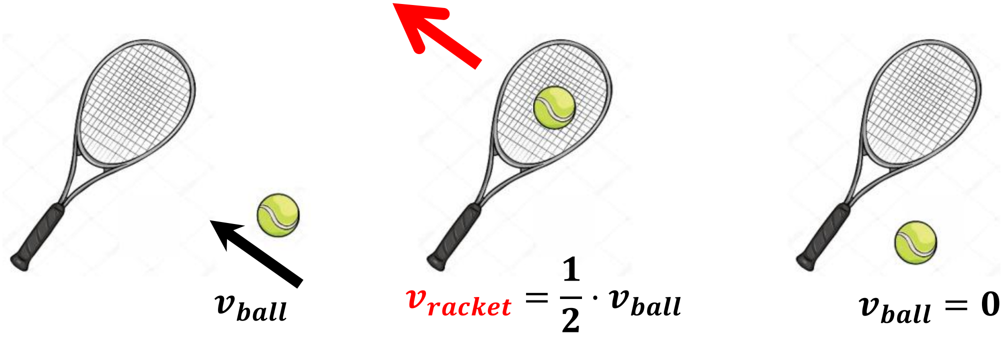
data taking
(p-detector)

Phase III of τSPECT, $\Delta\tau \lesssim 0.3\ s$

Phasespace transformer at pulsed UCN source



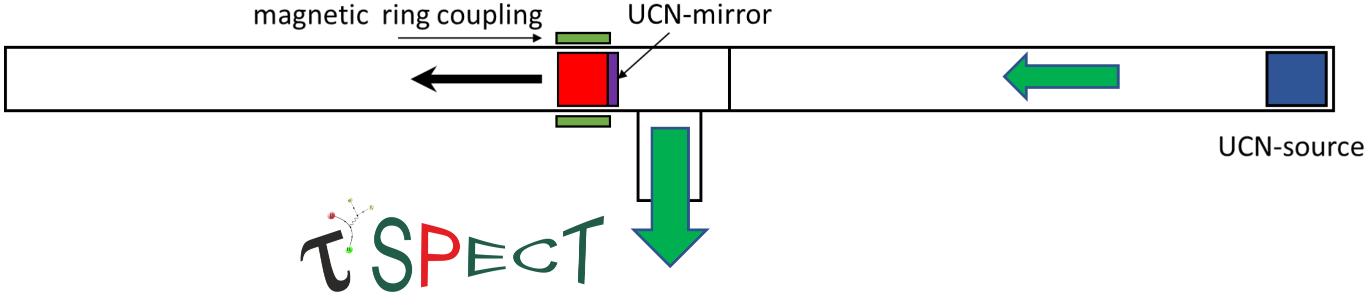
movable neutron reflector

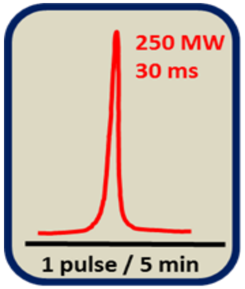


v_{ball}

$v_{racket} = \frac{1}{2} \cdot v_{ball}$

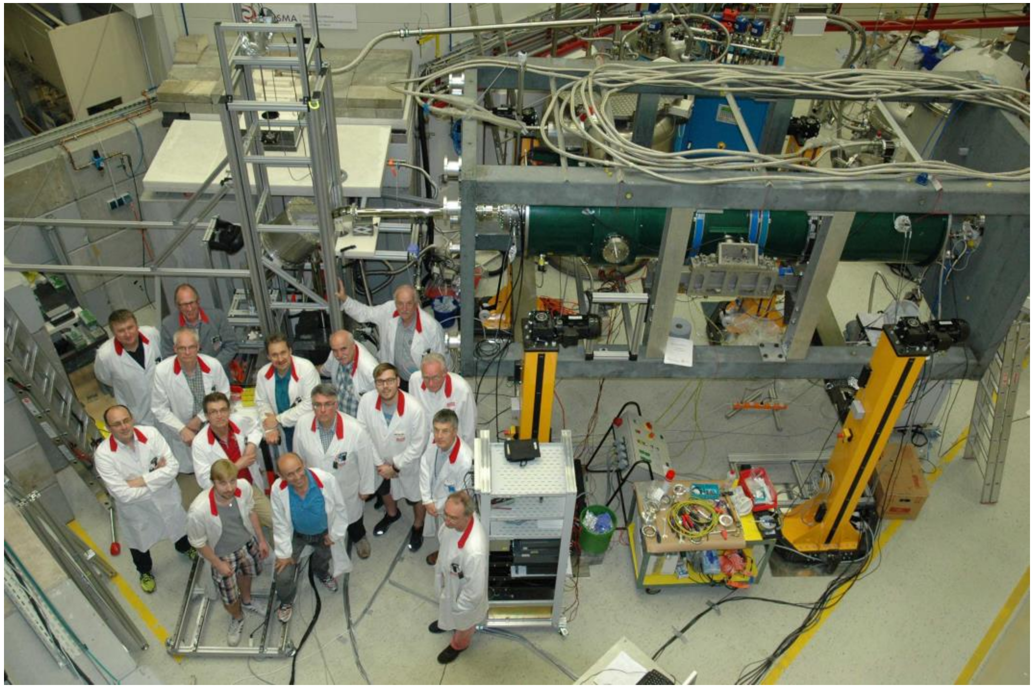
$v_{ball} = 0$



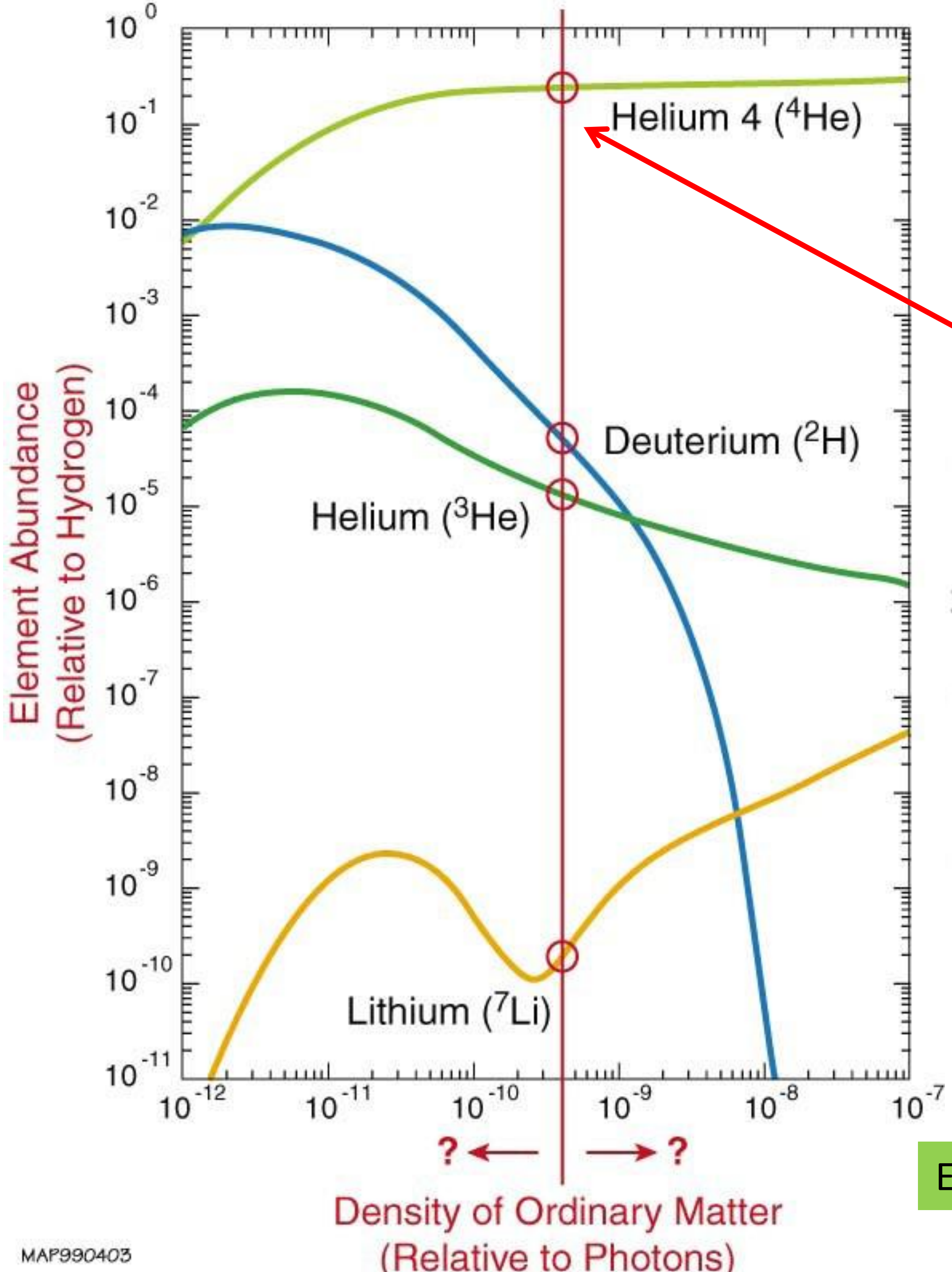


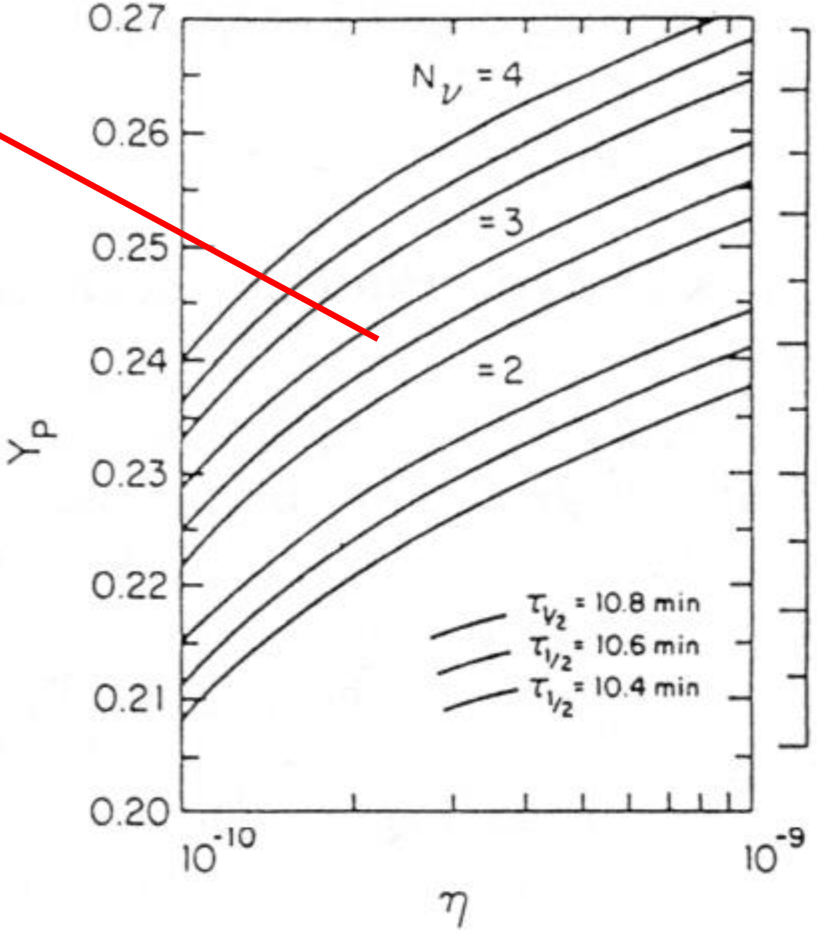
τSPECT

Thanks for your attention!



PRISMA
Symmetry Breaking
Carl Zeiss Stiftung
DFG Deutsche Forschungsgemeinschaft
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
JG|U





Empfindlichkeit auf Neutron-Lebensdauer

Unitary of CKM matrix:

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

super-allowed $0^+ \rightarrow 0^+$ nucl. ß-decays: $|V_{ud}|^2 = 0.94916(58)$

K- decays: $|V_{us}|^2 = 0.05076(41)$

semileptonic B-decays: $|V_{ub}|^2 = 1.5 \times 10^{-5}$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999(8)$$

Neutron decay: $|V_{ud}|^2 = \dfrac{4908.7(1.9)}{\tau_n \cdot (1 + 3 \cdot \lambda^2)}$

PDG 2016: $\lambda = -1.2723(23)$

$$\boxed{|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = \begin{cases} 0.9932(17) \ @ \tau_n = 885.7 \\ 1.0010(17) \ @ \tau_n = 878.5 \end{cases}}$$

The Parameters of Big Bang Nucleosynthesis

$$\boxed{Y_p} = 0.228 + 0.023 \log \boxed{\eta_{10}} + 0.012 \boxed{N_\nu} + 0.018 (\boxed{\tau_n} - 10.28)$$

Cosmic Helium Abundance

Cosmic Baryon Density

Number of Neutrino Flavors

Neutron Lifetime in Minutes

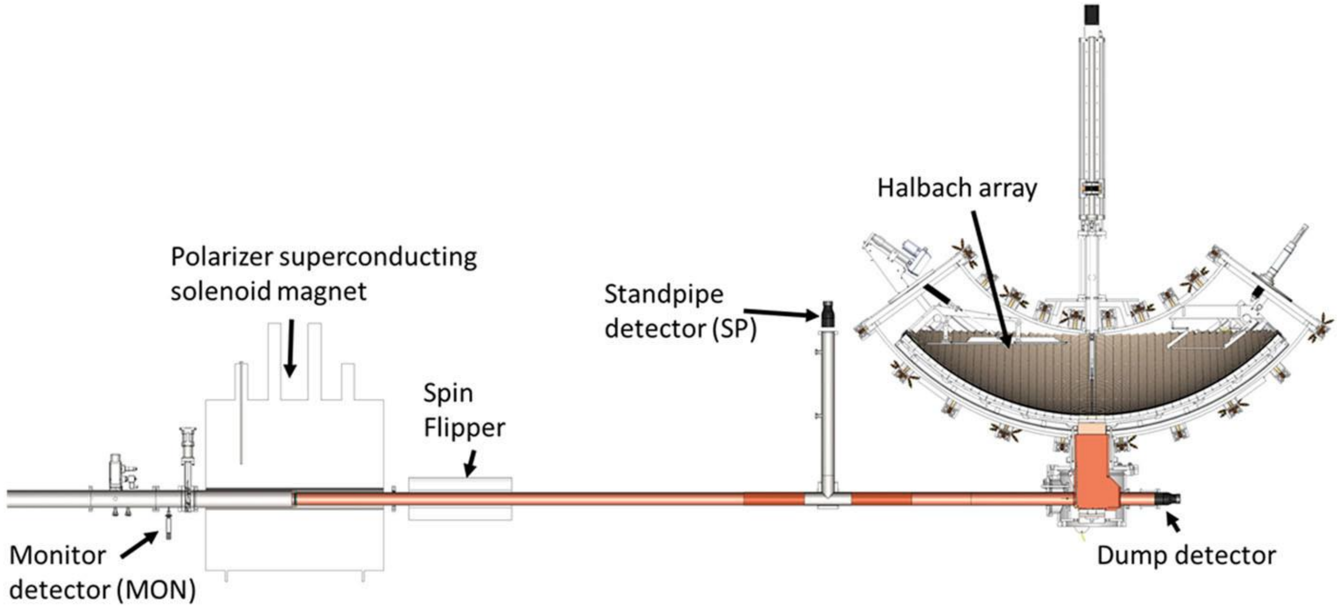


FIG. 2. Schematic layout of the UCN beam line showing the monitor detector locations relative to the trap.

Published in: C. L. Morris; E. R. Adamek; L. J. Broussard; N. B. Callahan; S. M. Clayton; C. Cude-Woods; S. A. Currie; X. Ding; W. Fox; K. P. Hickerson; M. A. Hoffbauer; A. T. Holley; A. Komives; C.-Y. Liu; M. Makela; R. W. Pattie Jr.; J. Ramsey; D. J. Salvat; A. Saunders; S. J. Seestrom; E. I. Sharapov; S. K. Sjue; Z. Tang; J. Vanderwerp; B. Vogelaar; P. L. Walstrom; Z. Wang; Wanchun Wei; J. W. Wexler; T. L. Womack; A. R. Young; B. A. Zeck; *Review of Scientific Instruments* **2017,** 88,
DOI: 10.1063/1.4983578
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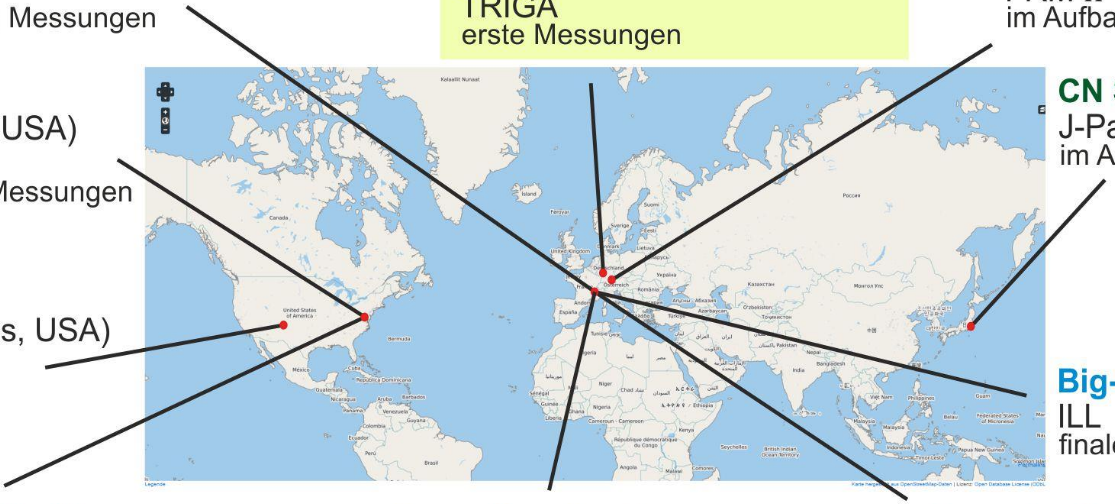
Aktueller Stand der Forschung



HOPE (Grenoble, France)
ILL
erste Messungen

τSPECT (Mainz, Deutschland)
TRIGA
erste Messungen

PENeLOPE (München, Deutschland)
FRM II
im Aufbau

CN Strahl (Tokio, Japan)
J-Parc
im Aufbau

CN Strahl (NIST, USA)
NCNR
Publiziert, weitere Messungen

UCNτ (Los Alamos, USA)
LANL
erste Messungen

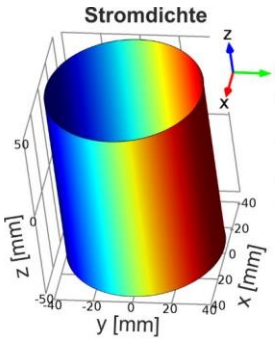
Big-Gravitrap (PNPI, Russland)
ILL
finale Messungen

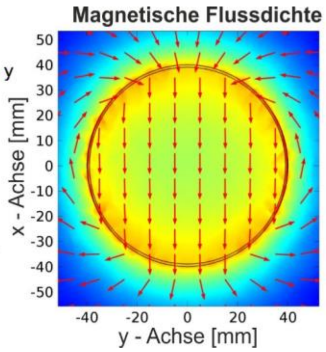
Magnetische Fall in ℓHe (NIST, USA)
NCNR
erste Messungen

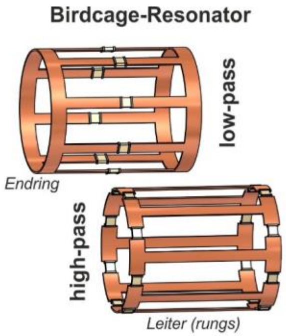
Accordion-like Trap (URI, USA)
ILL
erste Messungen

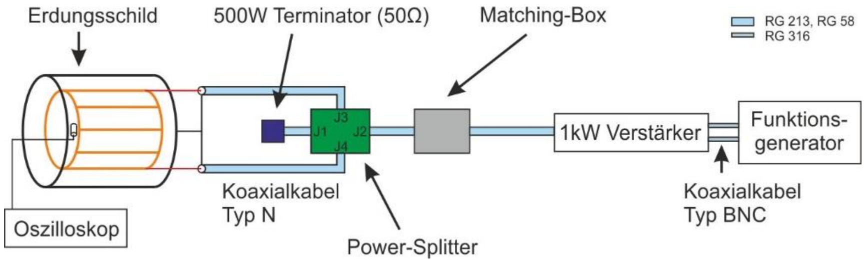
Magneto-Gravi Falle (PNPI, Russland)
ILL
publiziert, weitere Messungen

Der Birdcage-Resonator zur AFP

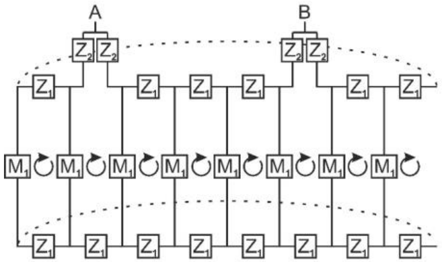


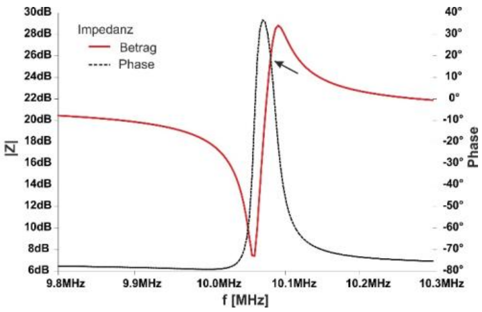






$$\varepsilon > 1 - \frac{(\nabla_z B_0)^2 v_n^2}{(\nabla_z B_0)^2 v_n^2 + \gamma^2 B_1^4}$$



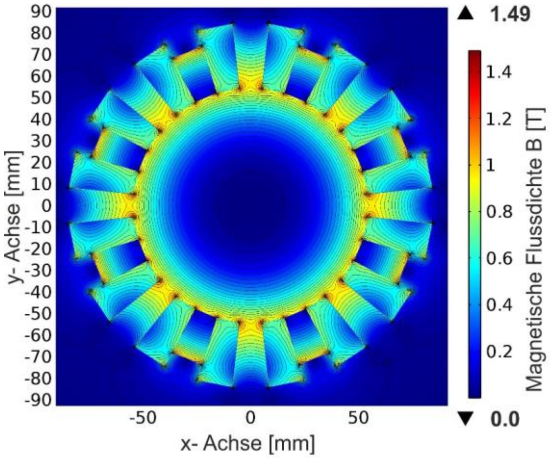


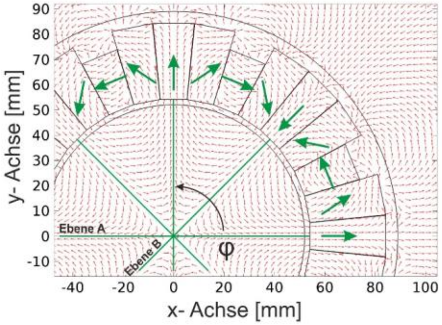
- Reduziere $\nabla_z B_0$ (longitudinales Feld) und $\nabla_r B_r$ (Multipol-Feld)
- Erhöhe Leistung B_1 des Birdcage-Resonators

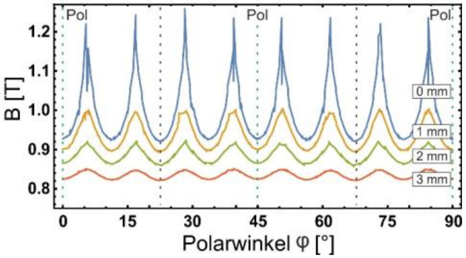
Der Multipol (Halbach-Design)

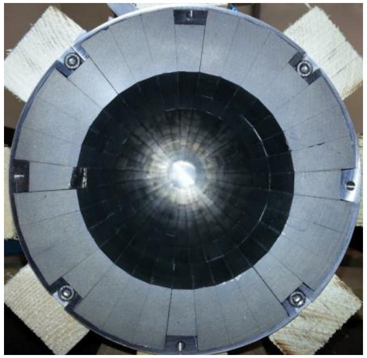
$$\boxed{B(r) = B_r \left(\frac{r}{r_i}\right)^{N-1} \frac{N}{N-1}\left[1-\frac{r_i}{r_a}\right]^{N-1}}$$

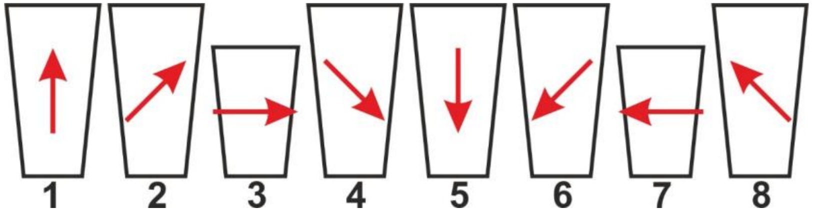
r_i : Innenradius des Multipols
r_a : Außenradius des Multipols
B_r : effektive Remanenz der Magnetsegmente



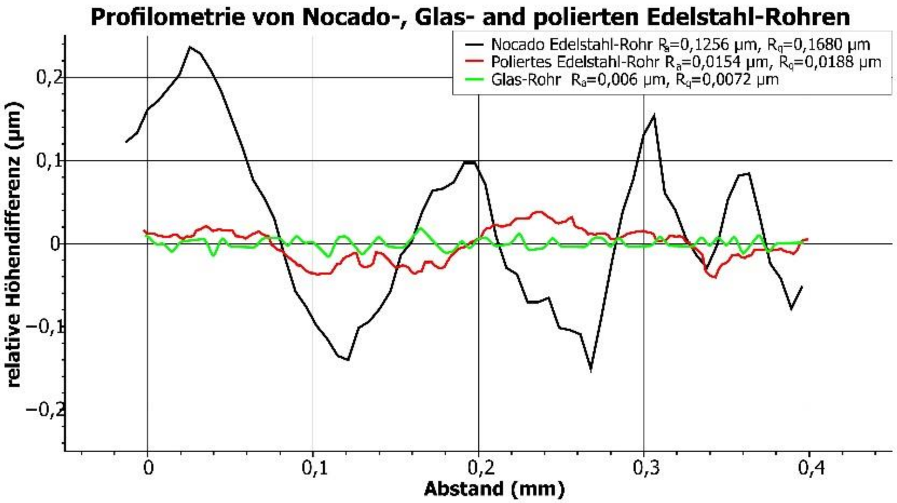








Upgrade of UCN-source

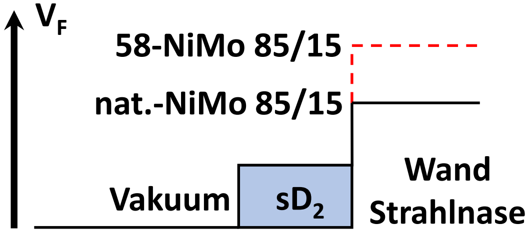


1. Verbesserung der Neutronenleiterqualität

- Reduzierte **Rauheit** der Leiteroberfläche → Erhöhte spekulare Reflexion der UCN an der Leiteroberfläche
- Optimierter Biegeradius der 45°-Bögen ($\rho \simeq 30\ cm$)

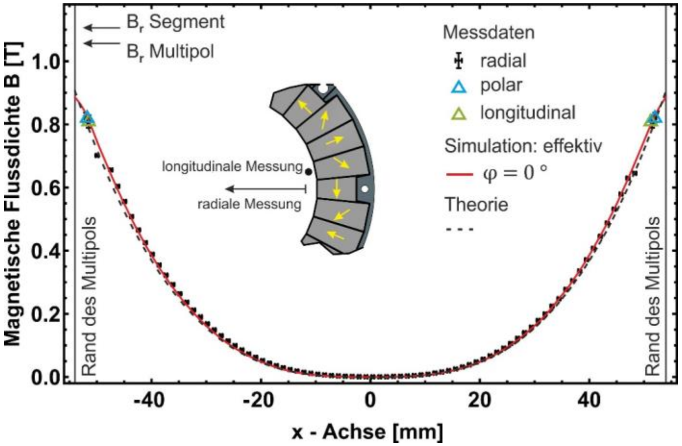
2. Verbesserte Phasenraumakzeptanz

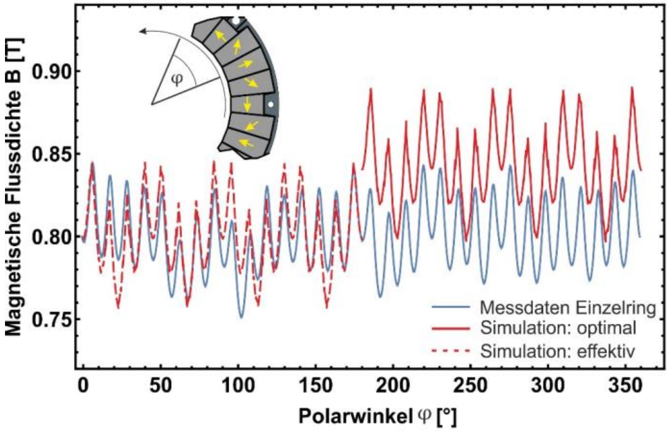
- Wand-Potential V_F der Strahlnase mit angereichertem 58-Nickel (NiMo 85/15) beschichtet

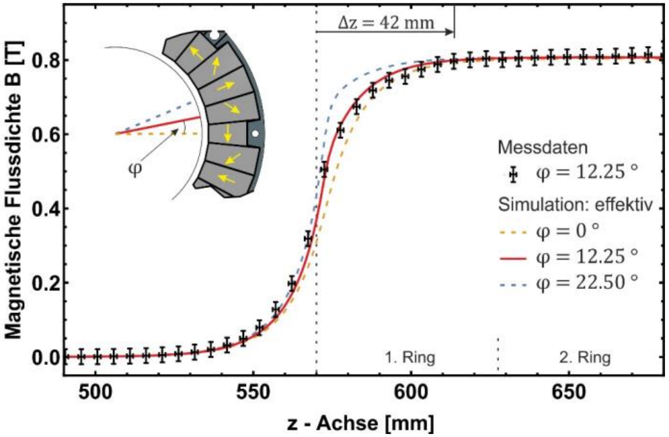


58-NiMo 85/15

Der Multipol: Vergleich von Simulation und Messdaten







Asymmetric Trap induces ``Phase-Space Mixing”

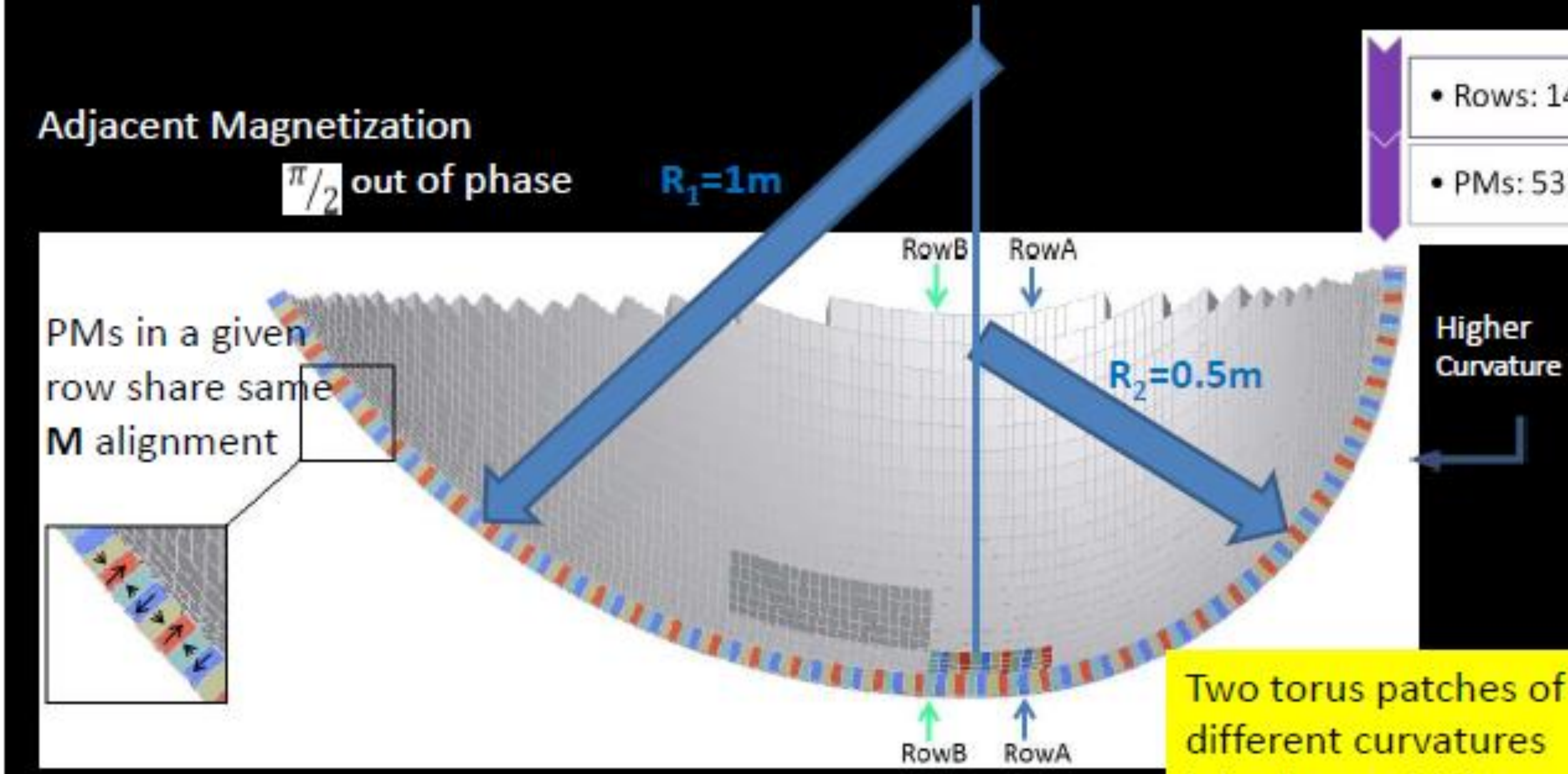
Low symmetry, together with field ripples, enhances state-mixing between (quasi)-periodic orbits through chaotic motion.

→ quick cleaning (~ 10s of seconds) of the ‘quasi-bound’ UCN.

Adjacent Magnetization

$\pi/2$ out of phase

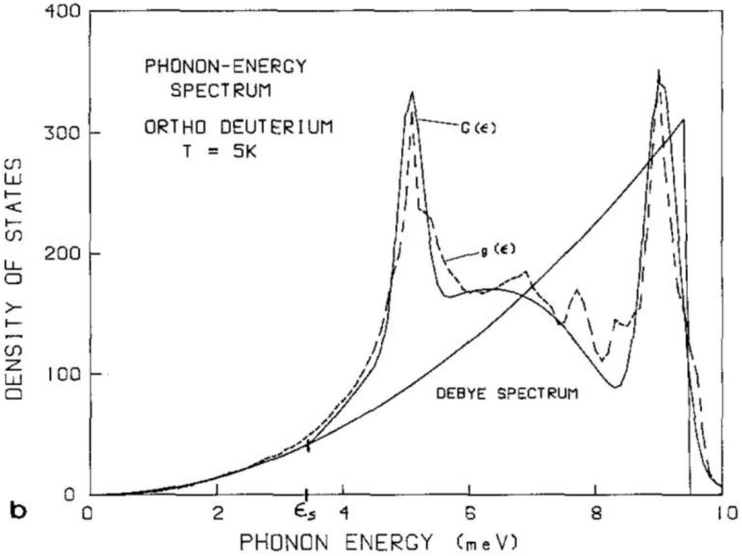
- Rows: 141
- PMs: 5310



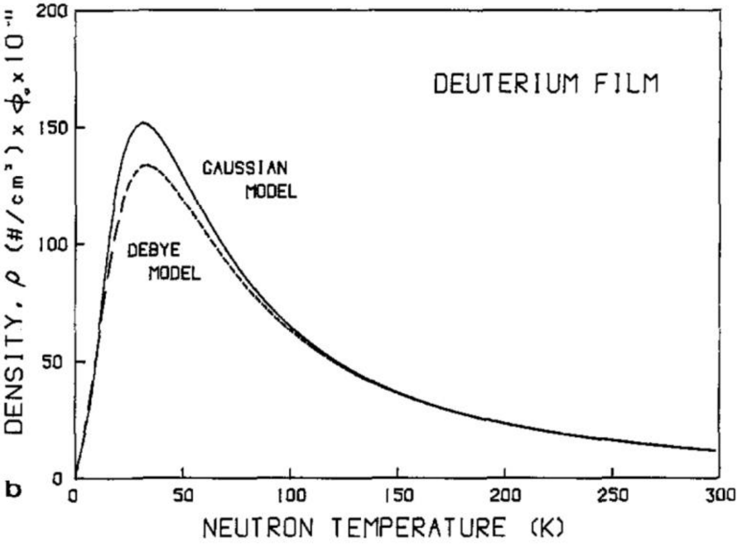
PMs in a given row share same **M** alignment

Two torus patches of different curvatures join along middle row

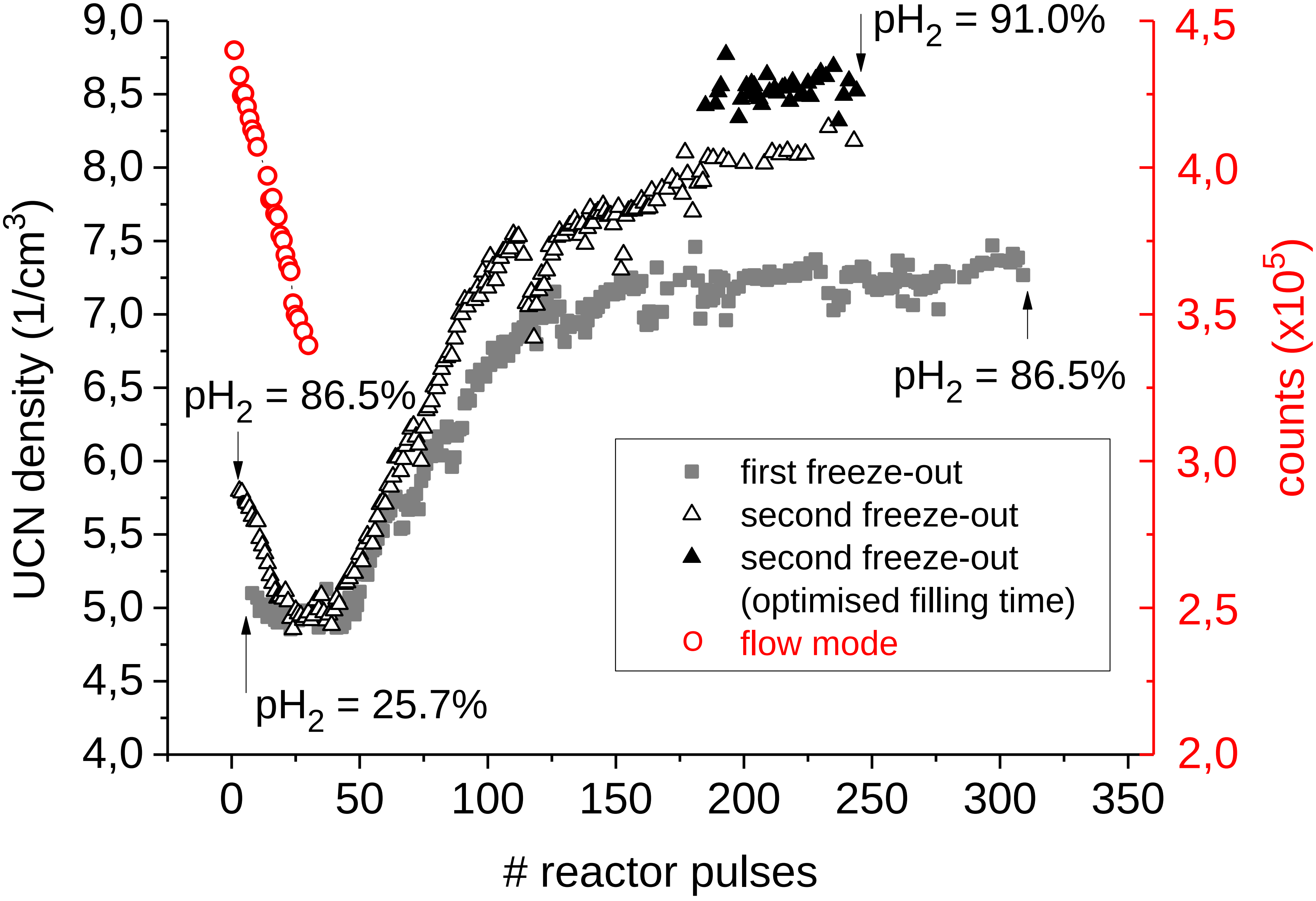
UCN-Produktion in sD_2

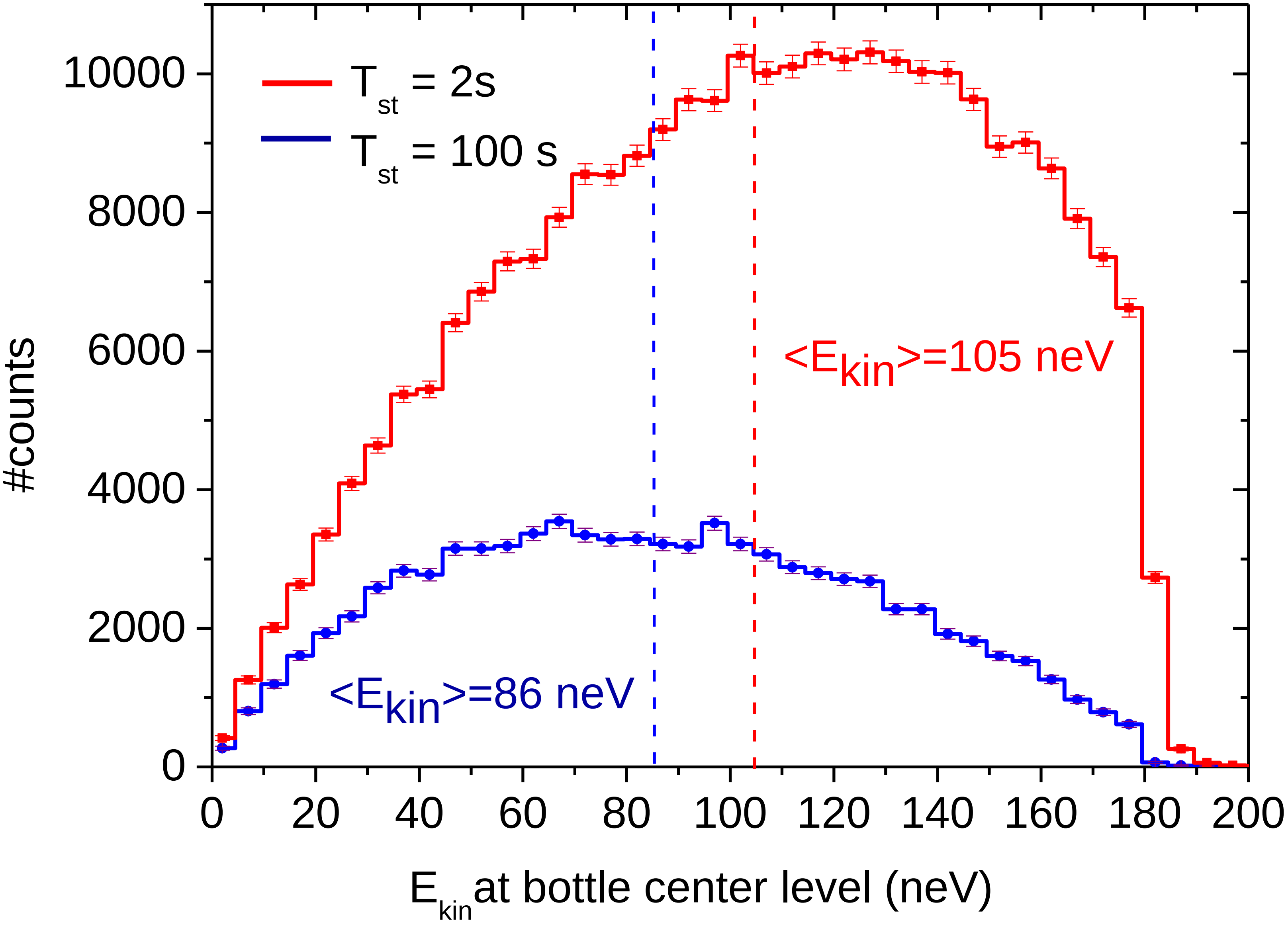


b



b


UCN density (1/cm^3)
counts (x10^5)
reactor pulses
9,0
8,5
8,0
7,5
7,0
6,5
6,0
5,5
5,0
4,5
4,0
4,5
4,0
3,5
3,0
2,5
2,0
0
50
100
150
200
250
300
350
pH$_2$ = 91.0%
pH$_2$ = 86.5%
pH$_2$ = 86.5%
pH$_2$ = 25.7%
■ first freeze-out
△ second freeze-out
▲ second freeze-out (optimised filling time)
○ flow mode


T_{st} = 2s
T_{st} = 100 s
<E_{kin}>=105 neV
<E_{kin}>=86 neV
#counts
0
2000
4000
6000
8000
10000
0
20
40
60
80
100
120
140
160
180
200
E_{kin} at bottle center level (neV)

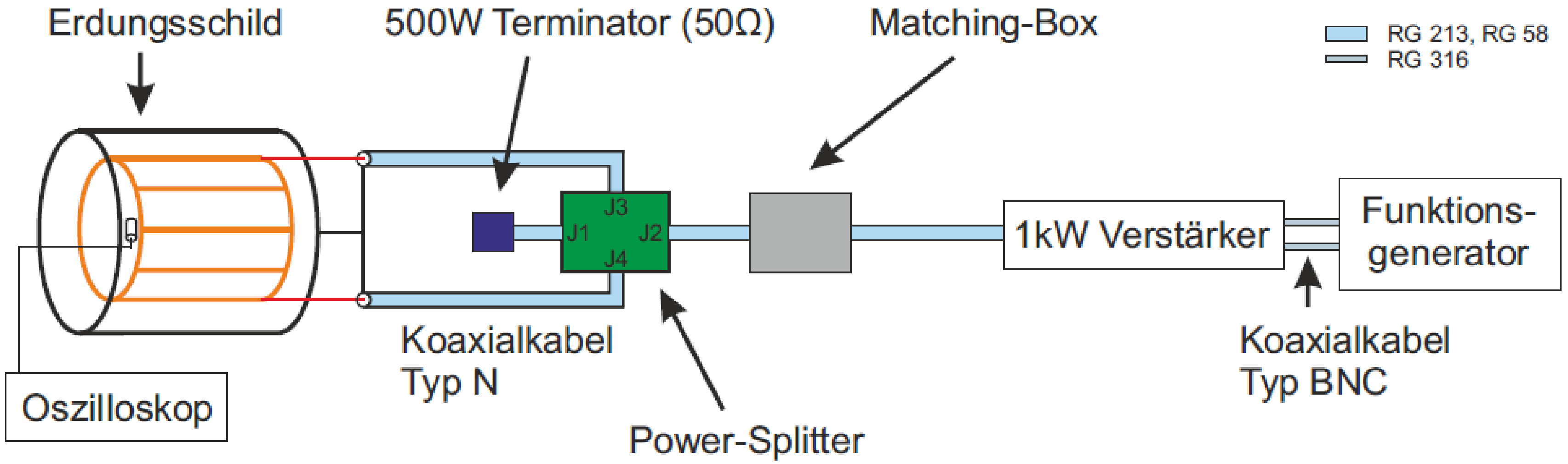


Abbildung 4.26: Skizze vom elektrischen Anschlussplan des Spin-Flippers.