Neutron lifetime experiment HOPE

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Beta-decay weak interaction studies in the era of the LHC, Brussels, 3 September 2014

CKM unitarity test - goals for neutron decay?

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

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Marciano & Sirlin PRL 96 (2006) 032002

uncertainty due to radiative corrections: $\delta |V_{ud}|^2_{RC} = 3.8 \times 10^{-4}$

	τ_n	λ
accuracy goal:	**0.34 s**	**0.0003**
PDG:	880 ± 1.1 s (S=1.8)	- 1.2701 ± 0.0025 (S=1.9)
Perkeo II: Mund et al. PRL 110 (2013)		- 1.2748 ± 0.0013
UCNA: Liu et al. PRL 105 (2010) 181803		- 1.2759 ± 0.0043
Perkeo III: Maerkisch et al.		- 1.2??? ± 0.00067

Experimental situation

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

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

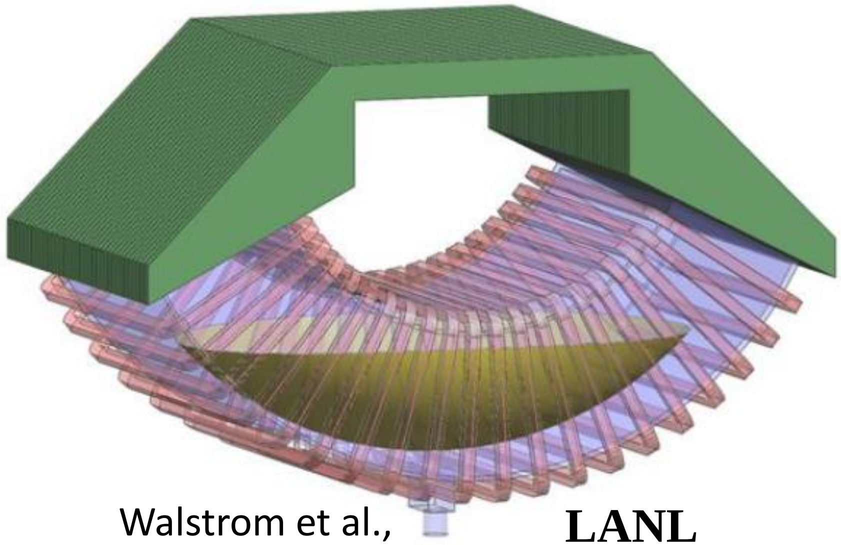
Magnetic bottle experiments

permanent magnet 20-pole bottle — Ezhov et al., still unpublished

He-II filled 4-pole trap: $833\ ^{+74}_{-63}$ s — Dzhosyuk et al. J. Res. NIST 110 (2005) 339

Projects: PENeLOPE, UCNτ, HOPE... all aiming at $\delta\tau_n << 1$ s

UCNτ (electron detection)



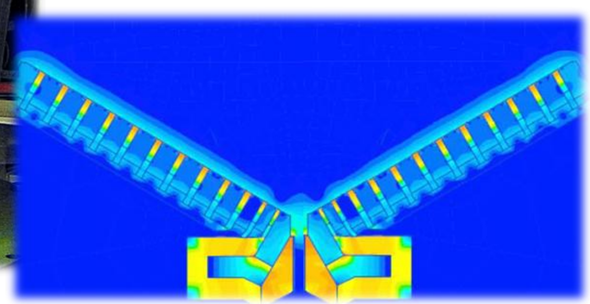
Walstrom et al.,

Nucl. Instr. Meth. A 599 (2009) 82

LANL

perm. mag. trap
("fill and empty")

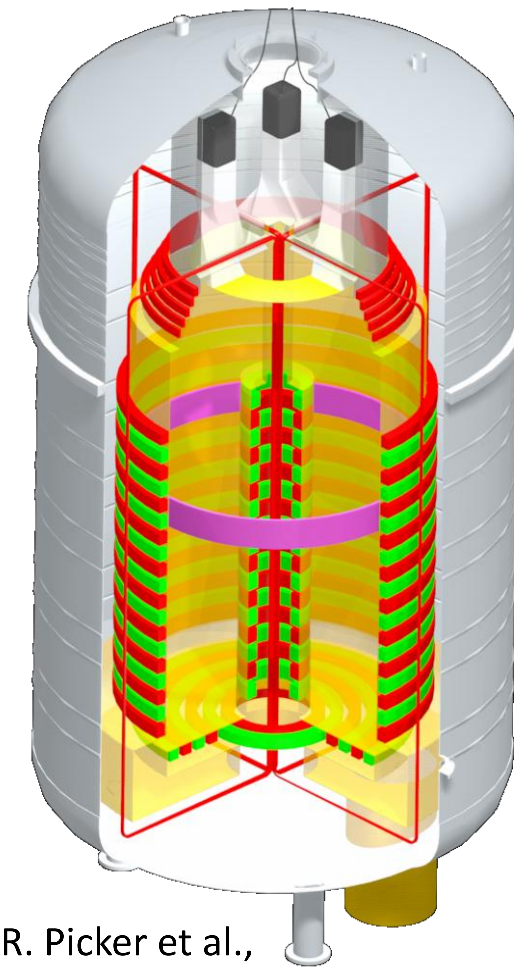
PNPI / LPC / ILL



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

PENeLOPE
(proton detection)

TU Munich



R. Picker et al.,

J. Res. NIST 110 (2005) 357

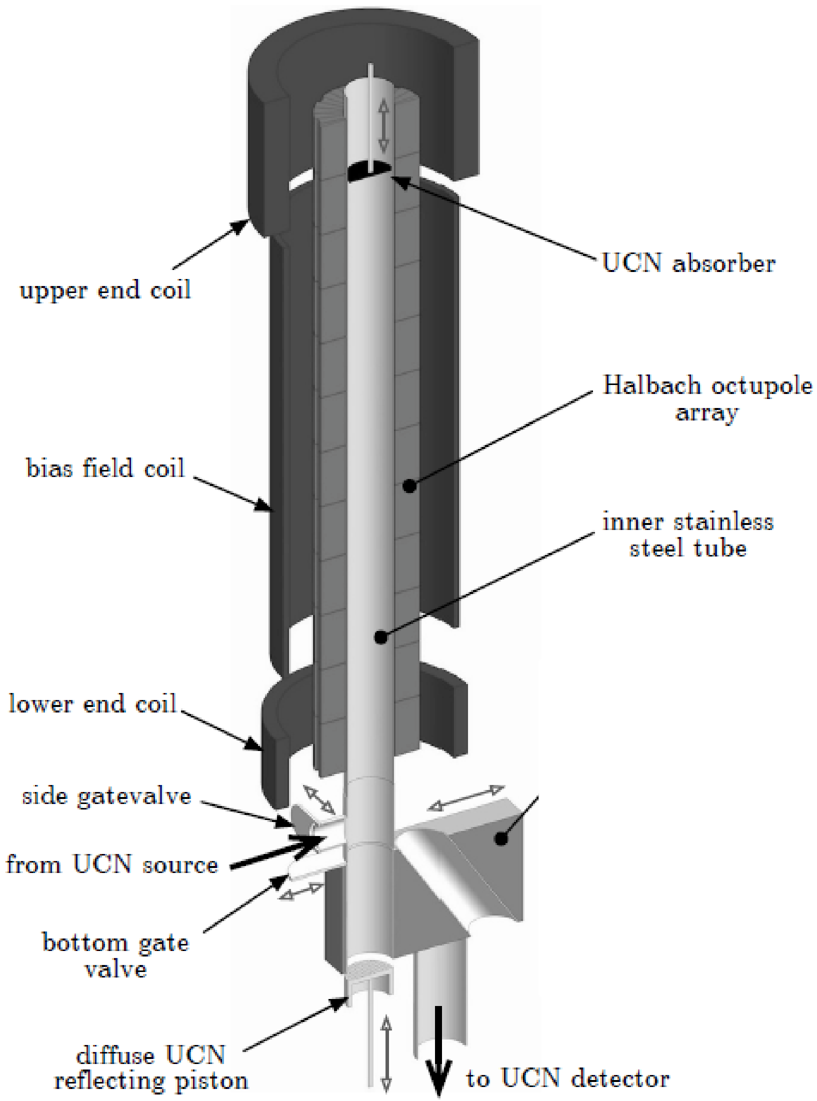
Benefit/challenge comparison of two magnetic trapping strategies

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

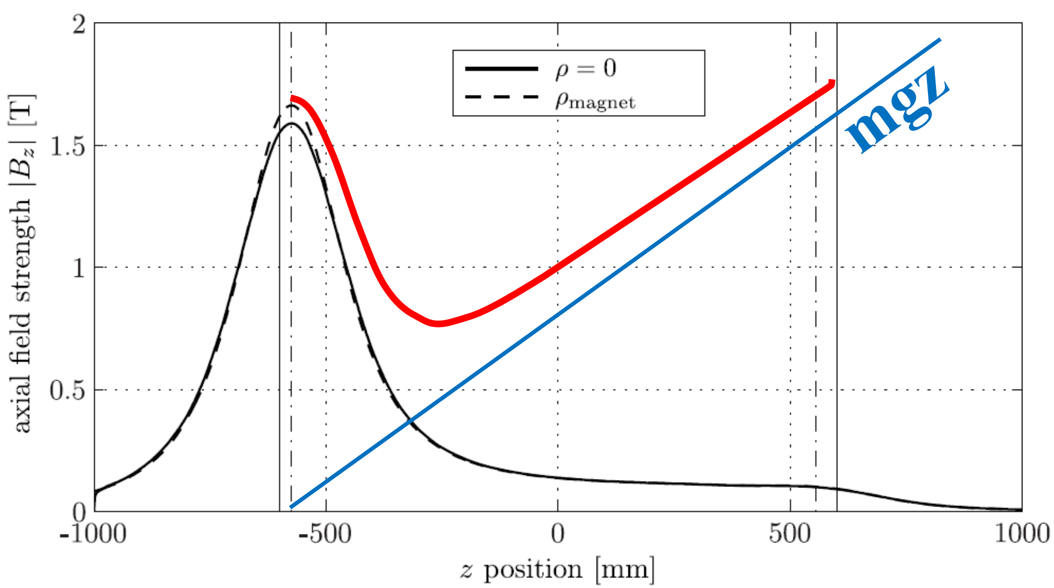
"fill and empty"	**"counting the deads"**
detection of UCN	detection of decay β or proton
– need to determine $N(t_0)$	⊕ get decay curve in one shot
– fast coil ramping required	⊕ needs only slow coil ramping
⊕ high SNR	– SNR for β-detection
⊕ Low sensitivity to time-dependent backgrounds	– stability issue for p-detection
⊕ Monitoring of depolarisation and leakage of marginally trapped neutrons	– susceptible to time-dependent backgrounds and variations of neutron density distributions

HOPE – Halbach OctuPole neutron lifetime Experiment

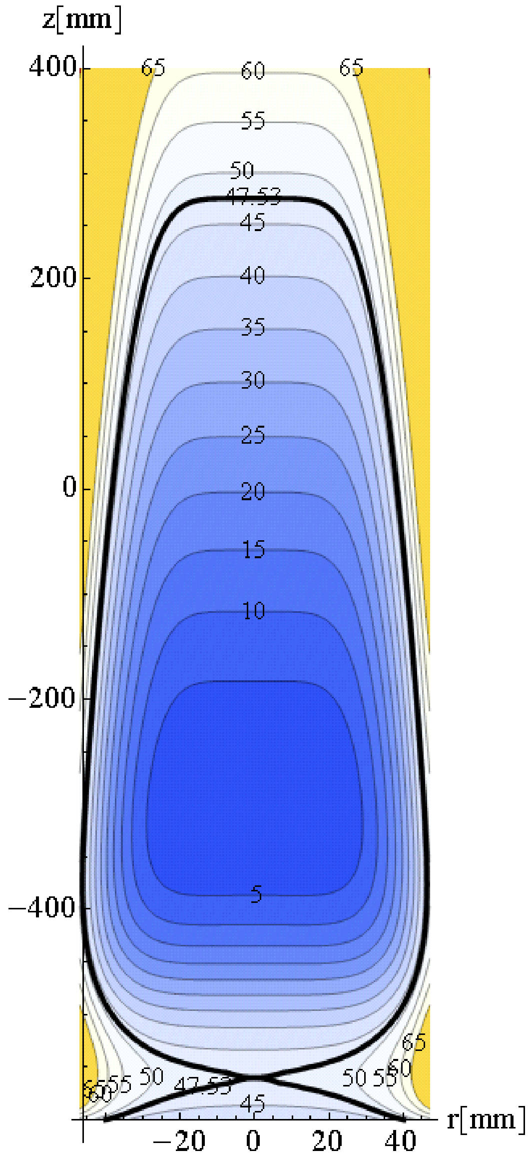
PhD works **Felix Rosenau, Fabien Lafont, Kent Leung**



- magneto-gravitational trap
- $V_{\text{eff}} \approx 2$ l
- trap depth 47 neV
- high-density UCN source
- counting the dead & survivors



HOPE – Halbach OctuPole neutron lifetime Experiment



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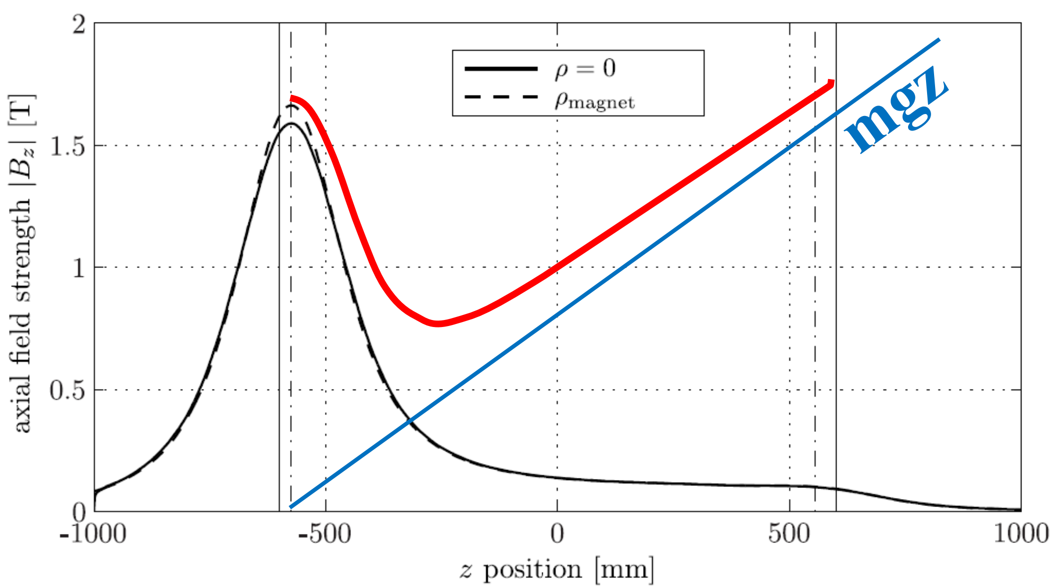
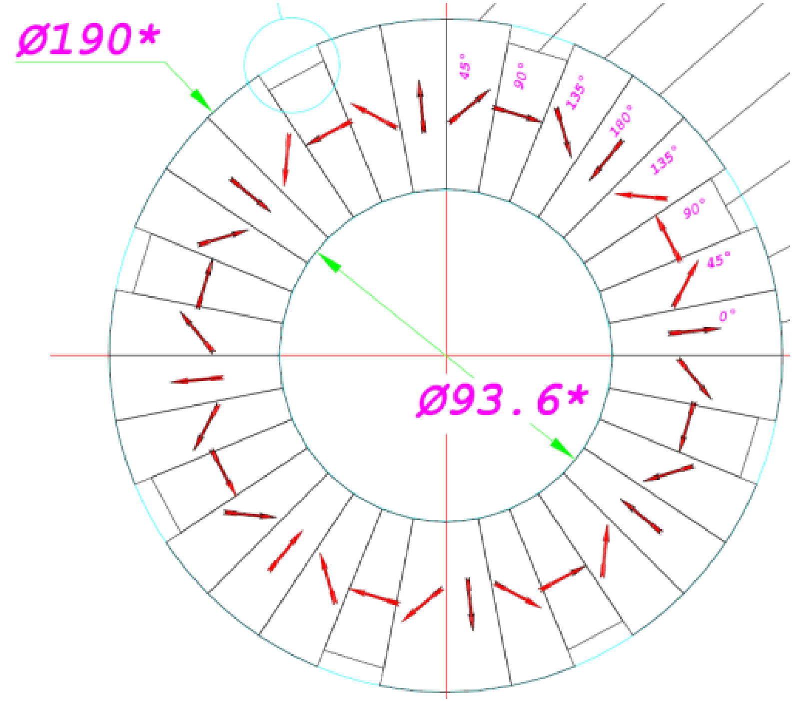
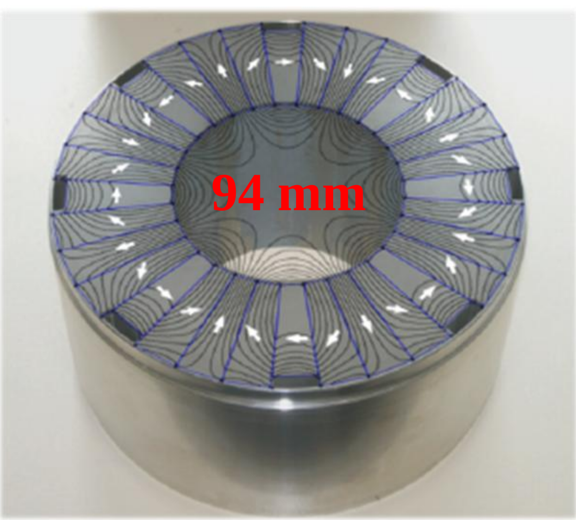
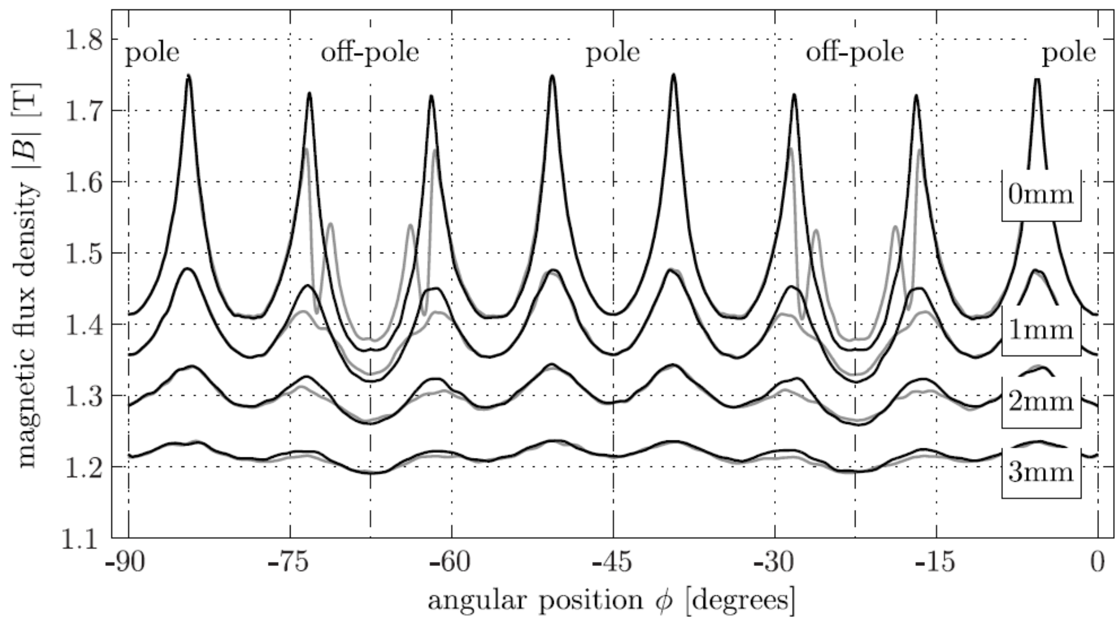


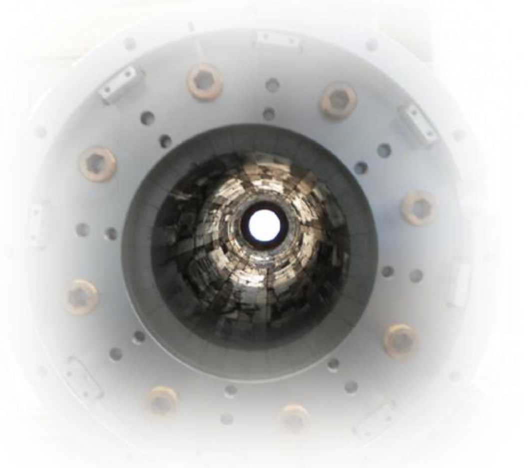
Halbach octupole

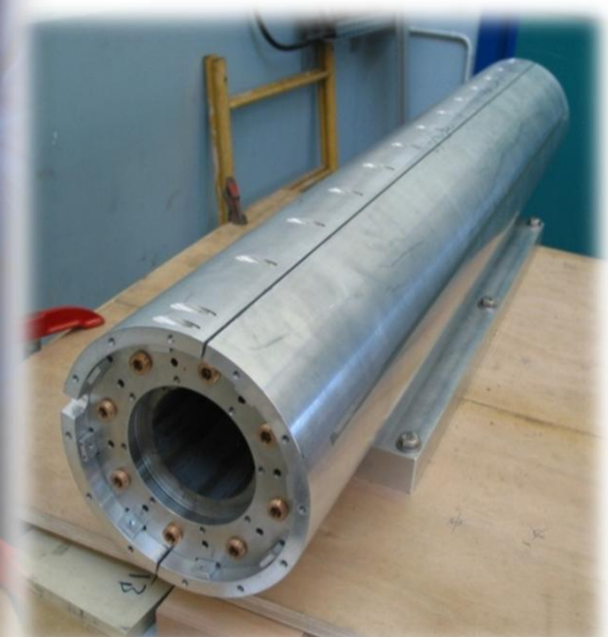
- $B(r) = B_R(r/R)^3$
- 32 magnet slices
- NdFeB magnets: B_R = 1.35 T





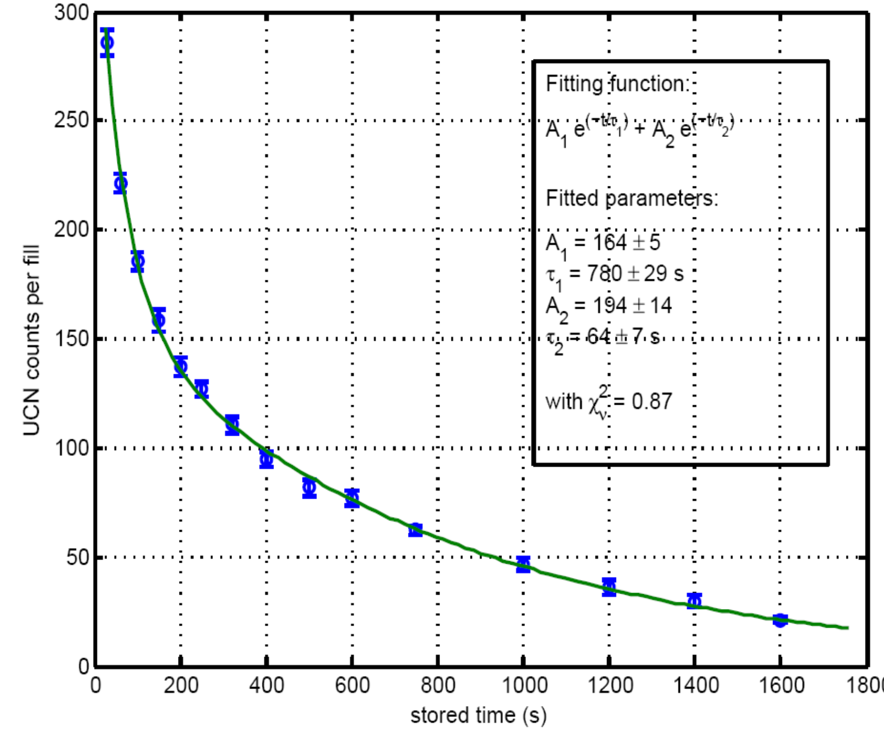






12 octupoles + hands & forces = magnetic trap

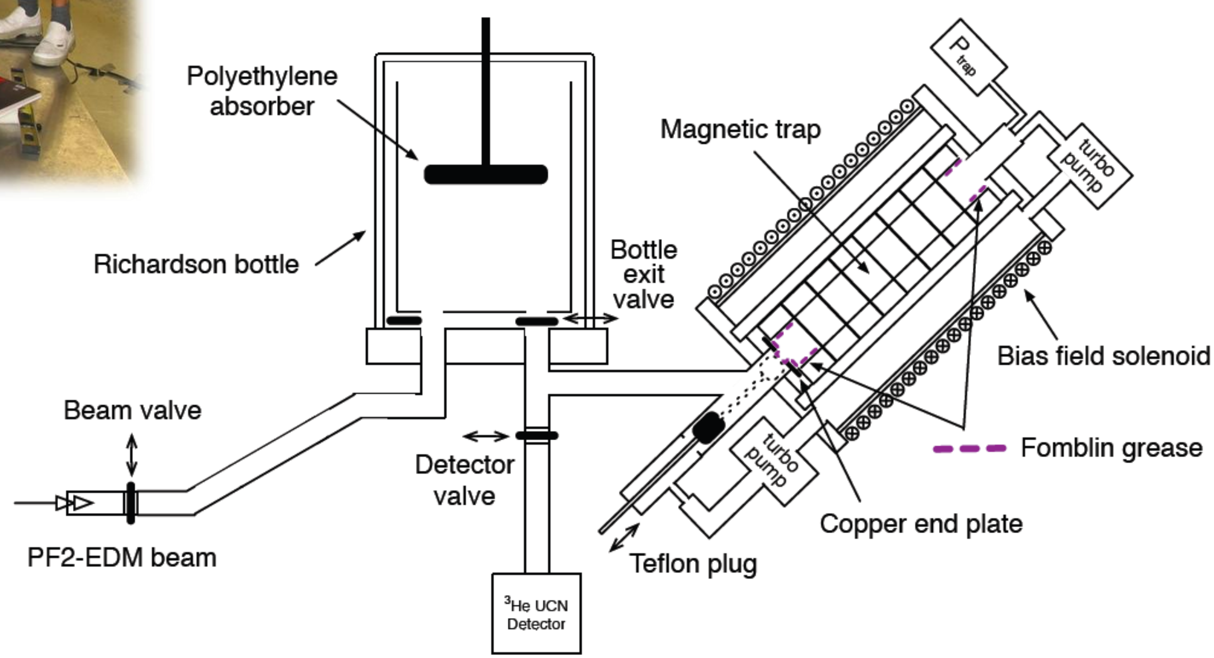
UCN trapping tests at PF2



$\tau_{storage} \approx$ **800 s**

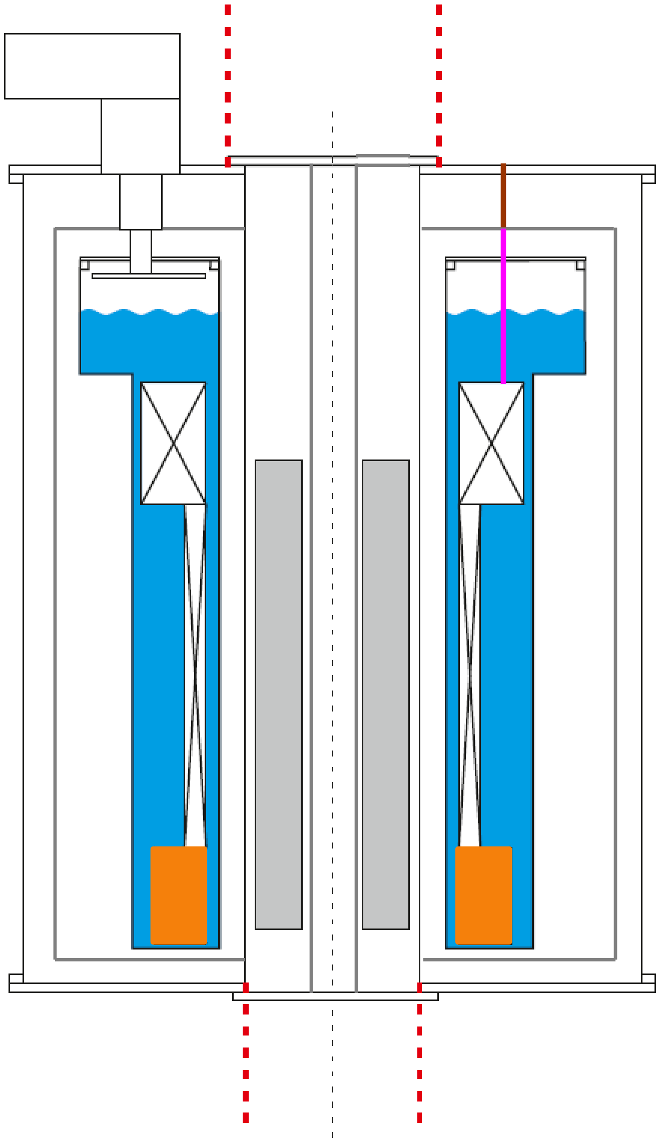
(teflon plug at trap bottom and a few mT bias field)

PhD thesis **Kent Leung**



Shutter coil for vertical confinement

<u>for "fill and empty" method</u>



(5 T upper coil for later, optional proton focusing onto an *a*SPECT-type SDD)

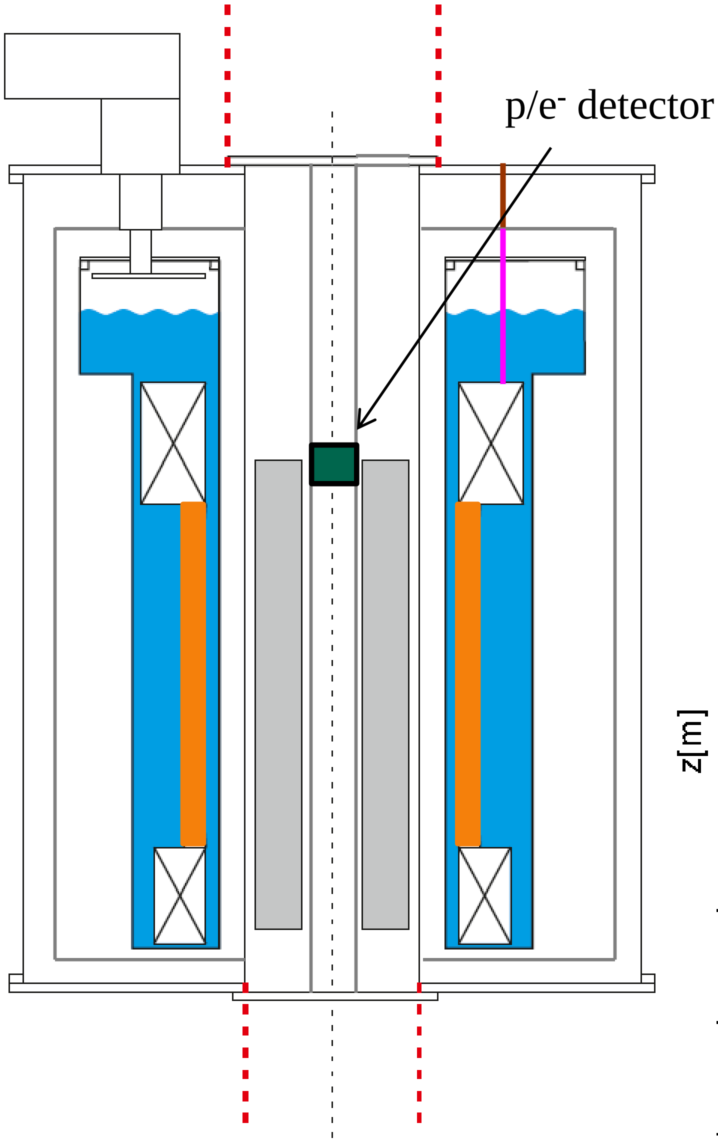
lower superconducting coil: 1.7 T @ 300 A

5 s ramping time (29 V)

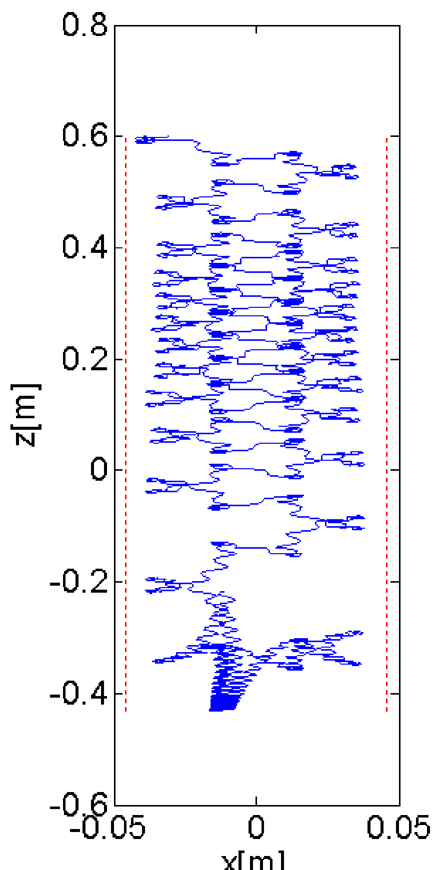
Bias coil to guide decay products to detector

<u>for "counting the deads"</u>

PhD thesis **Fabien Lafont** (electron detector)



p and β gyrate about vertical bias field



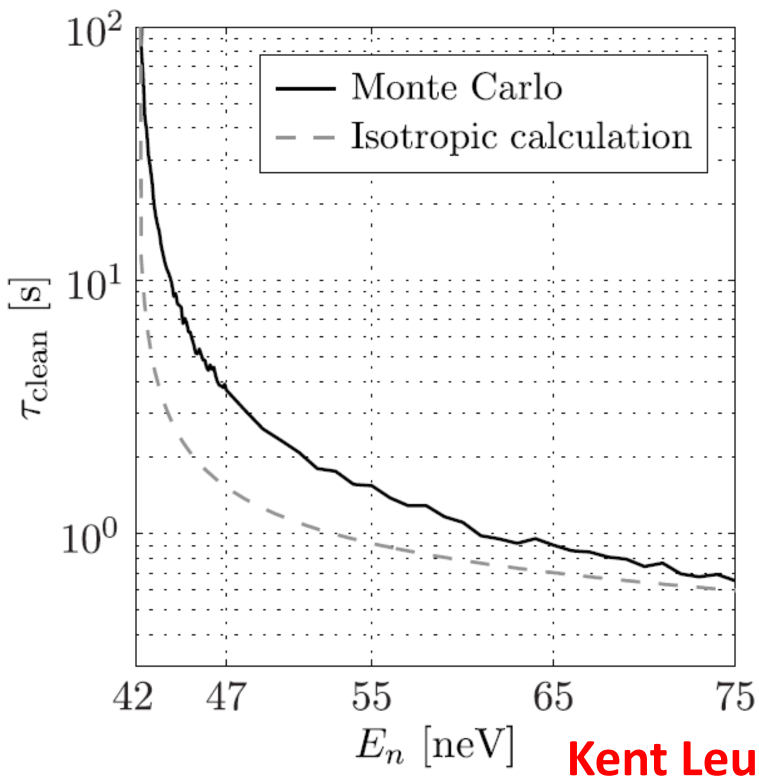
Simulation:
60 % probability
to reach detector

Simple geometry with free access from top and bottom

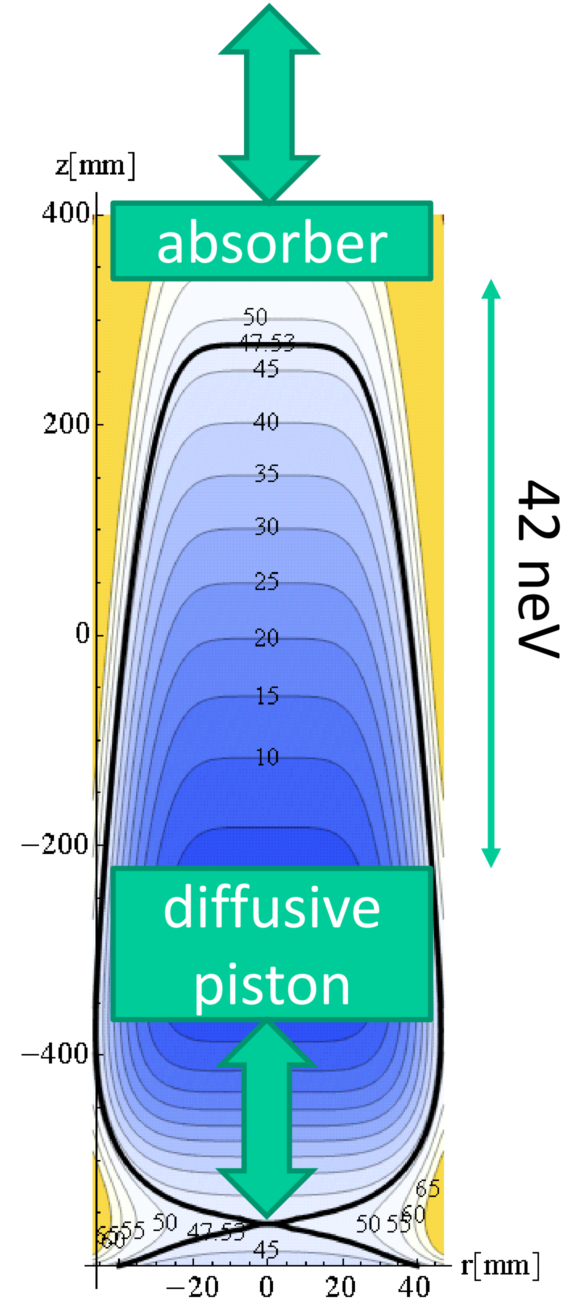
Preparation of spectrum

- Diffusive piston for trajectory mixing
- Cut into spectrum with absorber

→ get rid of marginally trapped neutrons



Kent Leung



Experiments?

Start with well established
"fill and empty" method

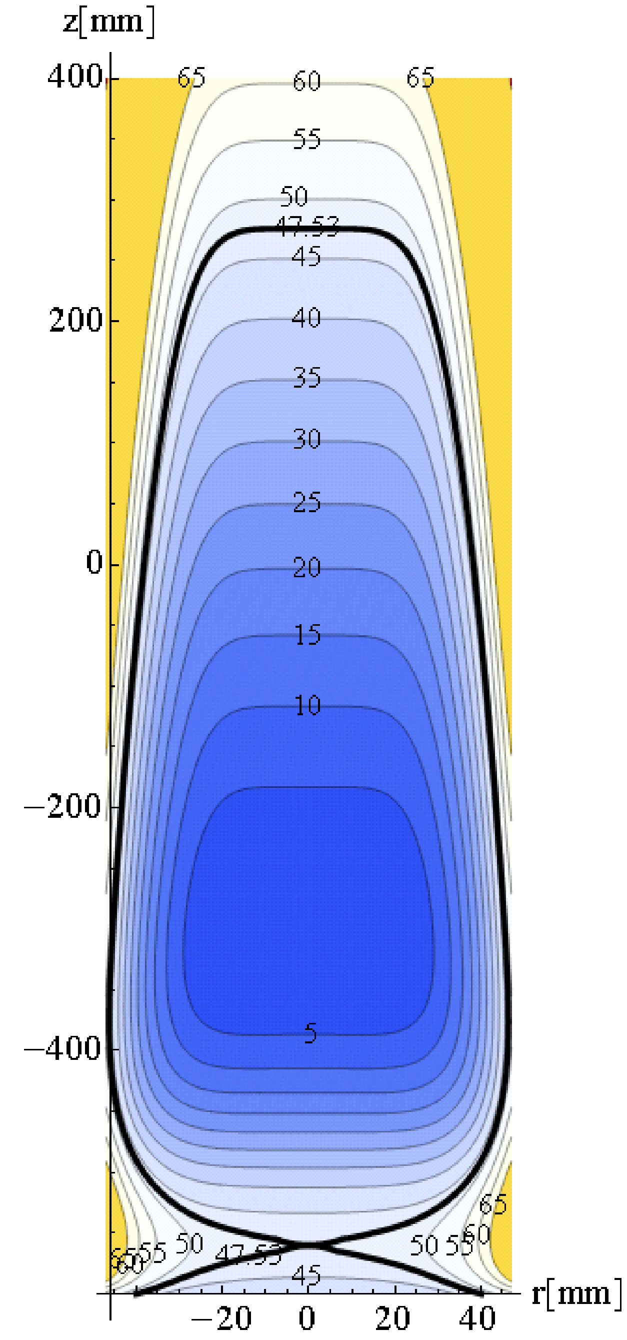
Full-bore access from top and bottom:

- insertion of diffusive paddle and absorber
- monitoring of depolarisation
- detection of marginally trapped neutrons

Couple experiment to superfluid-helium
UCN source **SUN-2** at ILL
(pessimistic estimate: 3000 UCN/fill)

$\delta\tau_n$ ~ 0.5 s in 50 days (statistical)

To be started in mid 2014



Various “minor problems”:

- 15 months delay of cryostat delivery
- too much heat generated in current leads
  (solved by redesign in our group)
- superconducting switches transit at 220 A

  $\rightarrow$ 5 times less UCN in trap at 200 A
  $\rightarrow$ several l/h liquid helium consumption at 300 A

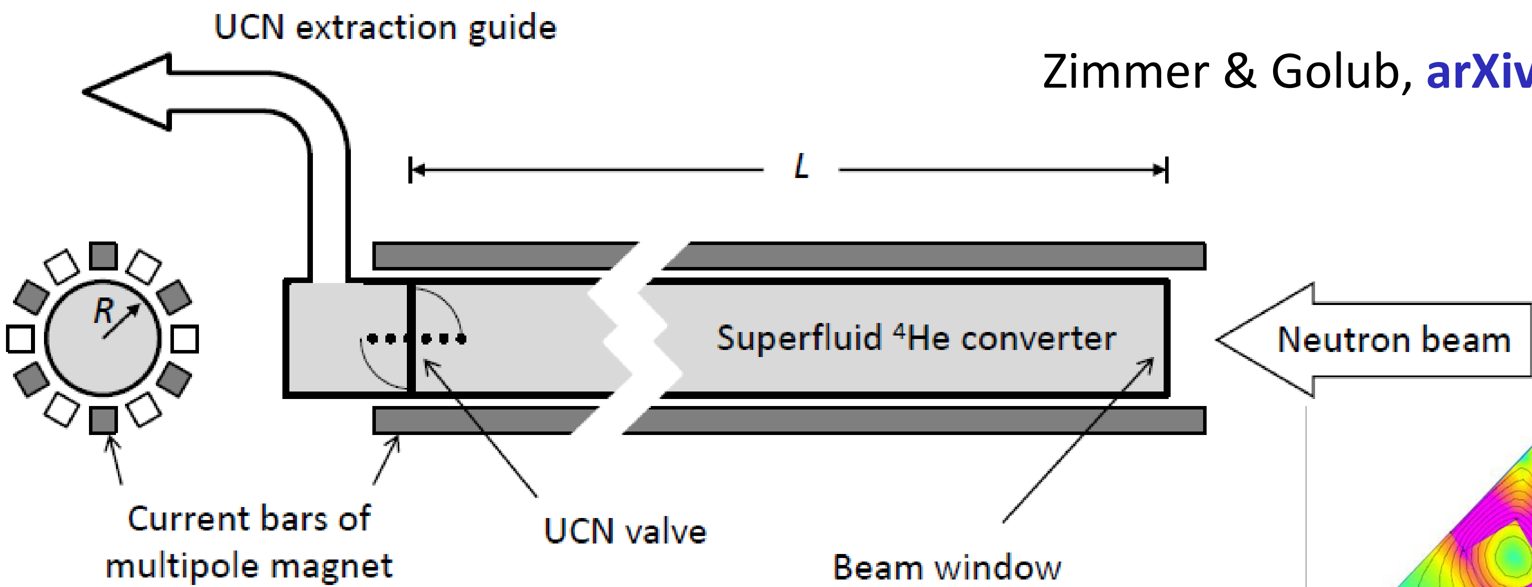
First runs at PF2 just started

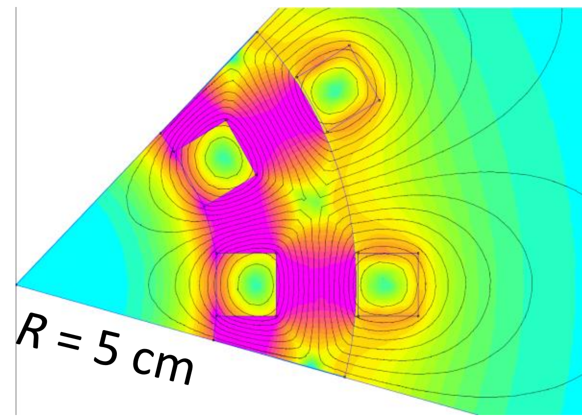
→ Study magnetic UCN storage
→ benchmark for other UCN sources

Switch problem to be solved later

Project **SuperSUN** (3 m magnetic 12-pole UCN reflector)

Zimmer & Golub, **arXiv:1303.1944**





- In-situ UCN polarizer
- Enhancement of UCN spectrum possible
- Weak dependence of ρ_{UCN} on wall quality (values in source for E < 296 neV):

f = W/V	3×10^{-5}	1×10^{-4}	2×10^{-4}	4×10^{-4}
$n_\infty^\uparrow$ (cm^{-3}, for $B_R = 2.5$ T)	1820	1400	1200	1040
$n_\infty^\uparrow$ (cm^{-3}, without magnet)	820	390	230	130

numbers for monochromatic beam H172b (5 times more in direct beam)