# Status of $V_{ud}$ from neutron β-decay

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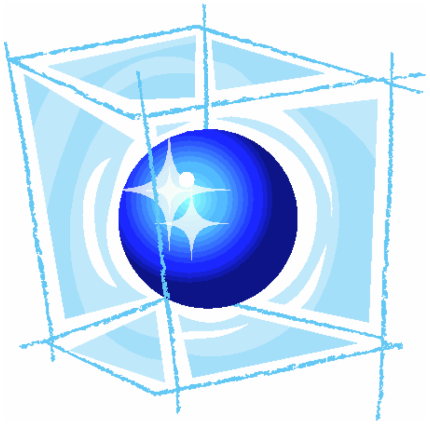
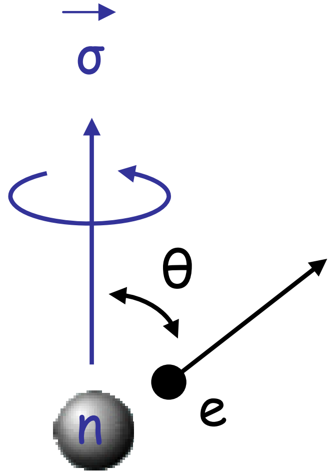




CKM 2008

Rome, Italy

September 9, 2008

# $V_{ud}$ from neutron β-decay

Value for neutron lifetime

$\tau_n$

Ratio of axial-vector and vector couplings

$\lambda = g_A / g_V$

$$\frac{1}{\tau_n} \propto G_F^2 \, |V_{ud}|^2 \, (1 + 3\lambda^2) \, (1 + RC)$$

*input*

*EW radiative corrections*

Common with 0+ → 0+

[Marciano and Sirlin (2006)]

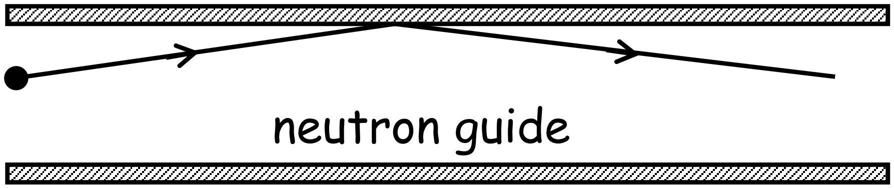
*nuclear structure effects absent*

| | *experiments* | *PDG value* | *precision* |
|---|---|---|---|
| lifetime | beam, storage | 885.7(8) s | 0.09 % |
| $g_A / g_V$ | β-asymmetry | -1.2695(29) | 0.23 % |

# Types of neutron beams

**Cold neutrons** E ~ 3 meV, T ~ 40 K, v ~ 800 m/s

Flux from reactor,
spallation source
moderated



neutron guide

*Glancing angles transported*

*Polarized with "supermirrors"*

Short interaction times in apparatus

↓

Need relatively large number of neutrons

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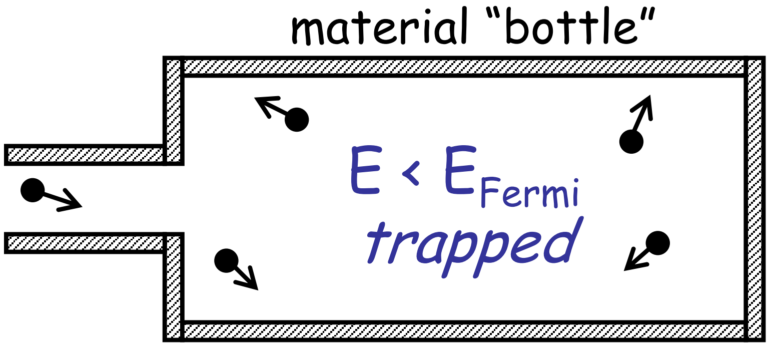
**Ultracold neutrons (UCN)** E < 300 neV, T ~ 1 mK, v < 7 m/s

Flux from reactor,
spallation source
moderated, then
"downscattered"
(phonon process)



material "bottle"

$E < E_{Fermi}$

*trapped*

Long interaction times in apparatus

↓

Need relatively small number of neutrons

# Neutron β-decay observables for $V_{ud}$

## Neutron lifetime

**Storage experiments (UCN)**

$$N(t) = N_0\, e^{-t/\tau_\beta}$$

Count decay electrons and/or "surviving" UCN

**In-beam experiments (cold neutrons)**

$$dN/dt = -N_0/\tau_\beta$$

Count $N_0$ and decay product(s)

## $g_A/g_V$: Polarized β-decay, correlation coefficients

$$dW \propto \mathcal{F}(E_e)\times\left[1 + a\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_e E_\nu} + \langle\vec{\sigma}_n\rangle\cdot\left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e\times\vec{p}_\nu}{E_e E_\nu}\right)\right]d\Omega_e\, d\Omega_\nu\, dE_e$$

e-ν correlation: −0.103(4) [3.9%]

spin

β-asymmetry: −0.1173(13) [1.1%]

ν-asymmetry: 0.983(4) [0.4%]

# Status of parameters

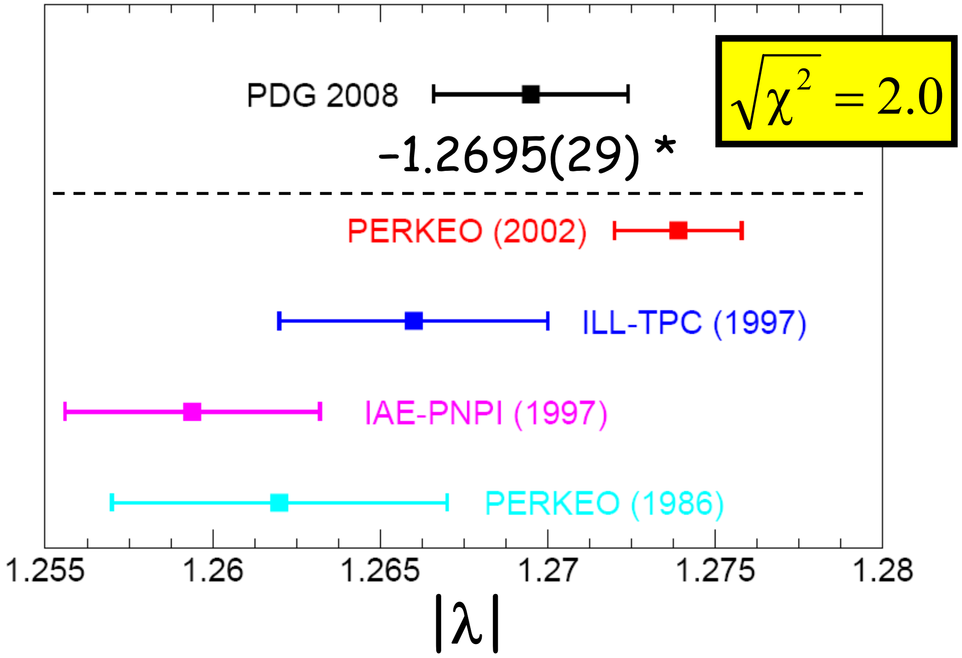
$$a_0 = \frac{1 - \lambda^2}{1 + 3\lambda^2}$$

$$A_0 = -2\frac{\lambda^2 + \lambda}{1 + 3\lambda^2}$$

$$B_0 = 2\frac{\lambda^2 - \lambda}{1 + 3\lambda^2}$$

$$\frac{\delta|\lambda|}{\lambda} \cong 0.27\frac{\delta a}{a} \cong 0.24\frac{\delta A}{A} \cong 2.0\frac{\delta B}{B}$$

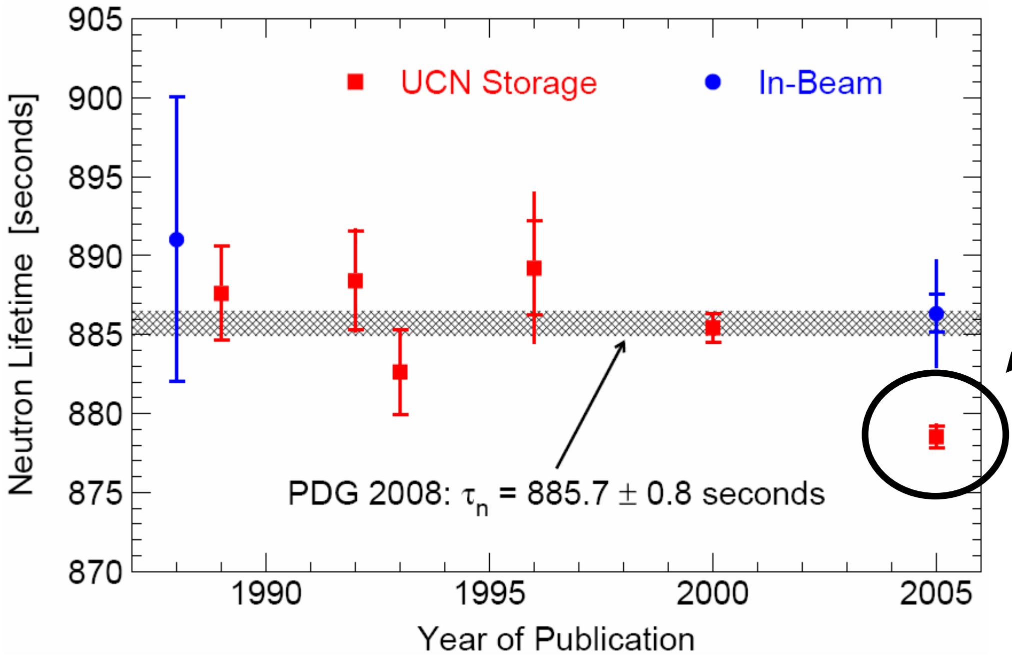
|  | ΔA/A [ % ] |
|---|---|
| PERKEO II | 0.6 |
| ILL-TPC | 1.3 |
| IAE-PNPI | 1.2 |
| PERKEO I | 1.7 |
| PDG Mean | 1.1 |



* PDG λ extraction also employs 1 result for A and B

B. Plaster

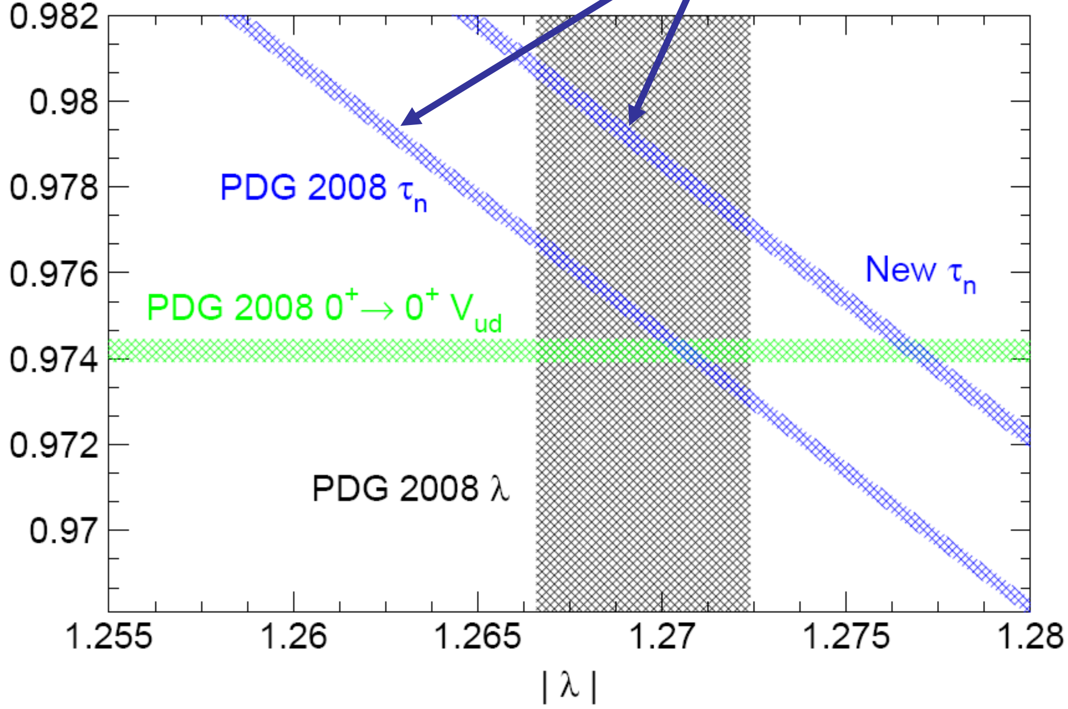
# Status of parameters



Serebrov (2005)
6-sigma discrepancy with world average

*No new results since*

$$\tau^{-1} \propto V_{ud}^2(1+3\lambda^2)$$



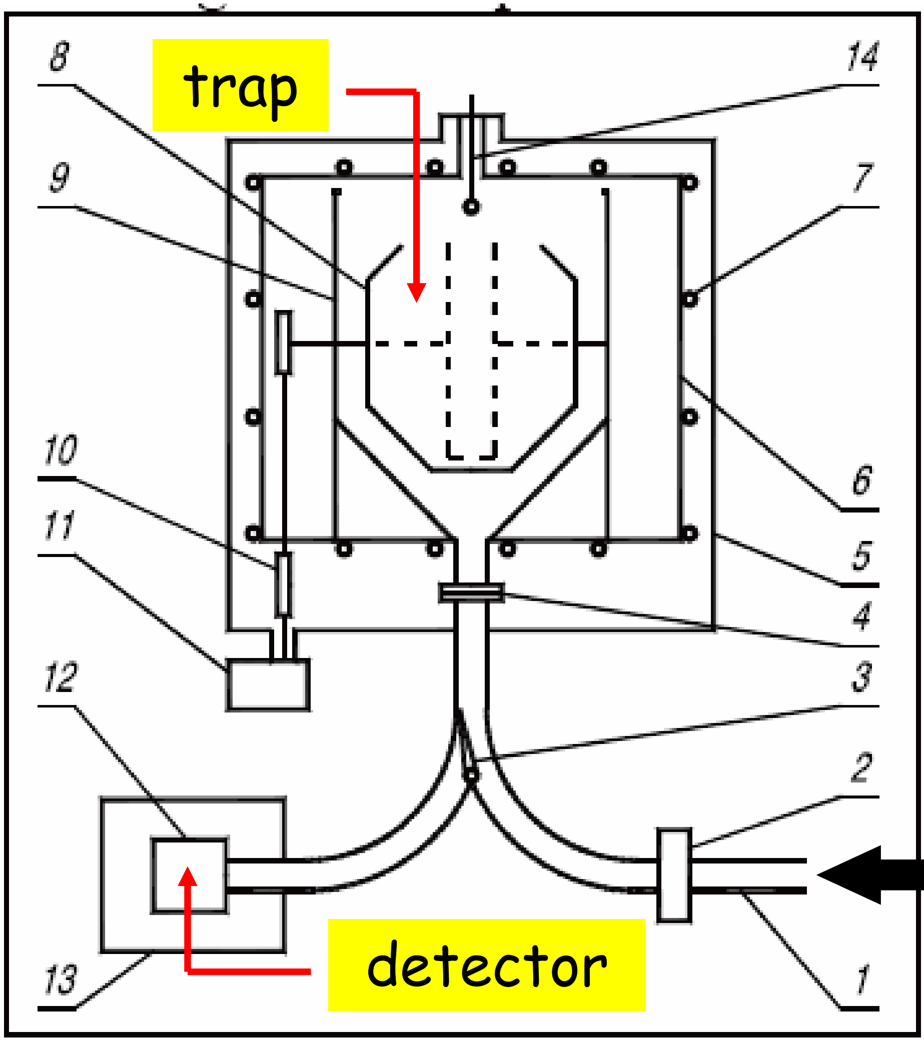
**PDG 2008 Neutron Result**

**$V_{ud}$ = 0.9746 $(4)_{\tau}$ $(18)_{gA}$ $(2)_{RC}$**

*But includes no possible systematic error from $\tau_n$ spread*

$V_{ud}$ = 0.97418 (27) [PDG 2008 superallowed]

# Recent neutron lifetime result



UCN from source

Serebrov (2005)

$$\frac{1}{\tau_{\text{storage}}} = \frac{1}{\tau_{\beta}} + \frac{1}{\tau_{\text{loss}}}$$

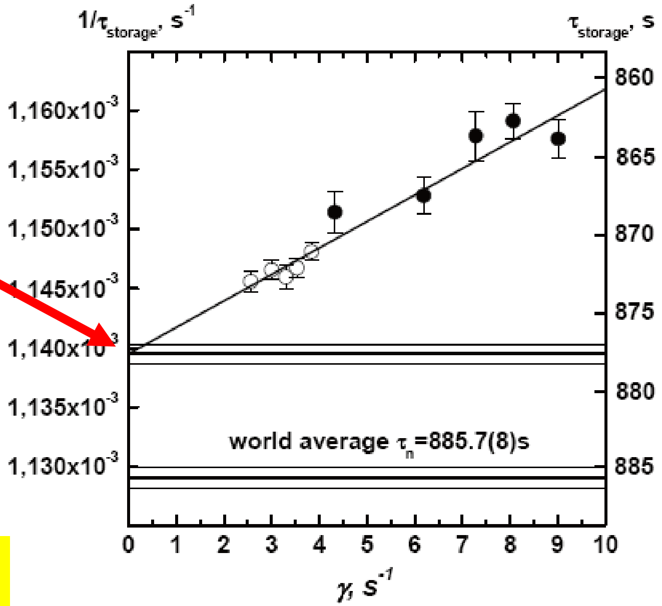
measured

extract

account for

absorption
upscattering

extrapolated
to zero loss

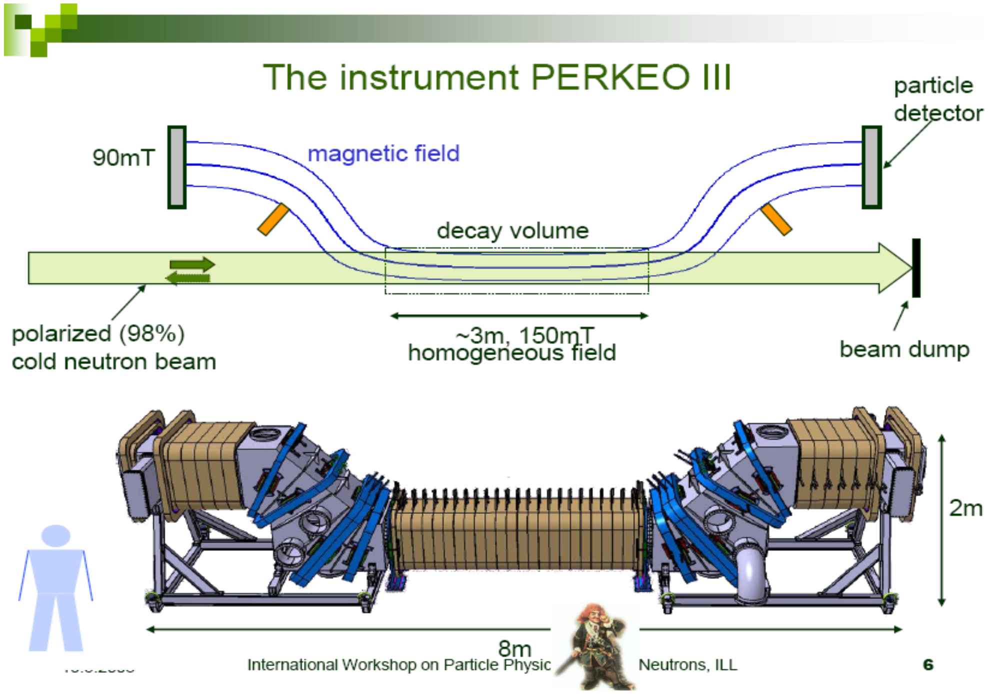


*previous smallest extrapolation ~ 105 s*

# A via cold neutrons: PERKEO at ILL

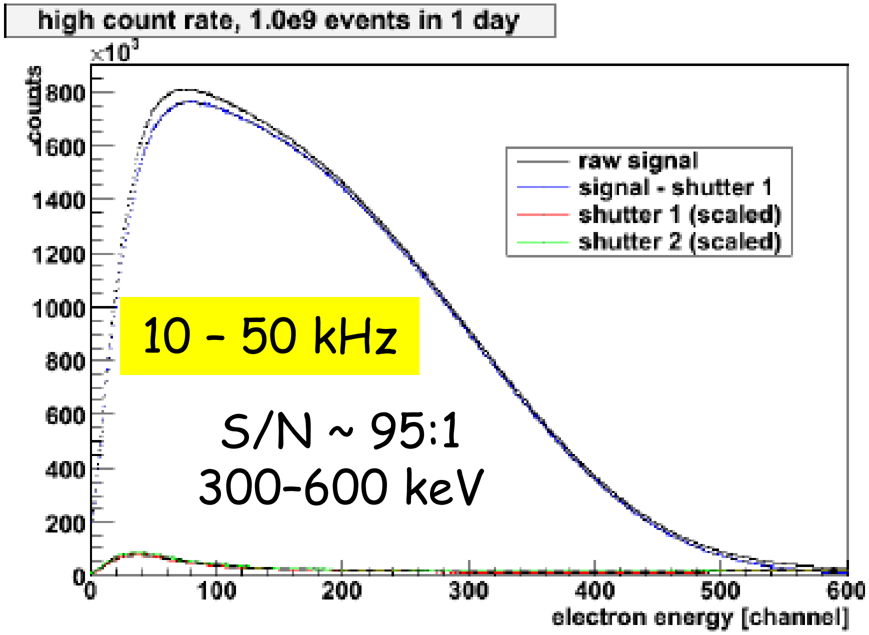
B. Märkisch

*Talk at ILL Workshop (May 2008)*



The instrument PERKEO III

International Workshop on Particle Physic Neutrons, ILL 6



10 - 50 kHz

S/N ~ 95:1
300-600 keV

*Backgrounds require further careful study*

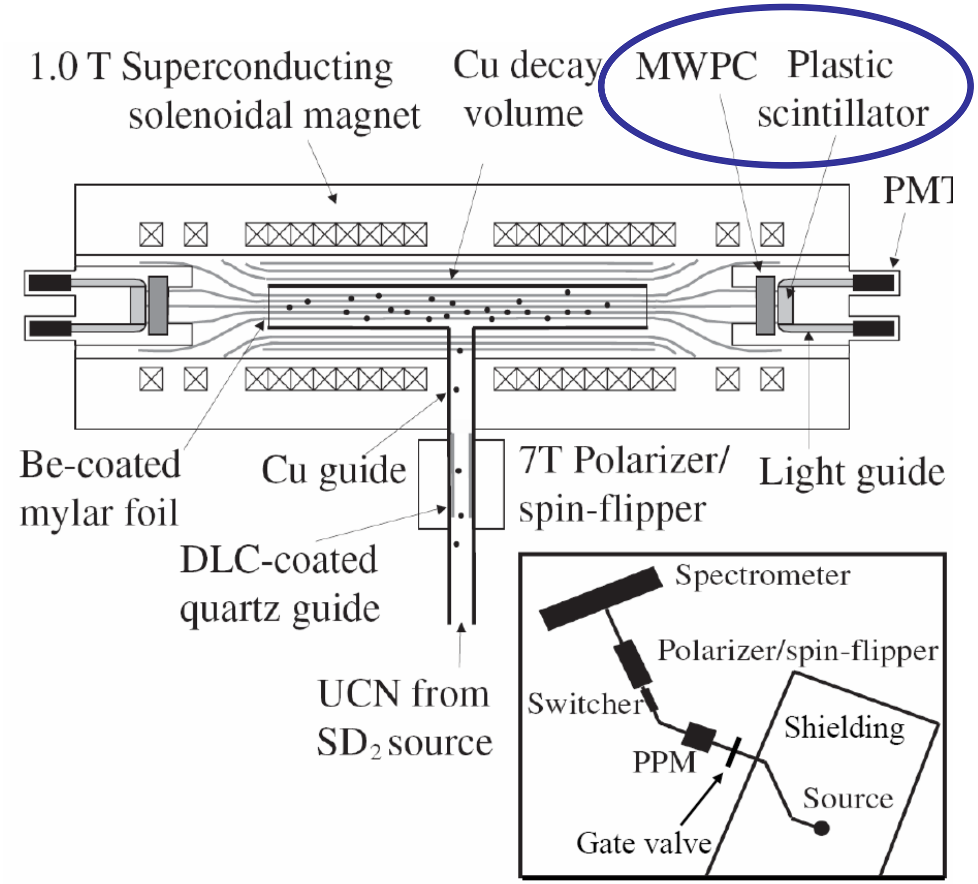
$W(\theta) \propto 1 + \beta_e P_n A \cos\theta$

A corrected for weak magnetism, $g_A$-$g_V$ interference, and nucleon recoil, O(1%)

$$A_{\exp} = \frac{N_1 - N_2}{N_1 + N_2} = P\langle \beta \cos\theta \rangle A$$

$$A = A_0 (1 + A_{\mu m} (A_1 W_0 + A_2 W + A_3 / W))$$

# A via UCN: UCNA at LANL



**Novel features of using UCN**

*Pulsed spallation source*

Beam-related backgrounds small in pulsed mode

*Polarizations > 99%*

Polarized via transport through magnetic fields, $\vec{\mu}\cdot\vec{B}$ potential

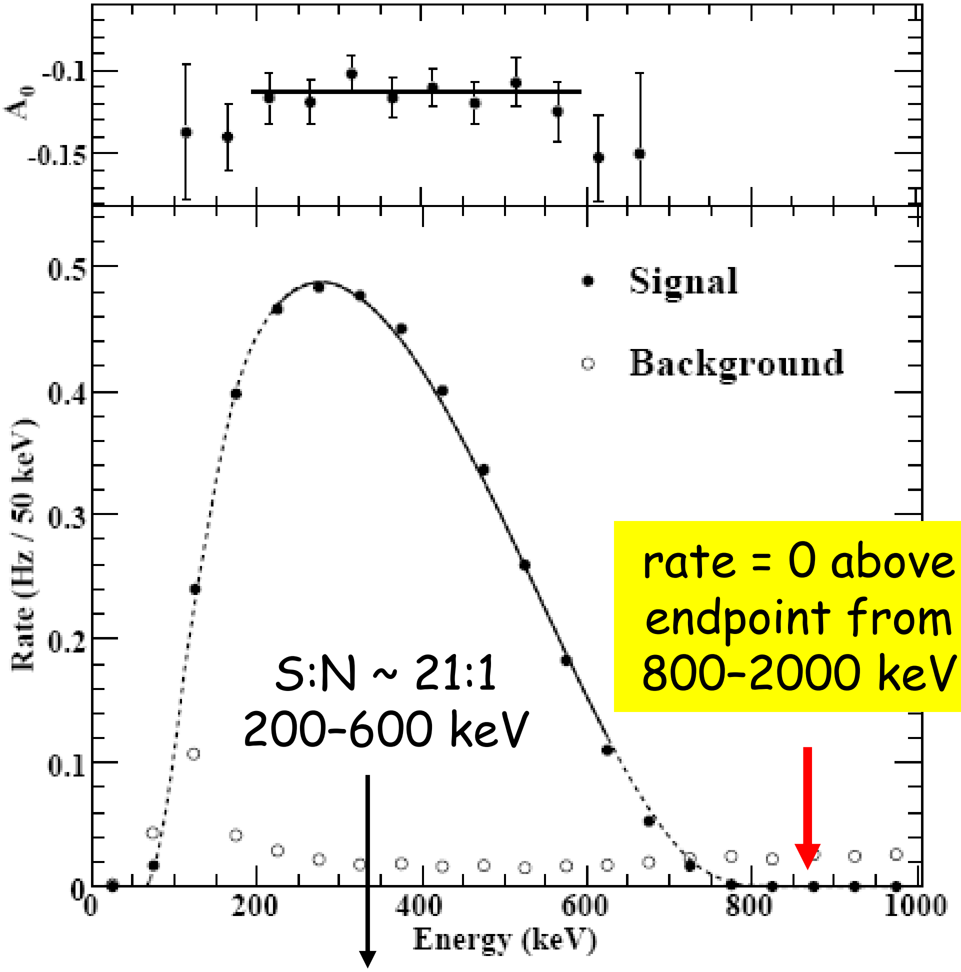
*Storage, long interaction times*

Requires relatively small number of neutrons, intrinsic neutron-induced backgrounds *small*

*First measurement of any neutron β-decay correlation parameter with UCN*

# A via UCN: UCNA at LANL

*asymmetry after correcting for energy dependence*



S:N ~ 21:1
200–600 keV

rate = 0 above
endpoint from
800–2000 keV

now ~35:1

## Systematic *corrections* comparison

| | Polarization | Background |
|---|---|---|
| PERKEO I | 2.6% | 2.6% |
| IAE-PNPI | 27% | small |
| ILL-TPC | 1.9% | 3% |
| PERKEO II | 1.1% | 0.5% |
| PERKEO III | 1.0% | < 0.1% |
| UCNA | small | < 0.2% |

with uncertainty < 0.4%

# Near-term prospects for A and $\lambda = g_A/g_V$

| | A | $\lambda$ | Notes |
|---|---|---|---|
| **Current PDG 2008** | 1.1%<br>*4 results* | 0.23%<br>*4 results on A, 1 on A and B* | $\sqrt{\chi^2} = 2.3$ for A<br>$\sqrt{\chi^2} = 2.0$ for $\lambda$ |
| **PERKEO III**<br>*Projected result* | 0.3% | 0.07% | Running now 2008 |
| **UCNA** | 1.0% | 0.25% | Running now 2008 |
| *Projected results* | < 0.7% | < 0.12% | Projected 2009 |

$$V_{ud} = 0.9746\ (4)_\tau\ (18)_{gA}\ (2)_{RC}$$

*Significant reduction in contribution of $g_A$ error to $V_{ud}$ possible, but results must be consistent !*

# Near-term prospects for $\tau_n$

One could give 1-hour-long talk on this subject … (and I'm not an expert)

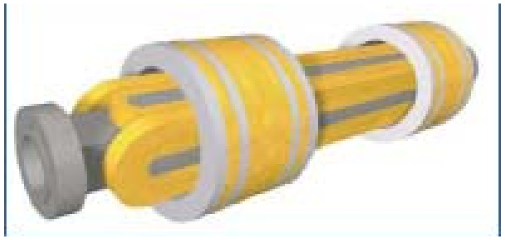
[e.g., *see S. Paul talk at ILL Workshop 2008* ]

Many next-generation experiments to utilize magnetic trapping of one particular UCN spin state via the $\vec{\mu} \cdot \vec{B}$ potential

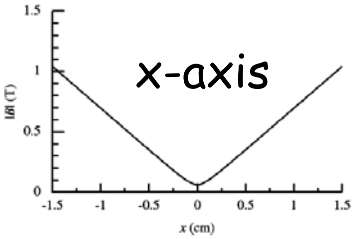
Eliminates uncontrolled losses from absorption and upscattering on material walls

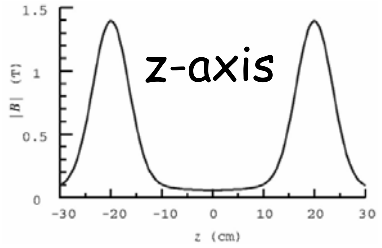
*But can still have "marginally-trapped" neutrons*

*__Example__*: NIST experiment



*Ioffe trap: superposition of 2x solenoid with quadrupole*





Experiments at SNS, ILL, LANL, PSI, FRM-II, PULSTAR, …

*Aim for 0.1 s errors*

*Control of systematics*

# Other correlation coefficients

$$dW \propto \mathcal{F}(E_e)\times\left[1+a\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_eE_\nu}+\langle\vec{\sigma}_n\rangle\cdot\left(A\frac{\vec{p}_e}{E_e}+B\frac{\vec{p}_\nu}{E_\nu}+D\frac{\vec{p}_e\times\vec{p}_\nu}{E_eE_\nu}\right)\right]d\Omega_e\, d\Omega_\nu\, dE_e$$

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## Longer-term for A

abBA experiment at SNS with cold neutron beam
0.1% on A

Experiment at PNPI

Simultaneous measurement of A and B eliminates need for precise polarimetry

## Other coefficients

Redundant check of Standard Model parameters
e.g., B relatively insensitive to λ, but sensitive to right-handed currents

aCORN (NIST, a ~ 1%), aSPECT (ILL, a ~ 0.25%), Nab (SNS, a, b), abBA (SNA, a, b, A, B), …

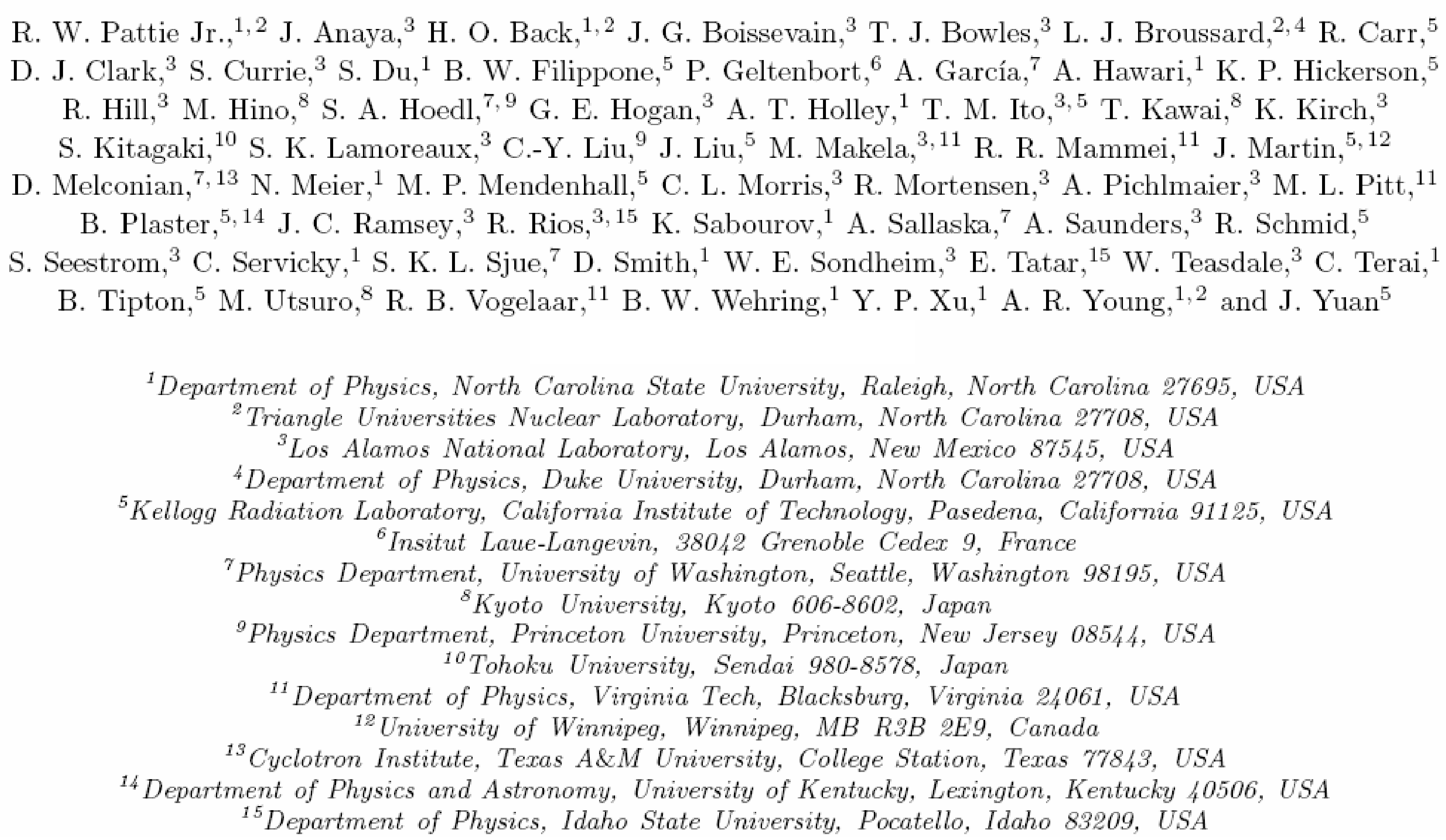
# Summary

Potential for much progress in extracting $V_{ud}$ from neutron β-decay

- Largest contribution to uncertainty from error on $\lambda = g_A/g_V$
  - PERKEO III (ILL) and UCNA (LANL) experiments new precision data on λ to sub-0.1% level within next 2–3 years
  - Potentially reduce error contribution of λ to $V_{ud}$ by factor of 3–4, *but need consistency among results !!*
- Value of neutron lifetime needs to be re-evaluated after recent discrepant result
  - New round of experiments will probe lifetime to unprecedented precision
  - Is current error on lifetime underestimated ?

# Thanks to my collaborators

## The UCNA Collaboration



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