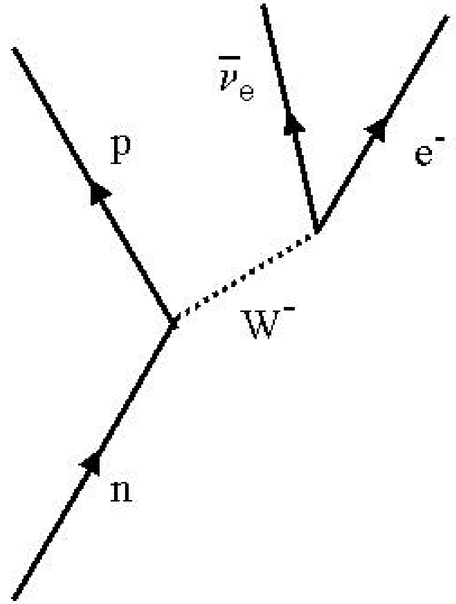
V_{ud} from neutron decay

Oliver Zimmer

Grenoble, France

CKM 2012, Cincinnati, 29 September 2012

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



endpoint energy of beta spectrum: 782 keV
maximum proton recoil energy: 750 eV
n's can be polarised close to 100%
quite abundant in cold neutron beams
long observation time for ultracold neutrons

$$g_V = G_F V_{ud}$$

$$G_F = 1.16639(1) \times 10^{-5}\ \text{GeV}^{-2} (\hbar c)^3$$

no nuclear corrections
in standard model:
V-A structure with known Fermi and GT matrix elements
$\rightarrow$ need two observables to access V_{ud}:

$$\tau_n^{-1} \propto g_V^2 \left(1 + 3\lambda^2\right) \qquad \lambda = g_A / g_V$$

Accuracy goal for neutron observables

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

Marciano & Sirlin PRL 96 (2006) 032002

uncertainty due to radiative corrections: $\delta\left|V_{\mathrm{ud}}\right|^2_{RC} = 3.8\times10^{-4}$

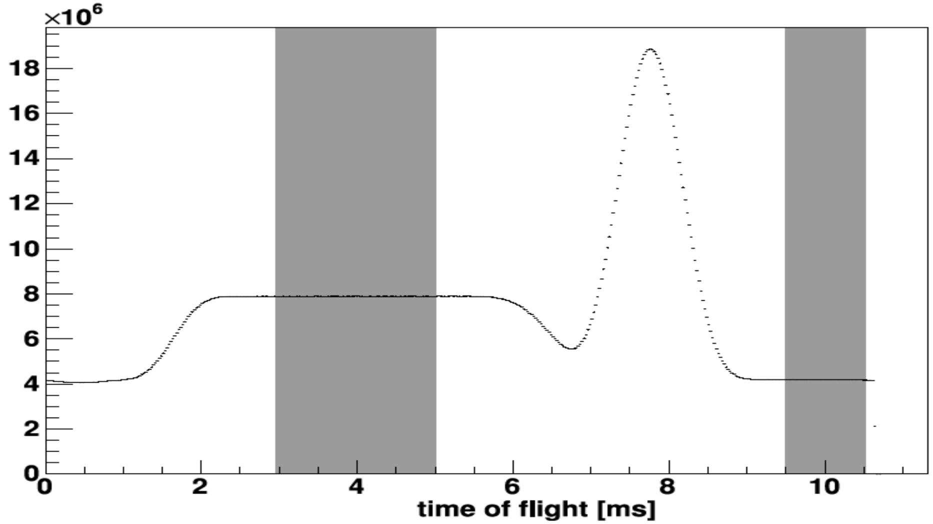
	τ_{n}	λ
accuracy goal:	0.34 s	0.0003
PDG 2012:	880 ± 1.1 s (S=1.8)	- 1.2701 ± 0.0025 (S=1.9)
Perkeo II: Mund et al. arXiv:1204.0013		- 1.2755 ± 0.0013
UCNA: Liu et al. PRL 105 (2010) 181803		- 1.2759 ± 0.0043
Perkeo III: Maerkisch et al.		- 1.???? ± 0.00067

Determination of λ via β asymmetry

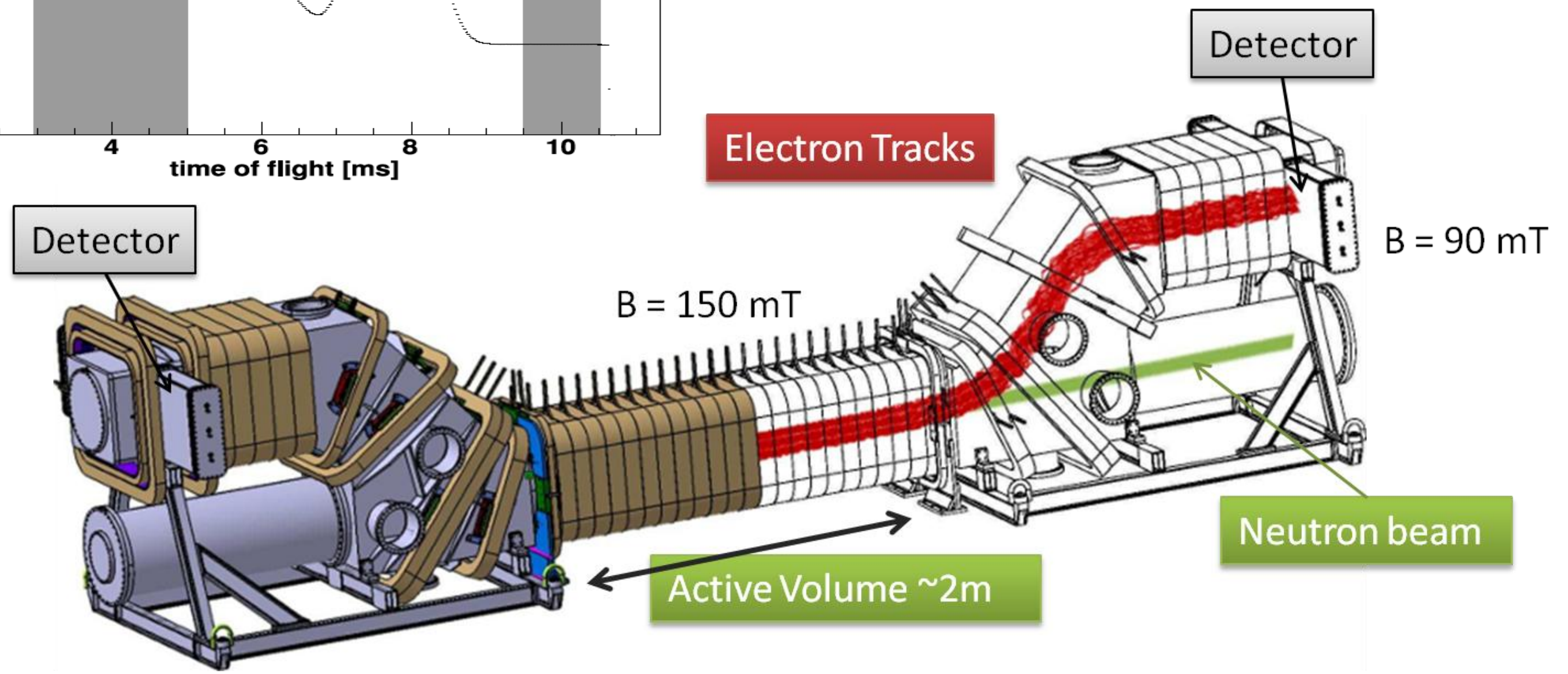
(Wu experiment with free neutrons)

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

Beta asymmetry: Perkeo II, UCNA, **Perkeo III**... PERC



Bastian Maerkisch:
Talk on CKM 2010



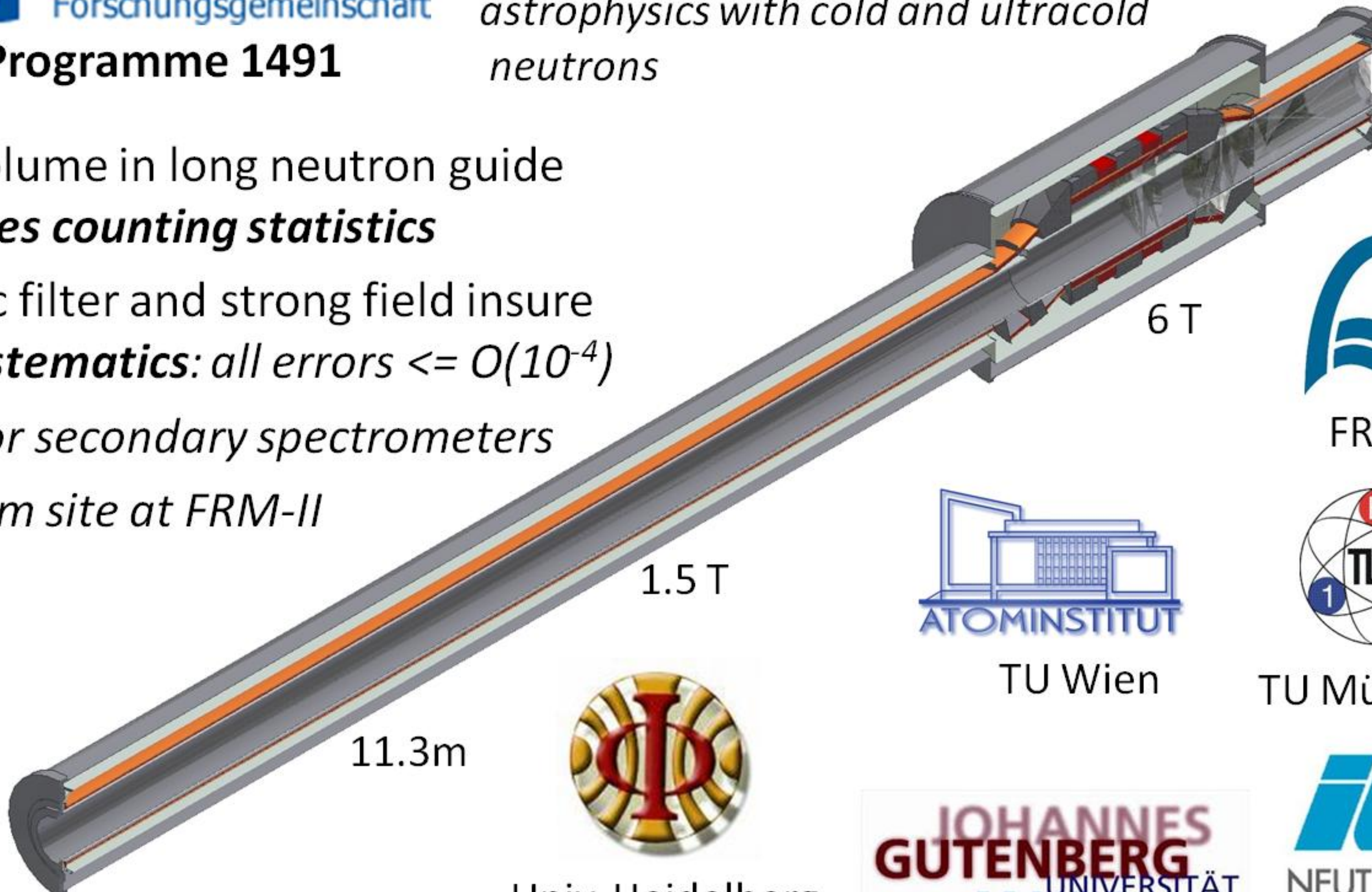
Proton **E**lectron **R**adiation **C**hannel

DFG Deutsche Forschungsgemeinschaft

Priority Programme 1491

Precision experiments in particle and astrophysics with cold and ultracold neutrons

- Active volume in long neutron guide ***maximises counting statistics***
- Magnetic filter and strong field insure ***clean systematics****: all errors <= O(10^{-4})*
- ***Source*** *for secondary spectrometers*
- *New beam site at FRM-II*



Preliminary Magnet Design

FRM-II

ATOMINSTITUT

TU Wien

TU München

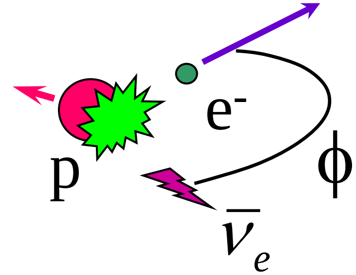
Univ. Heidelberg

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

NEUTRONS FOR SCIENCE

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

Alternative determinations of λ



Neutrino – electron angular correlation $a = \dfrac{1-\lambda^2}{1+3\lambda^2}$

$\delta a/a = 0.1\% \rightarrow \delta\lambda = 0.00036$

Best previous: 5% Stratowa et al. (1978), Byrne et al. (2002)
aCORN goal: 0.5% Wietfeldt et al. (2009)
aSPECT goal: 0.3% Glueck et al. (2005), Zimmer et al. (2000)
Nab goal: 0.1% Pocanic et al. (2009)

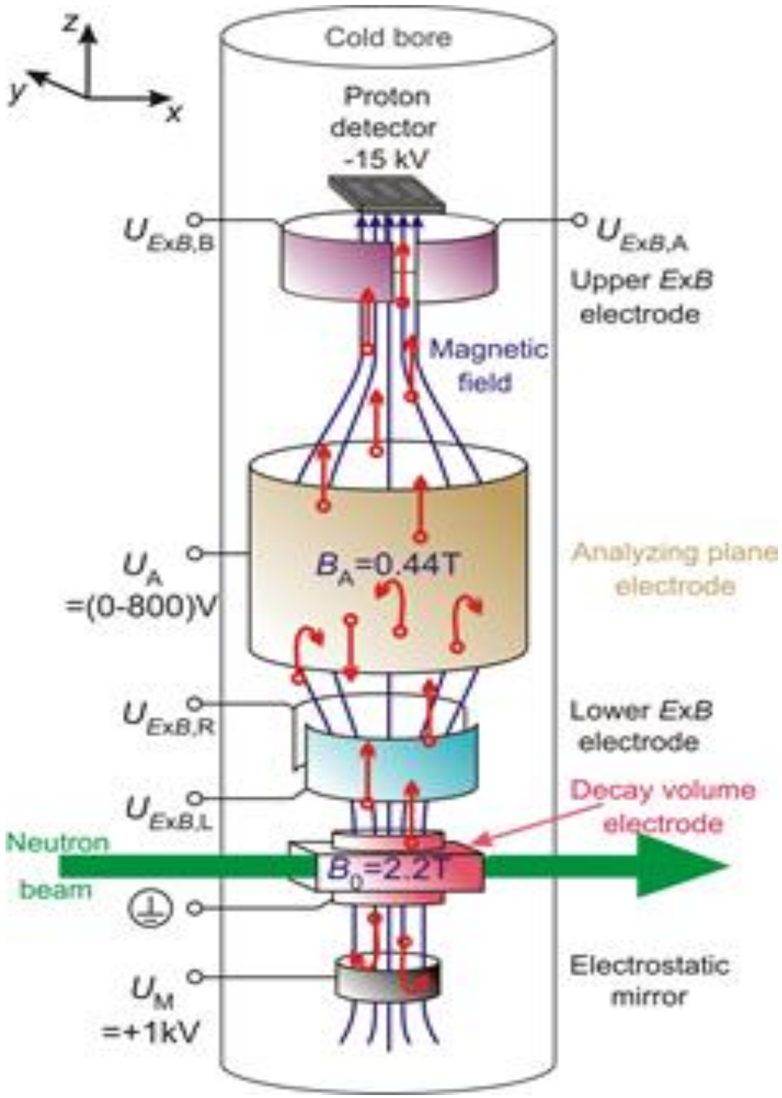
Proton asymmetry $C = 0.27484 \times \dfrac{4\lambda}{1+3\lambda^2}$

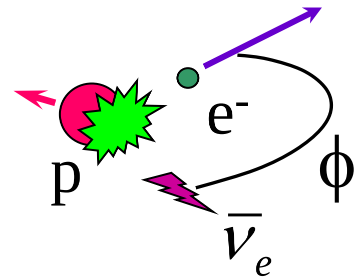
$\delta C/C = 0.1\% \rightarrow \delta\lambda = 0.0019$

Perkeo II: 1.1% ($C = -\,0.2377 \pm 0.0026$) Schumann et al. (2008)
Perkeo III goal: 0.1% Maerkisch et al.
aSPECT goal: 0.1%
PANDA goal: 0.1% Alarcon et al. (2008)

*a*SPECT

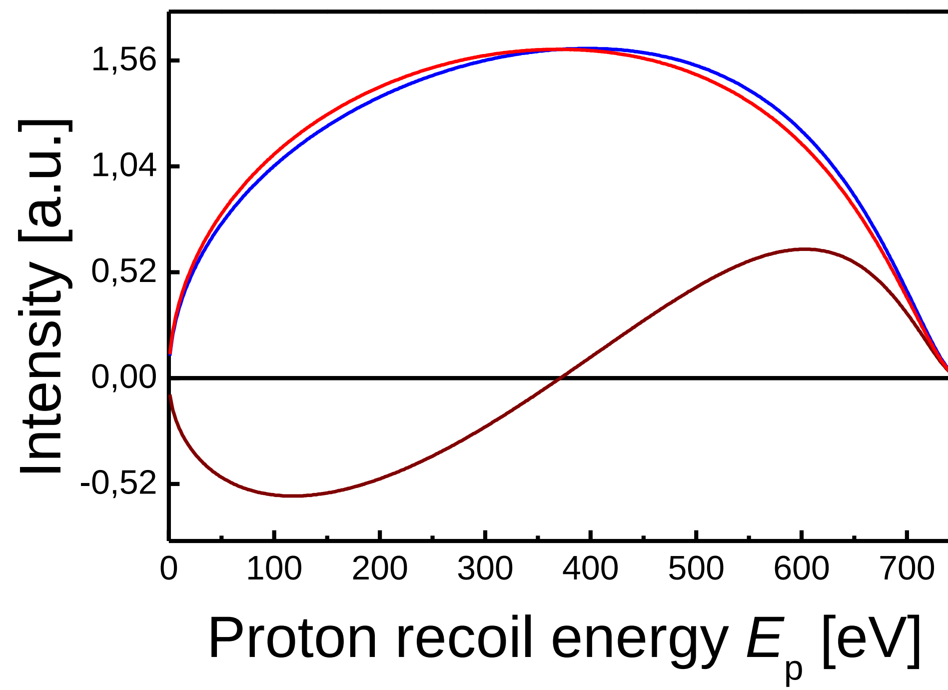
(ILL, Karlruhe, Mainz, Vienna, Virginia)





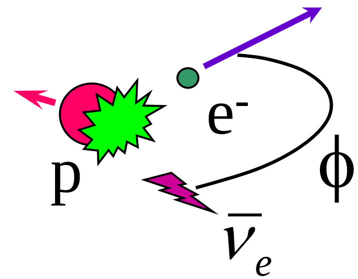
Proton recoil spectrum:

$W(E_p) = f(E_p) + a g(E_p)$

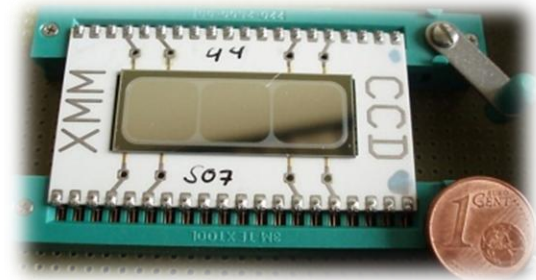


*a*SPECT

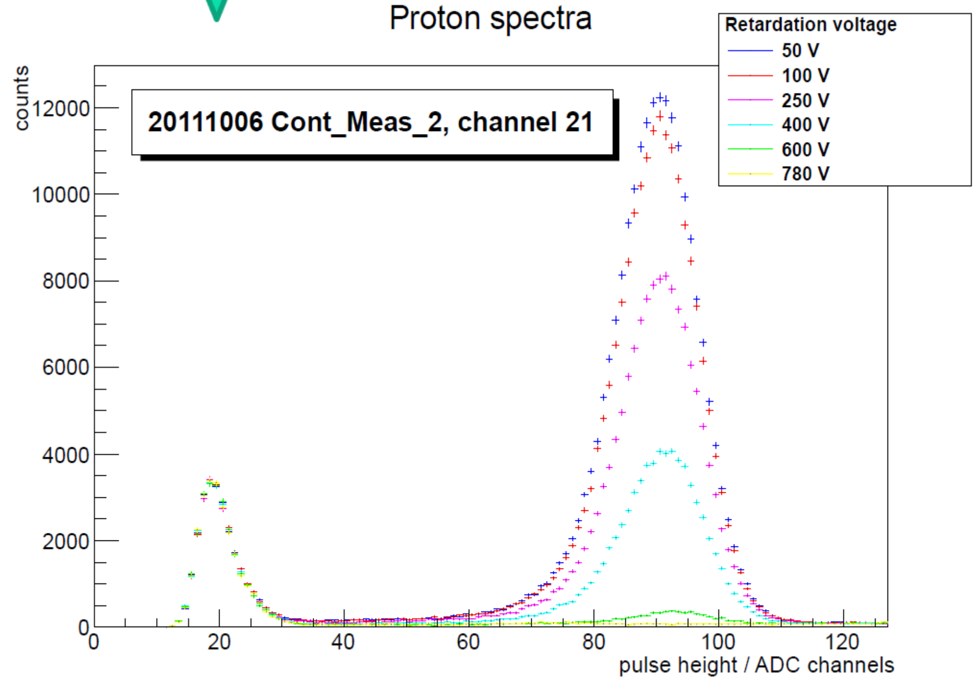
(ILL, Karlruhe, Mainz, Vienna, Virginia)



Si-drift-detector



Proton spectra



Neutron lifetime

In beam experiments

$886.3 \pm 1.2_{stat} \pm 3.2_{syst}$ s		Nico et al. Phys. Rev. C 71 (2005) 055502

Material bottle experiments

888.4 ± 3.3 s	($\Delta t \geq 12$ s)	Nesvizhevsky et al. JETP 75 (1992) 405
$885.4 \pm 0.9_{stat} \pm 0.4_{syst}$ s	($\Delta t \geq 100$ s)	Arzumanov et al. Phys. Lett. B 483 (2000) 15
878.5 ± 0.8 s	($\Delta t \geq 5$ s)	Serebrov et al. Phys. Lett. B 605 (2005) 72
880.7 ± 1.8 s	($\Delta t \geq 110$ s)	Pichlmaier et al. Phys. Lett. B 693 (2010) 221
$881.6 \pm 0.8_{stat} \pm 1.9_{syst}$ s		Arzumanov et al. JETP Lett. 95 (2012) 224

Magnetic bottle experiments

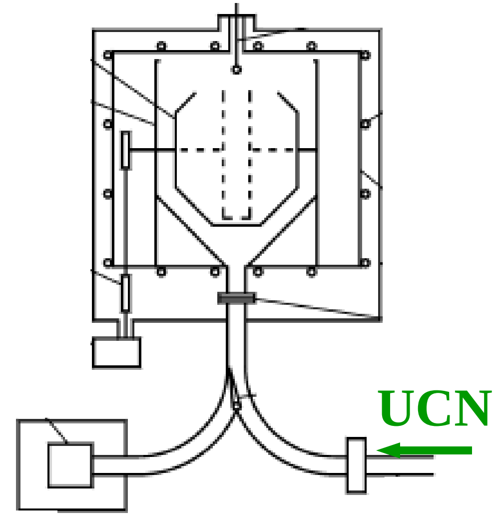
permanent magnet 20-pole bottle	Ezhov et al. to be published
He-II filled 4-pole trap: $833\ ^{+74}_{-63}$ s	Dzhosyuk et al. J. Res. NIST 110 (2005) 339

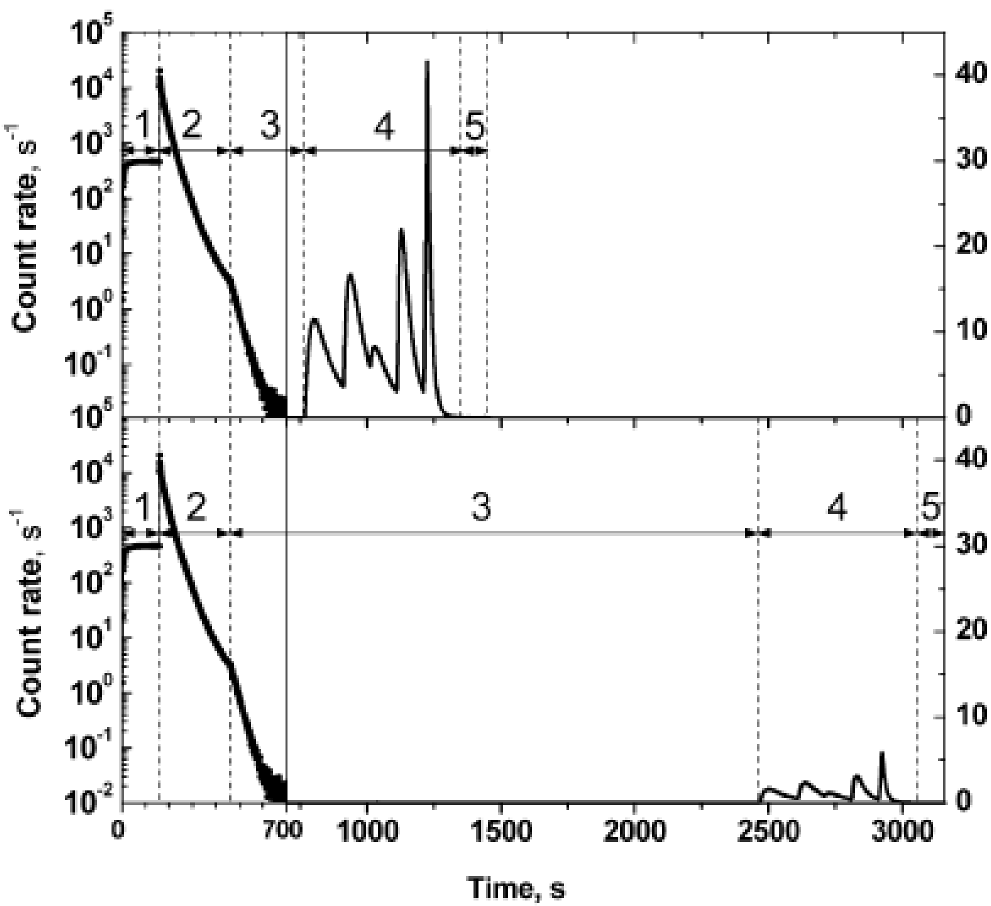
goal with new 3.1 T trap: 2 s per reactor cycle

projects: PENeLOPE, UCNτ, HOPE, all aiming at $\delta\tau_n \rightarrow 0.1$ s

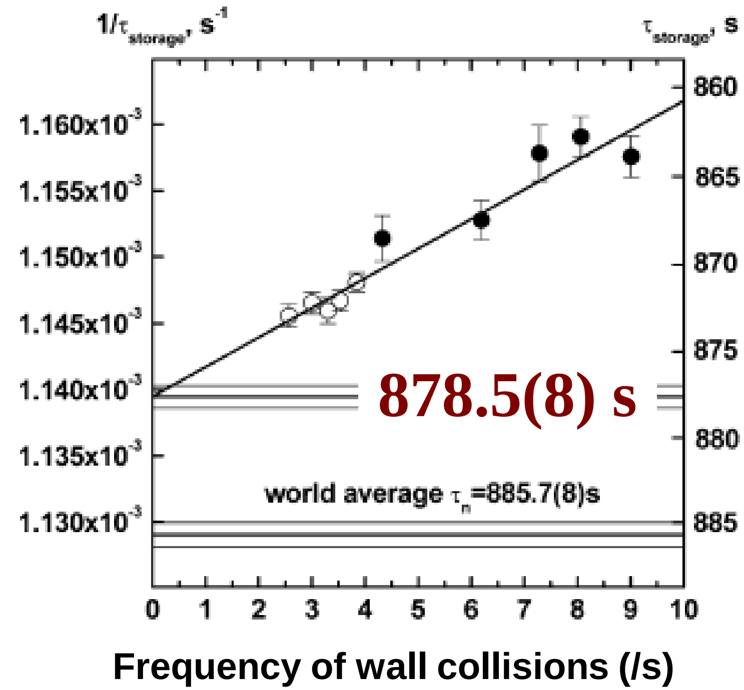
Neutron lifetime experiment with low-T fluorine-oil coated walls

A. Serebrov et al. Phys. Lett. B 605 (2005) 72



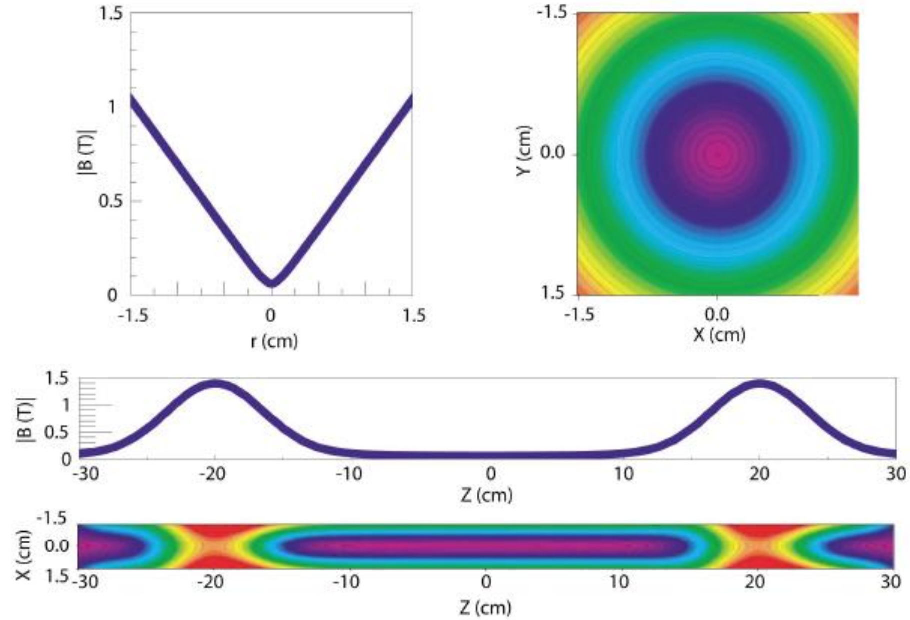


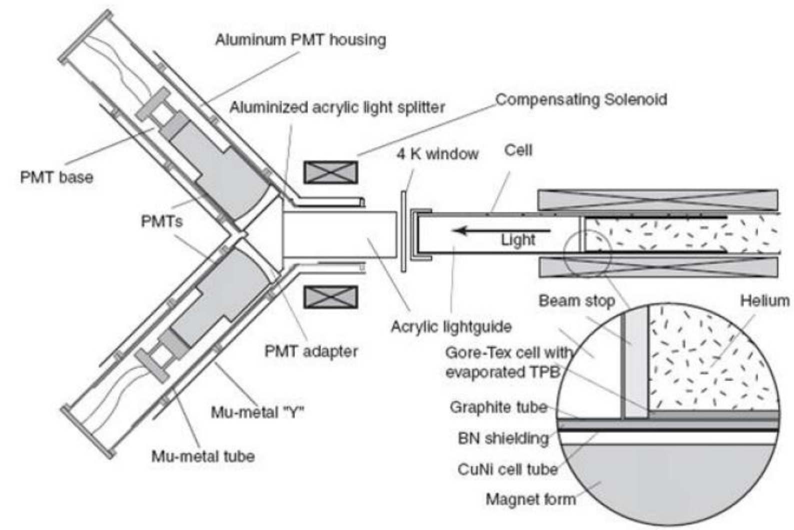
$$\tau_{\mathrm{storage}}^{-1} = \tau_{\mathrm{n}}^{-1} + \tau_{\mathrm{loss}}^{-1}$$



Superconducting Ioffe trap

UCN production in He-II
and in-situ detection (NIST)



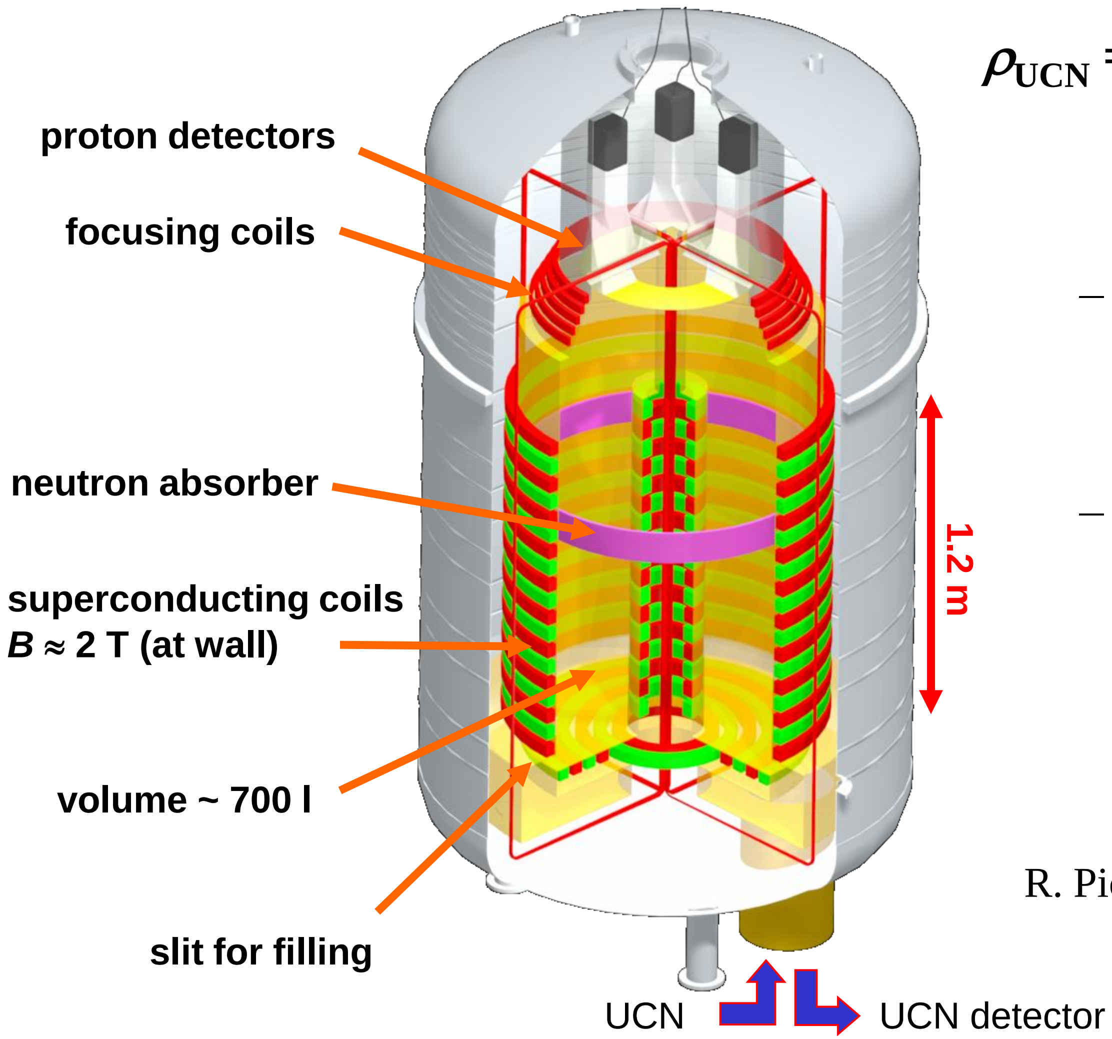


P. Huffman et al., **Int. workshop Particle Physics with slow Neutrons, May 2008 ILL**

proposed large volume magnetic storage experiment PENeLOPE

S. Paul et al.

$$N(t) = N(t_0)\exp\left(-\frac{t}{\tau_n}\right)$$



$\rho_{UCN} = 10^3 - 10^4\ cm^{-3}$ (PSI /FRM II):

$$N_{stored} = 10^7 - 10^8$$

- **Statistical accuracy:**

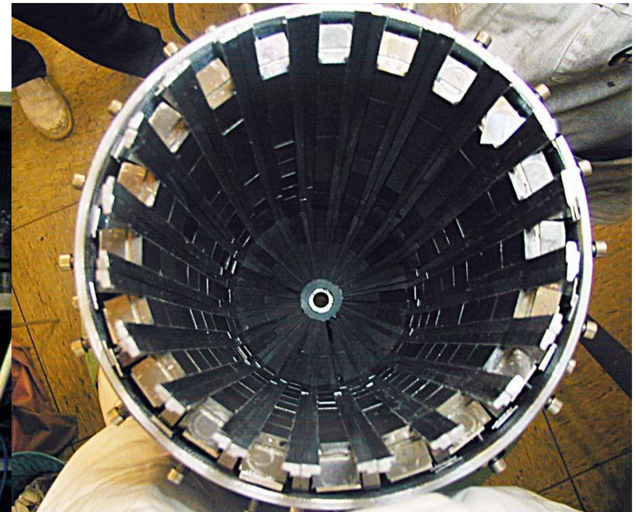
  $\delta\tau_n \sim 0.1$ s in 2-4 days

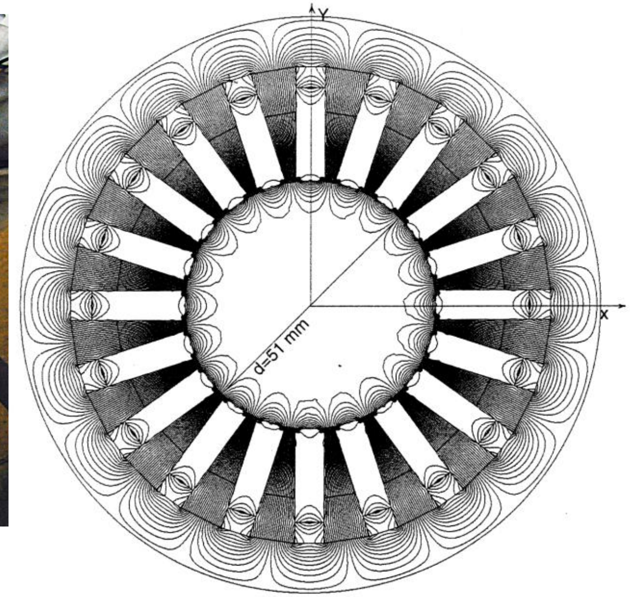
- **Systematics:**
  - **Spin flips negligible (simulation)**
  - **use different values B_{max} to check expected E_{UCN} independence of τ**

R. Picker et al., J. Res. NIST 110 (2005) 357

UCN storage in a trap from permanent magnets

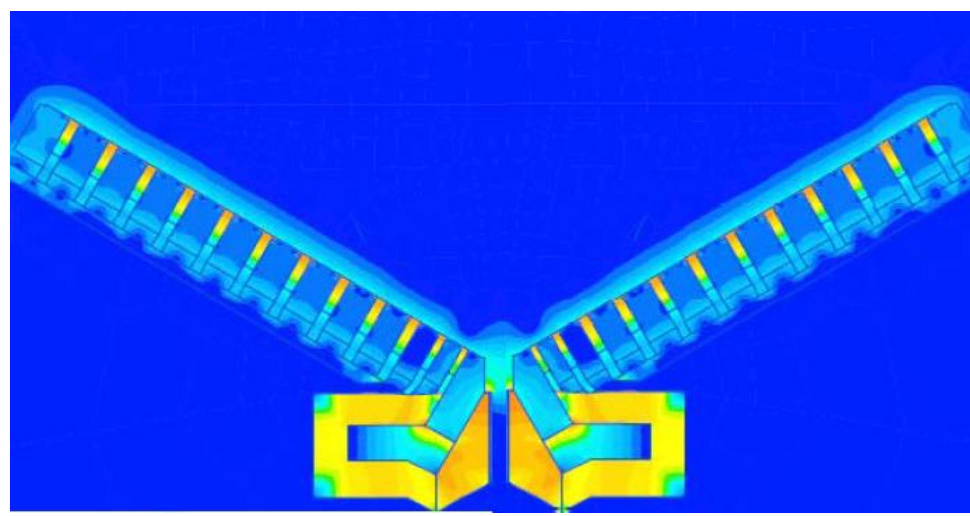
(PNPI – ILL – LPC – TUM)



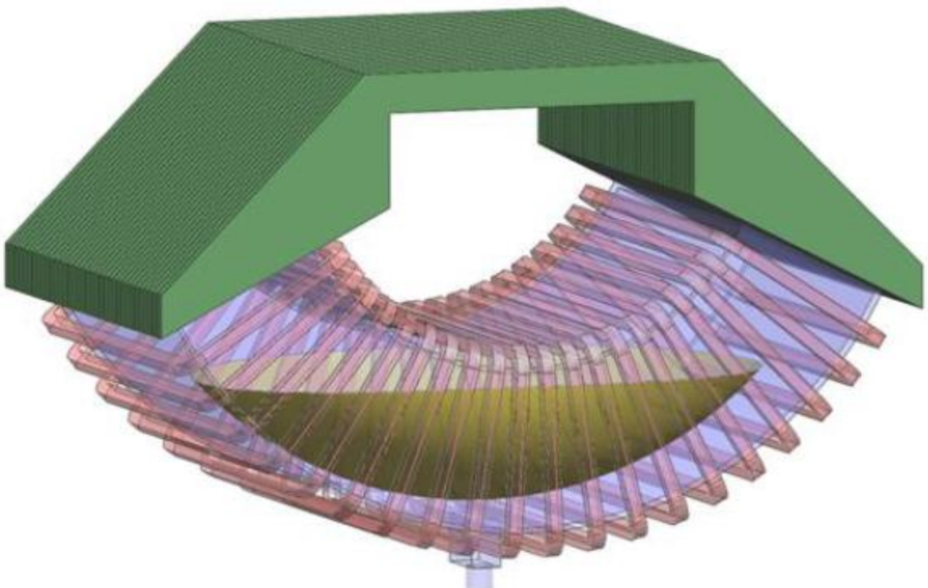


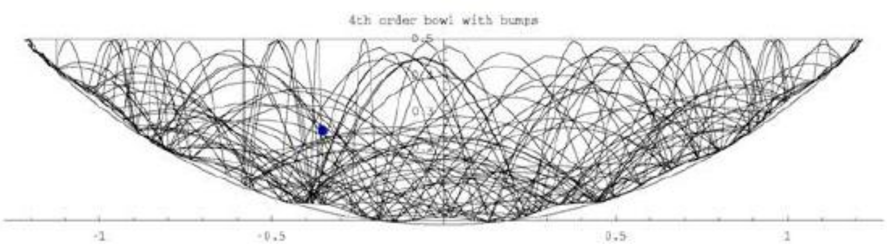
V. Ezhov et al. J. Res. NIST 110 (2005) 345

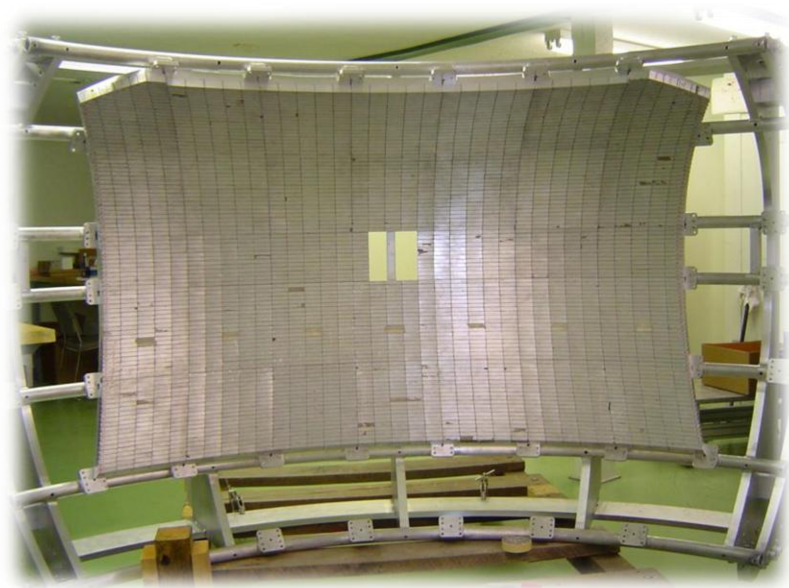
Follow-up trap design (90 l):



UCN τ





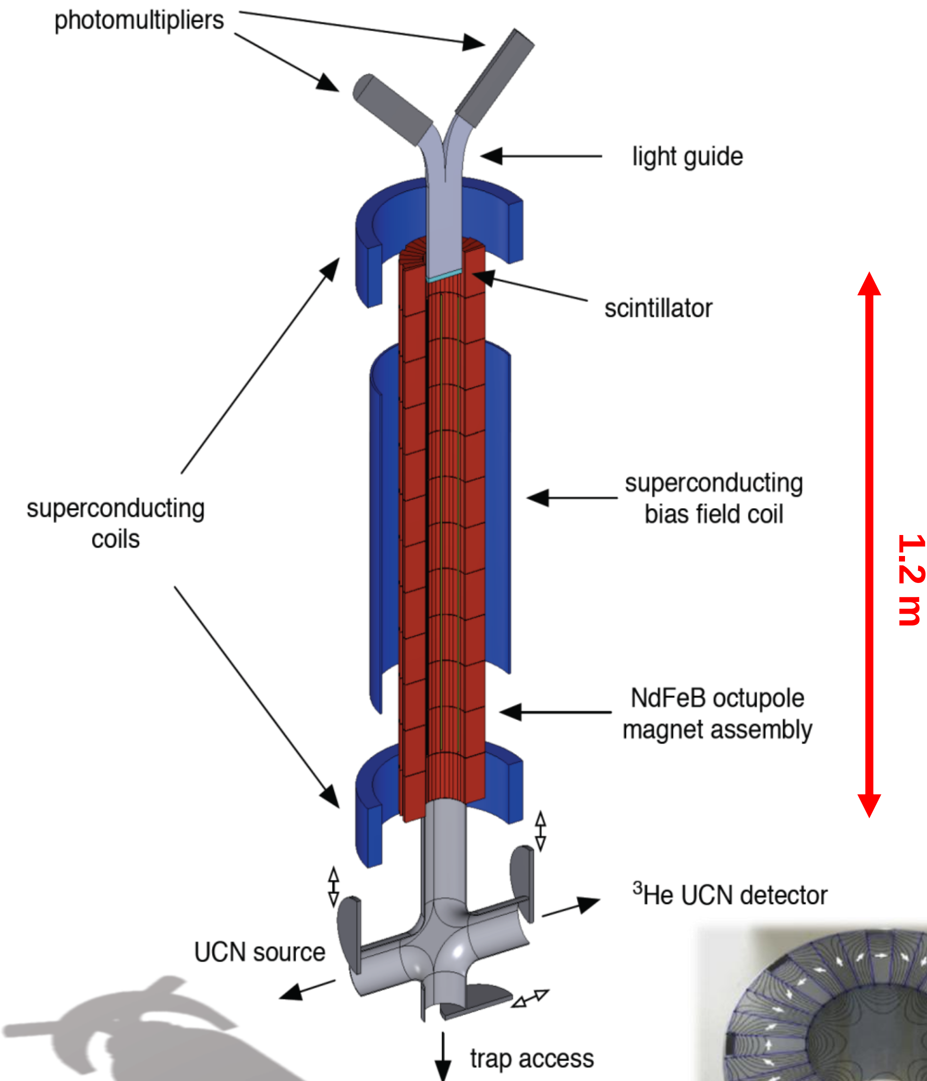


Walstrom et al. Nucl. Instr. Meth. A 599 (2009) 82

Pictures courtesy C.Y. Liu

D. Bowman, Int. Workshop UCN Sources and Experiments Sept. 13-14 2007 TRIUMF

Halbach OctuPole Experiment



$$N(t) = N(t_0)\exp\left(-\frac{t}{\tau_n}\right)$$

With new UCN source SUN-2 @ ILL:

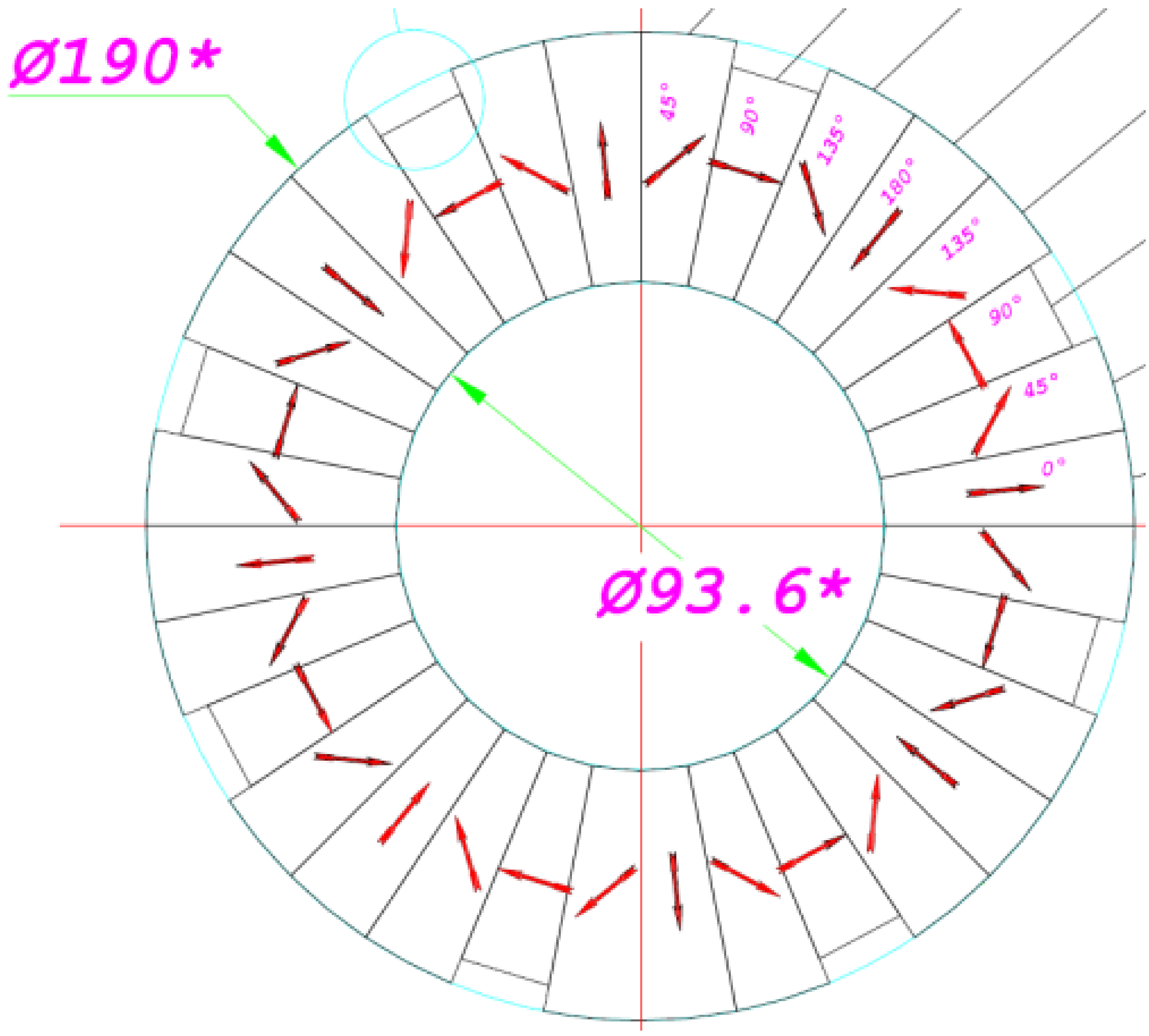
$$N_{\text{stored}} = 10^5$$

– **Statistical accuracy:**

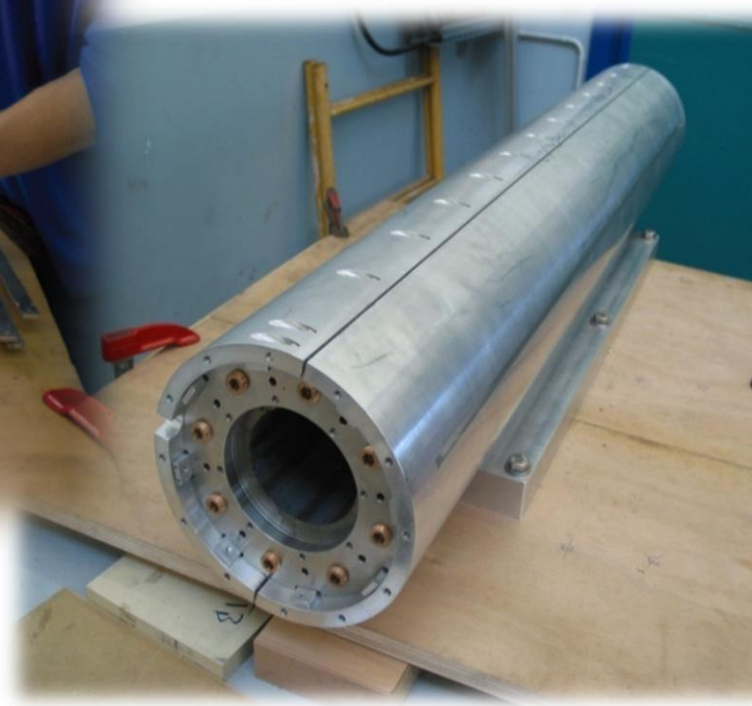
$$\delta\tau_n \sim 0.5\ \text{s in 10 days}$$

– **Systematics checks:**

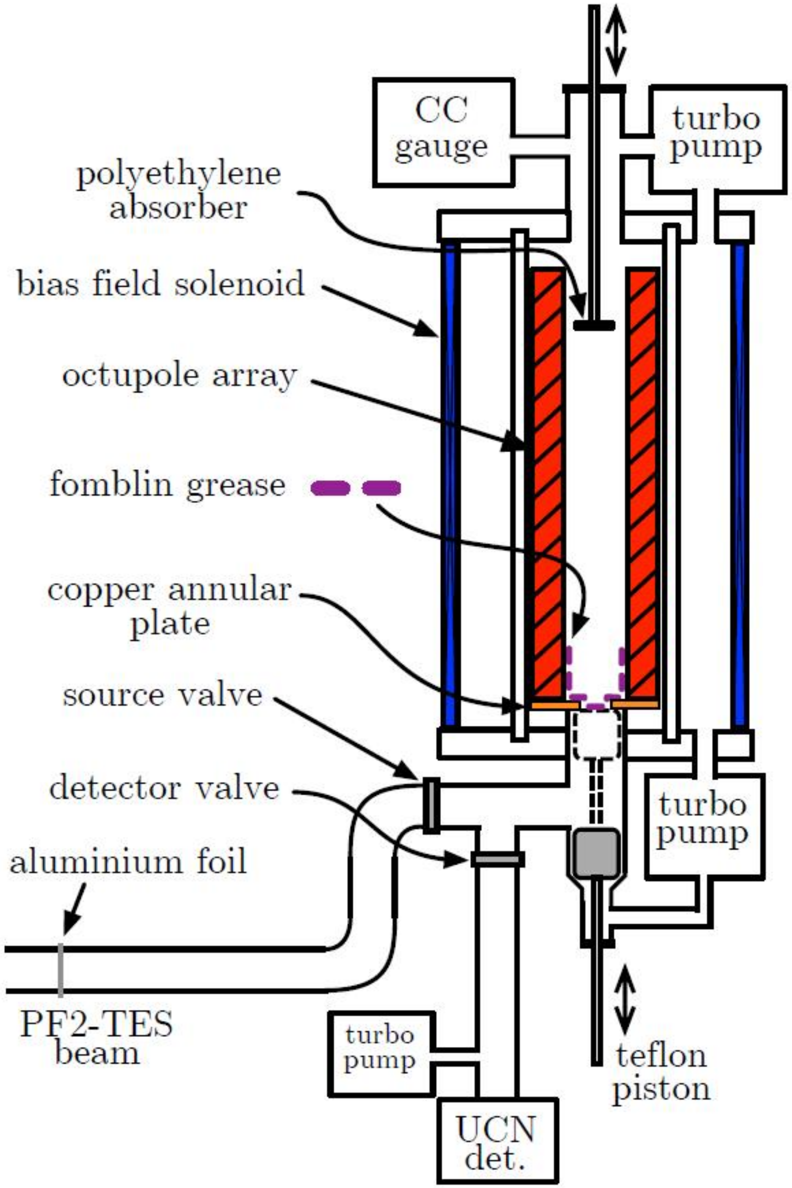
- **spin flips (negligible)**
- **spectral shaping with scatterer/ absorber to kill marginally trapped neutrons**



Ø190*
Ø93.6*
45°
90°
135°
180°
135°
90°
45°
0°

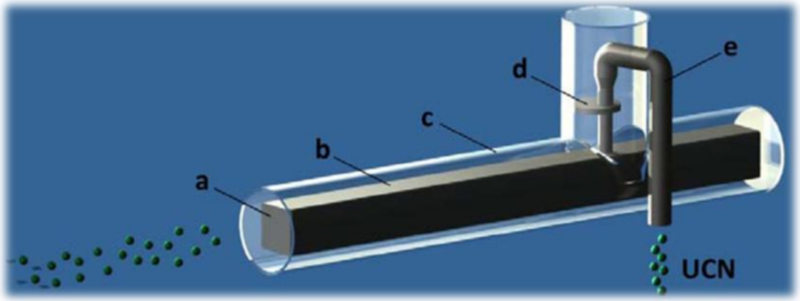


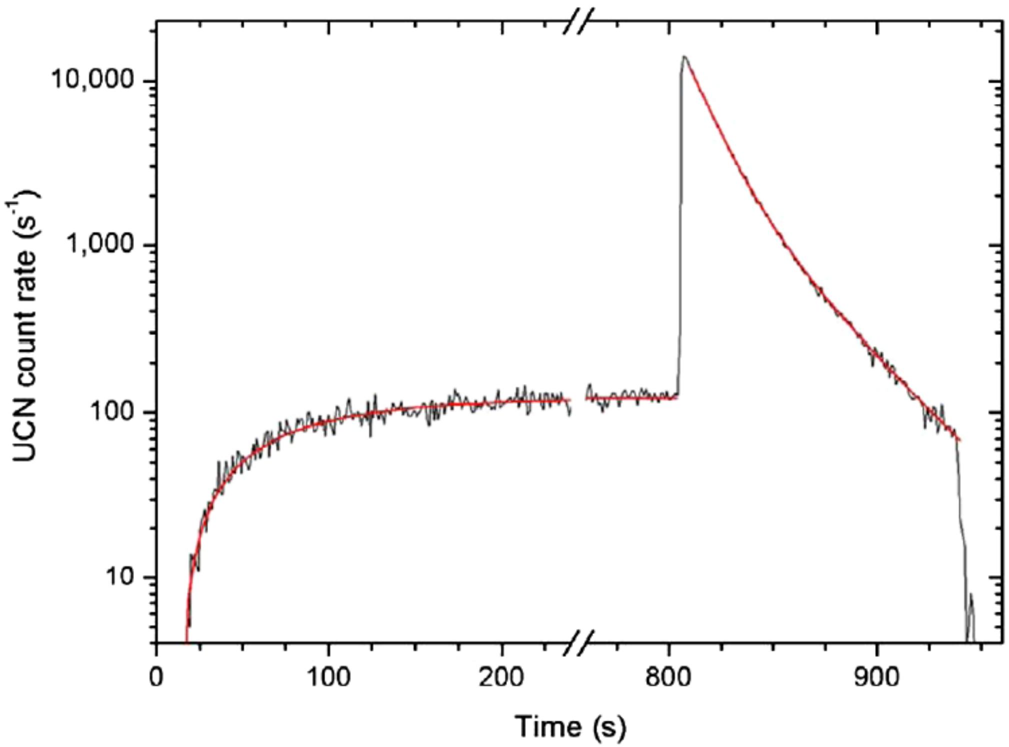
12 octupoles + hands & forces = magnetic trap

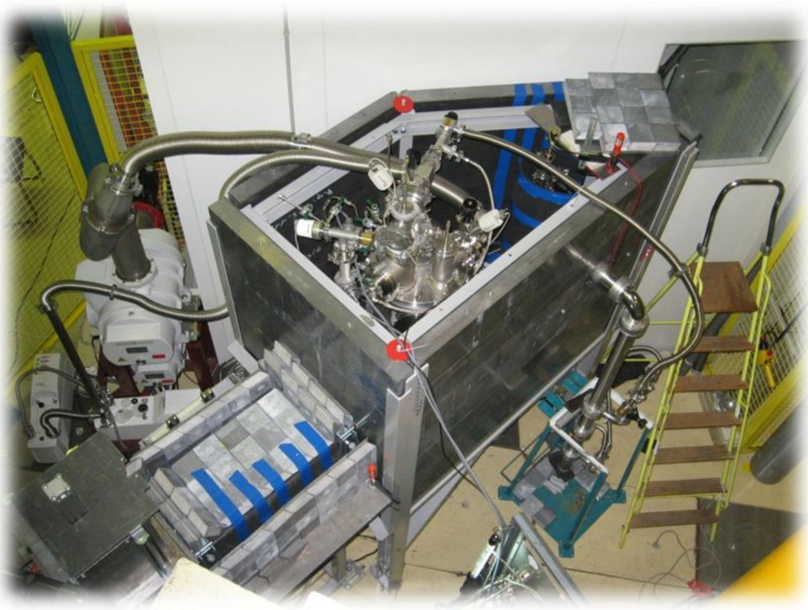


Storage time constant of trap closed with teflon plug: 800 s
(PhD thesis Kent Leung)

Development of new He-II UCN sources







274,000 counts from 5 l:

55 cm^3

PRL highlight O. Z., F.M. Piegsa, S.N. Ivanov, PRL **107** (2011) 134801

Conclusions

- Accuracy still insufficient compared to $0^+ \rightarrow 0^+$ decays
- Many projects in the pipeline, some well advanced,
  to reach the goals for $\delta\tau$ and $\delta\lambda$ in the years to come