The measurement of neutron beta decay observables with the Nab spectrometer

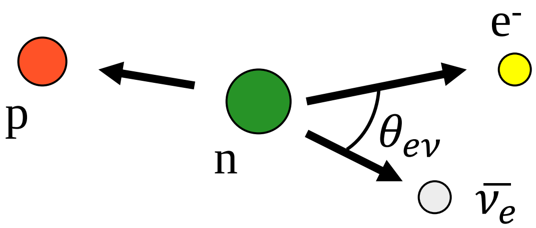
SNS-03671-2005

Stefan Baeßler

OAK RIDGE
National Laboratory

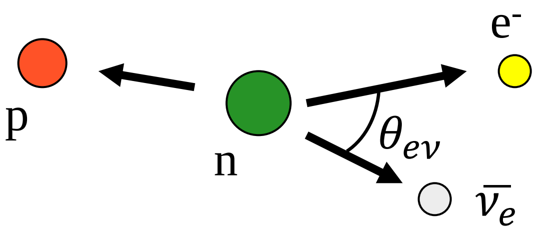
UNIVERSITY of VIRGINIA
Inst. Nucl. Part. Phys.

The neutrino electron correlation coefficient a



$$d\Gamma \propto \left(1 + {\color{red}a}\,\frac{p_e}{E_e}\cos\theta_{e\nu} + b\,\frac{m_e}{E_e}\right)$$

The neutrino electron correlation coefficient *a*



$$d\Gamma \propto \left(1 + a\frac{p_e}{E_e}\cos\theta_{e\nu} + b\frac{m_e}{E_e}\right)$$

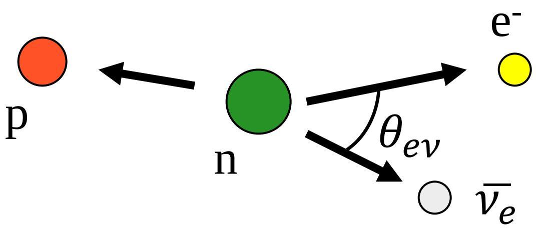
Novel approach to determine $\cos\theta_{ev}$:

Kinematics in Infinite Nuclear Mass Approximation:

1. Energy Conservation: $E_\upsilon = E_{e,max} - E_{e,kin}$
2. Momentum Conservation:

$$p_p{}^2 = p_e{}^2 + p_\upsilon{}^2 + 2p_e p_\upsilon \cos\theta_{ev}$$

The neutrino electron correlation coefficient a



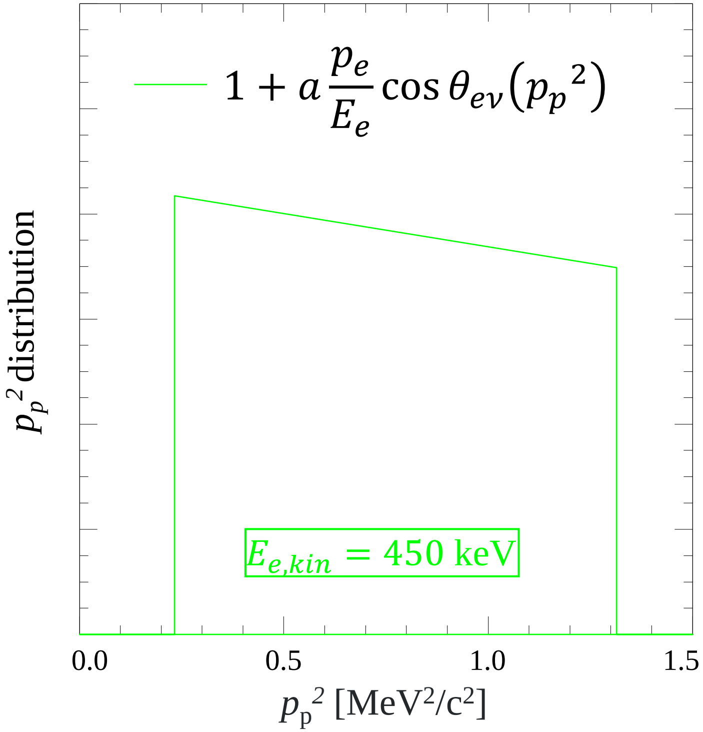
$$d\Gamma \propto \left(1 + a\frac{p_e}{E_e}\cos\theta_{ev} + b\frac{m_e}{E_e}\right)$$

Novel approach to determine $\cos\theta_{ev}$:

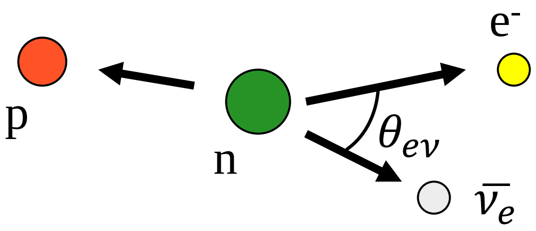
Kinematics in Infinite Nuclear Mass Approximation:

1. Energy Conservation: $E_\upsilon = E_{e,max} - E_{e,kin}$
2. Momentum Conservation:

$$p_p{}^2 = p_e{}^2 + p_\upsilon{}^2 + 2p_e p_\upsilon \cos\theta_{ev}$$



The neutrino electron correlation coefficient *a*



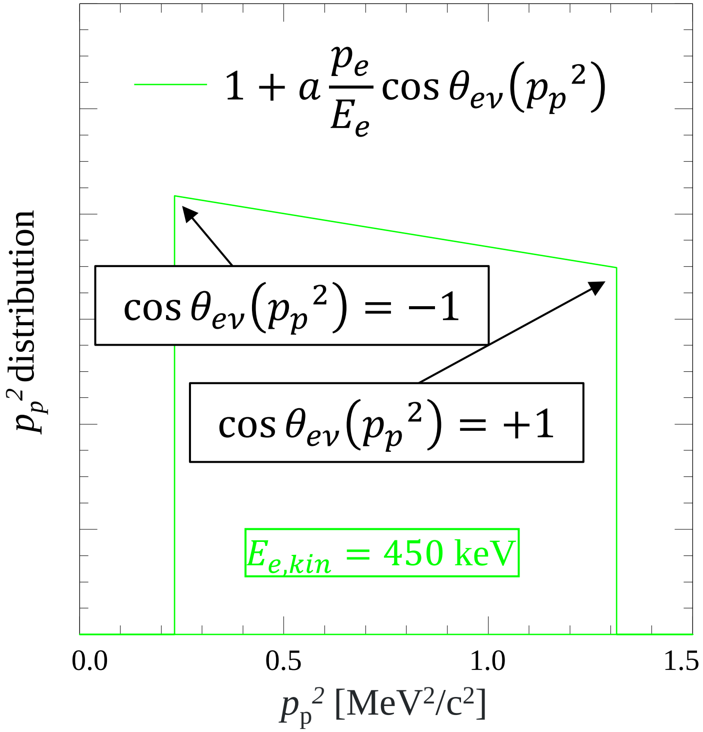
$$d\Gamma \propto \left(1 + a\frac{p_e}{E_e}\cos\theta_{ev} + b\frac{m_e}{E_e}\right)$$

Novel approach to determine $\cos\theta_{ev}$:

Kinematics in Infinite Nuclear Mass Approximation:

1. Energy Conservation: $E_\upsilon = E_{e,max} - E_{e,kin}$
2. Momentum Conservation:

$$p_p{}^2 = p_e{}^2 + p_\upsilon{}^2 + 2p_e p_\upsilon \cos\theta_{ev}$$



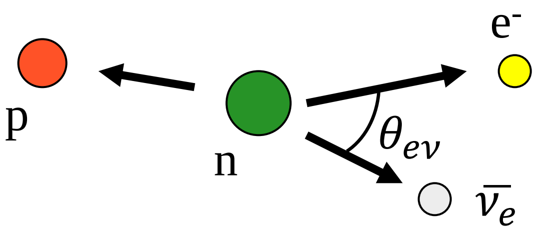
Properties of $p_p{}^2$ distribution for fixed E_e:

Edges $\left(p_p{}^2\right)_{min,max} = (p_e \pm p_\upsilon)^2$

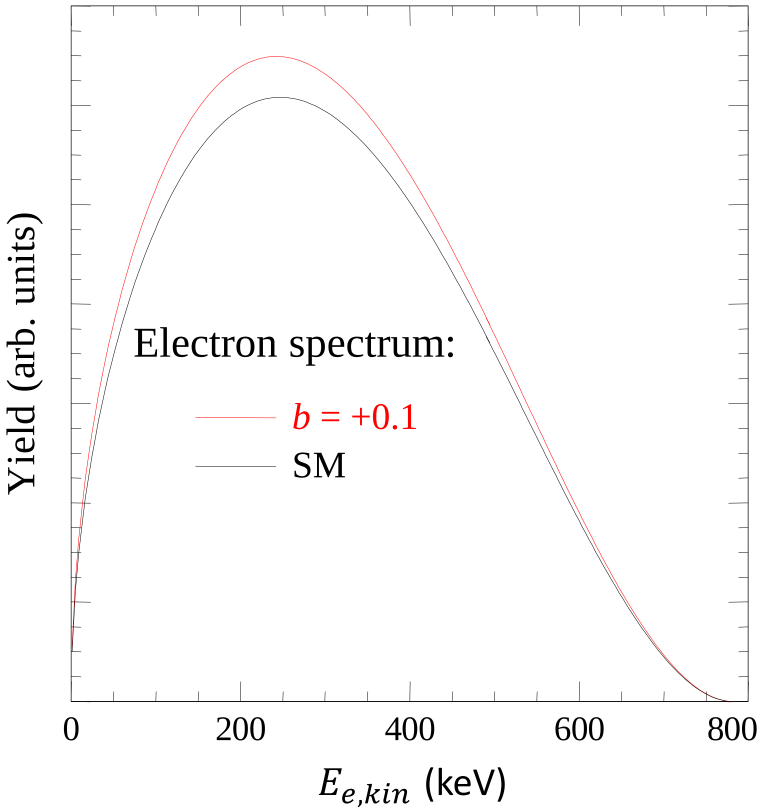
Slope $\propto \left(1 + a\frac{p_e}{E_e}\cos\theta_{ev}(p_p{}^2)\right)$

J.D. Bowman, Journ. Res. NIST 110, 40 (2005)

The Fierz Interference Term *b*

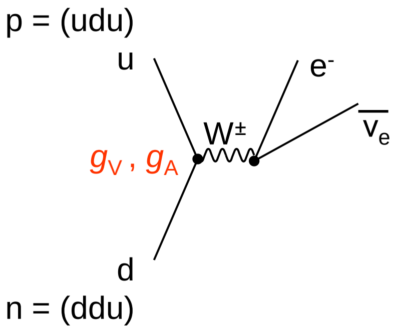


$$d\Gamma \propto \varrho(E_e)\left(1 + a\frac{p_e}{E_e}\cos\theta_{e\nu} + b\frac{m_e}{E_e}\right)$$



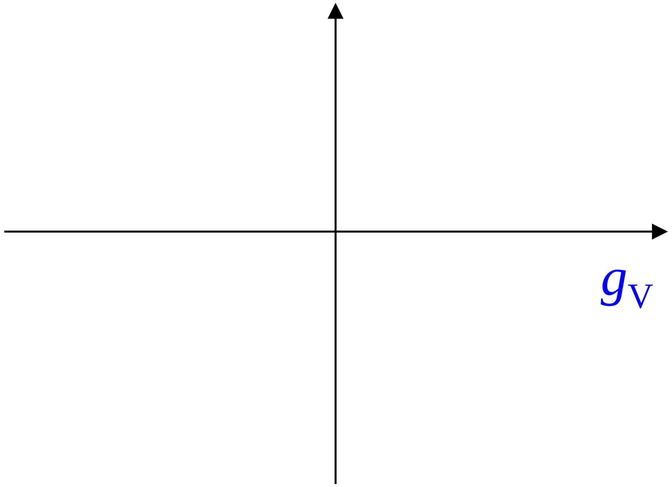
Coupling Constants of the Weak Interaction

Coupling Constants in Neutron Decay



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

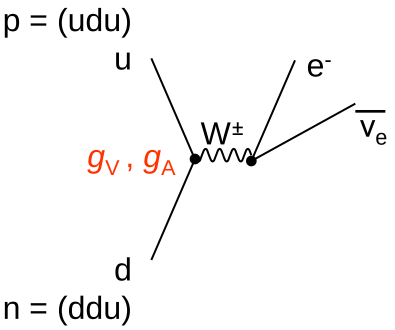
$$g_A = G_F \cdot V_{ud} \cdot \lambda$$



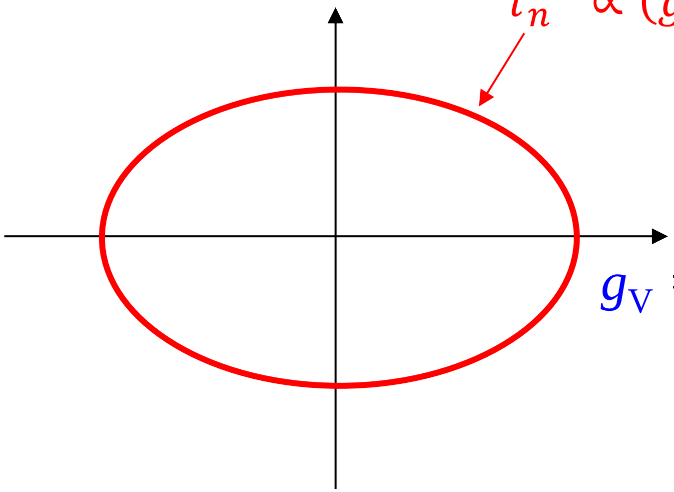
$$g_V = G_F \cdot V_{ud} \cdot 1$$

Coupling Constants of the Weak Interaction

Coupling Constants in Neutron Decay



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



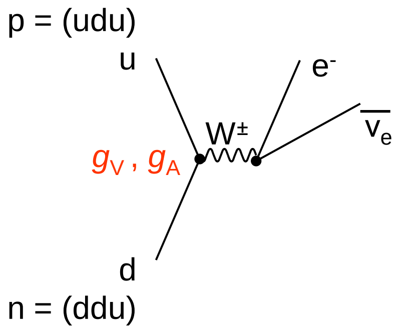
$g_A = G_F \cdot V_{ud} \cdot \lambda$

$\tau_n^{-1} \propto (g_V^2 + 3g_A^2)$

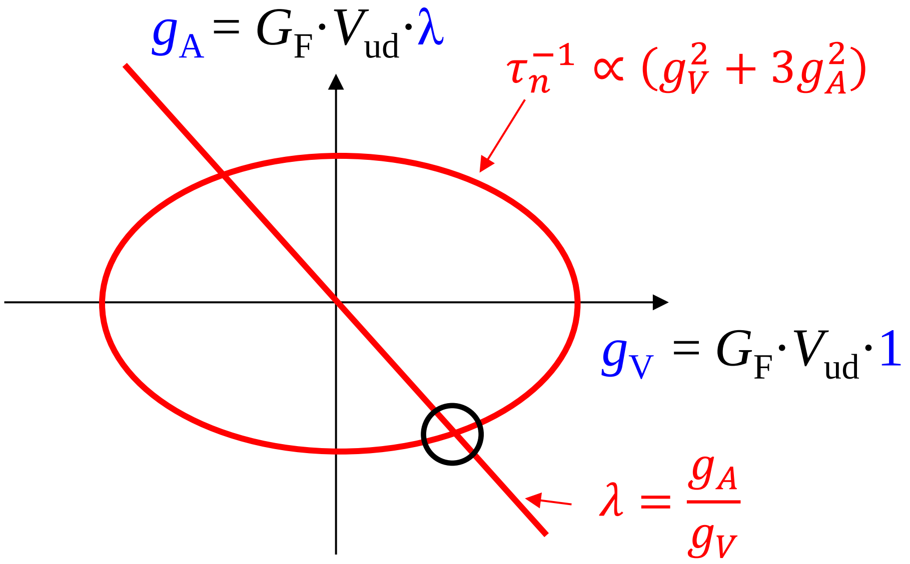
$g_V = G_F \cdot V_{ud} \cdot 1$

Coupling Constants of the Weak Interaction

Coupling Constants in Neutron Decay



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



$g_A = G_F \cdot V_{ud} \cdot \lambda$

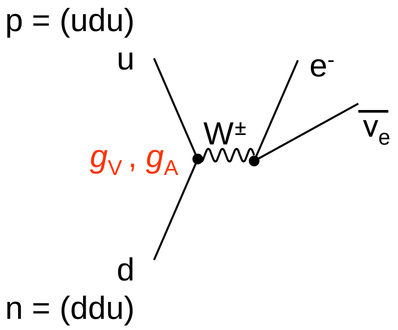
$\tau_n^{-1} \propto (g_V^2 + 3g_A^2)$

$g_V = G_F \cdot V_{ud} \cdot 1$

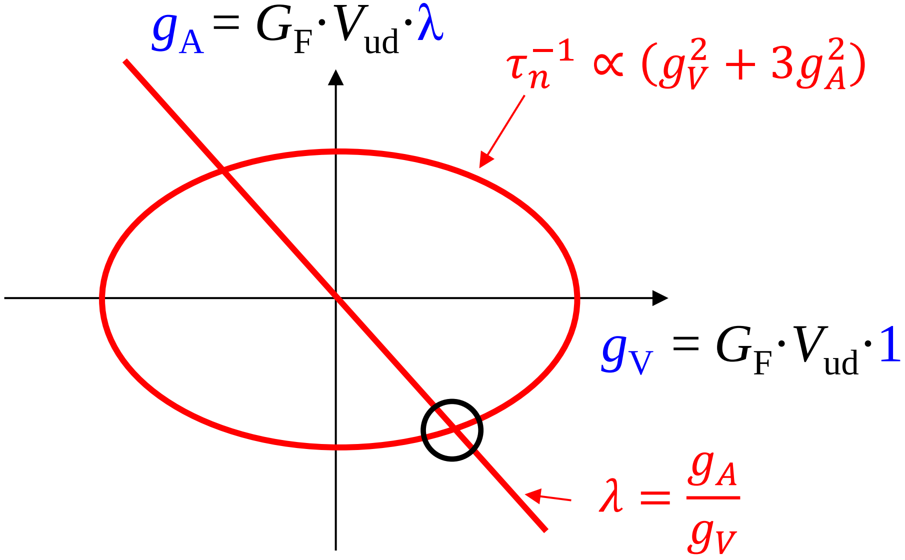
$\lambda = \frac{g_A}{g_V}$

Coupling Constants of the Weak Interaction

Coupling Constants in Neutron Decay



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



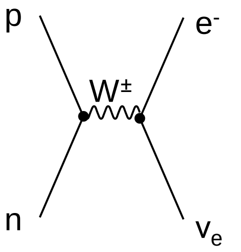
$g_A = G_F \cdot V_{ud} \cdot \lambda$

$\tau_n^{-1} \propto (g_V^2 + 3g_A^2)$

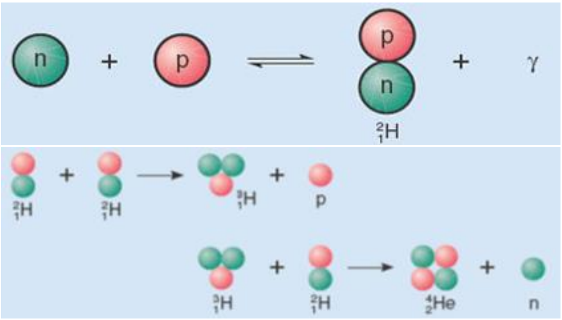
$g_V = G_F \cdot V_{ud} \cdot 1$

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

Primordial Nucleosynthesis

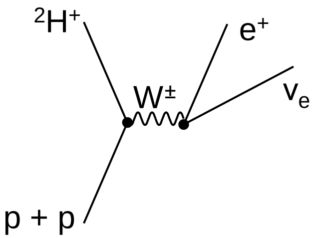


n + $\nu_e \leftrightarrow$ p + e^-



Start of Big Bang Nucleosynthesis, Primordial ^{4}He abundance

Solar cycle

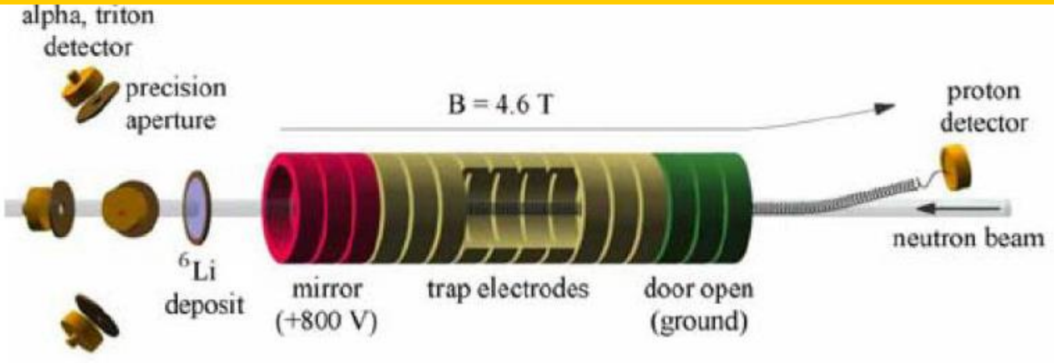


p + p $\to$ $^2H^+ + e^+ + \nu_e$

Start of Solar Cycle, determines amount of Solar Neutrinos

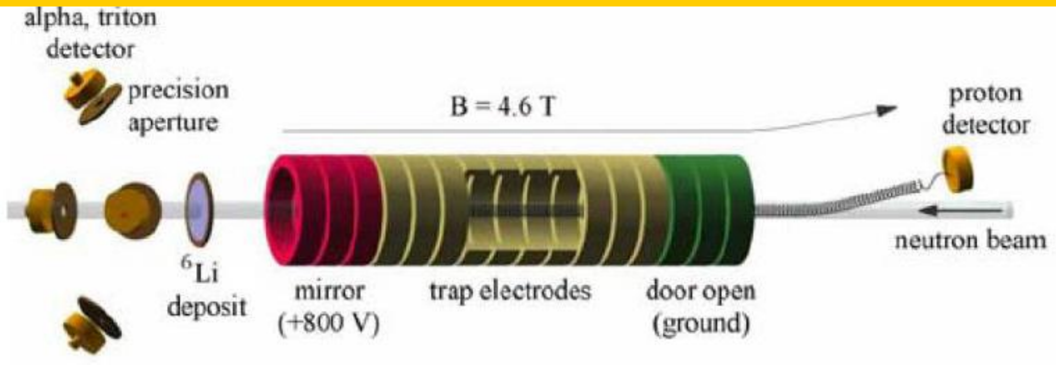
Neutron Lifetime Measurements

Beam: Decay rate: $\frac{dN}{dt} = \frac{N}{\tau_n}$



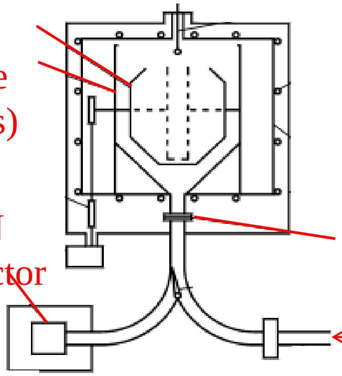
Neutron Lifetime Measurements

Beam: Decay rate: $\frac{dN}{dt} = \frac{N}{\tau_n}$



Bottle: Neutron counts : $N = N_0 e^{-\frac{t}{\tau_{eff}}}$

with $\frac{1}{\tau_{eff}} = \frac{1}{\tau_n} + \frac{1}{\tau_{wall}}$

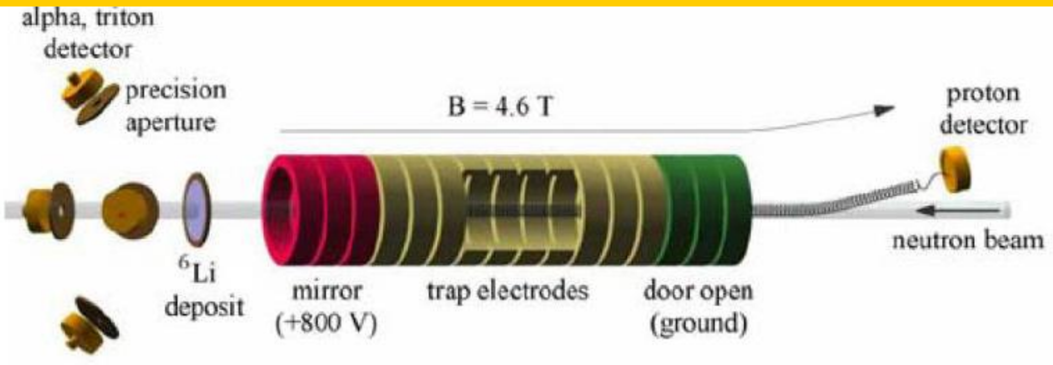


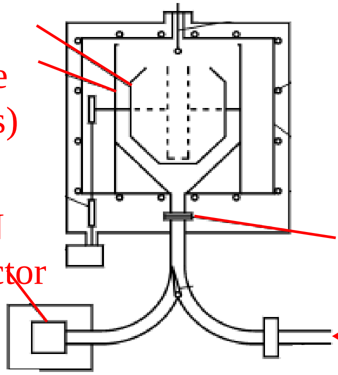
Neutron Lifetime Measurements

Beam: Decay rate: $\frac{dN}{dt} = \frac{N}{\tau_n}$

Bottle: Neutron counts : $N = N_0 e^{-\frac{t}{\tau_{eff}}}$

with $\frac{1}{\tau_{eff}} = \frac{1}{\tau_n} + \frac{1}{\tau_{wall}}$



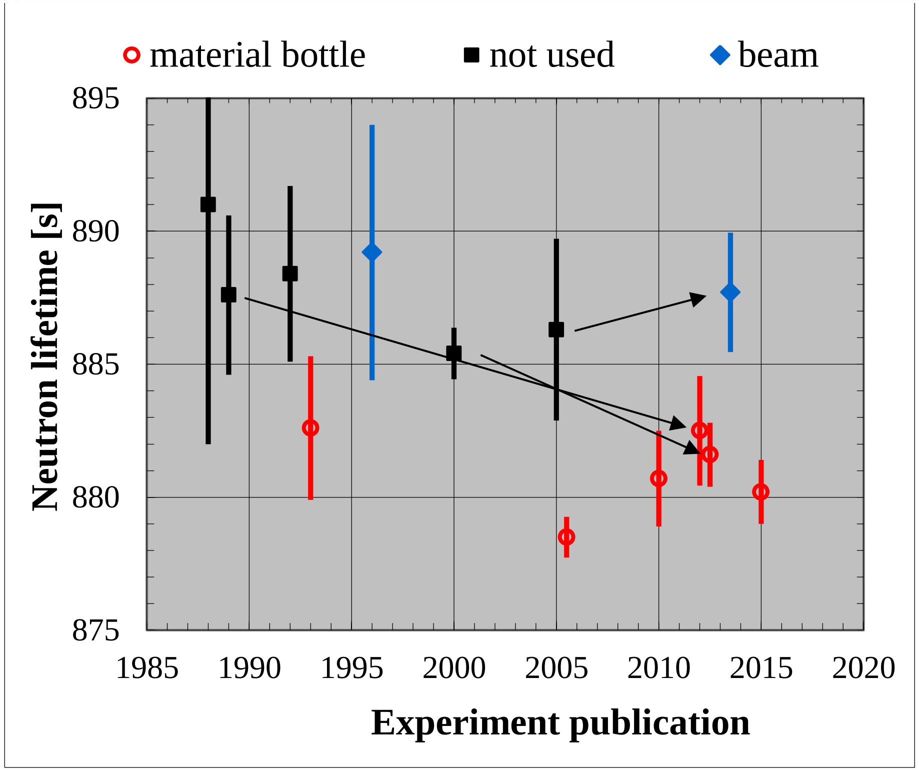


UCN Storage bottle(s)

UCN detector

Shutter

UCN from source

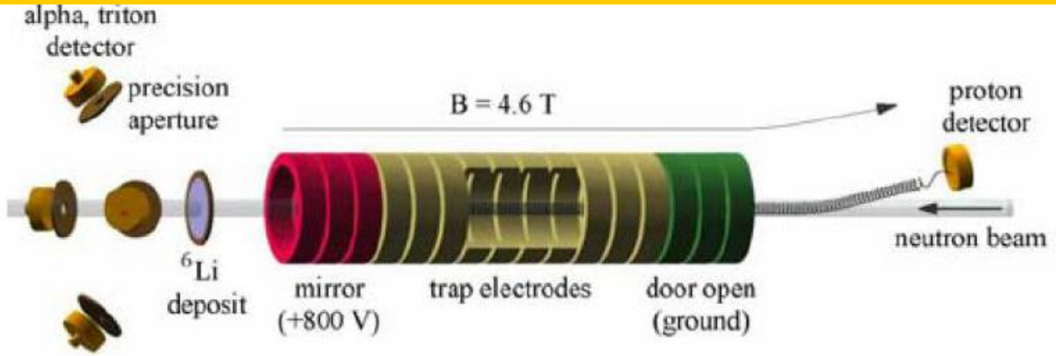


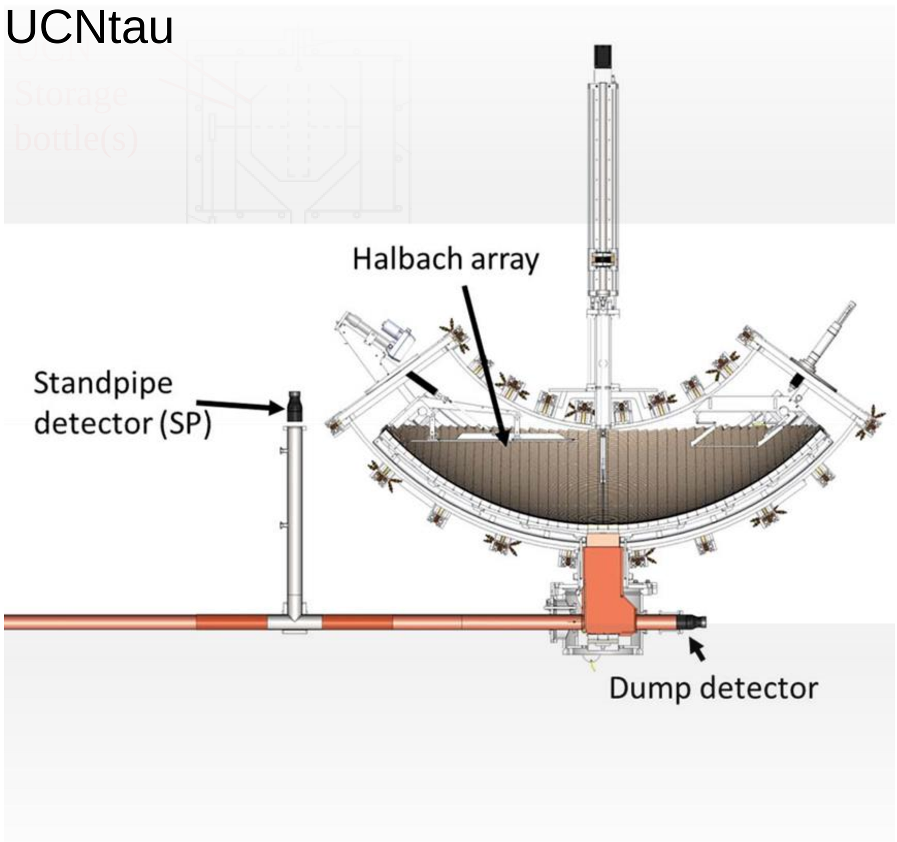
Neutron Lifetime Measurements

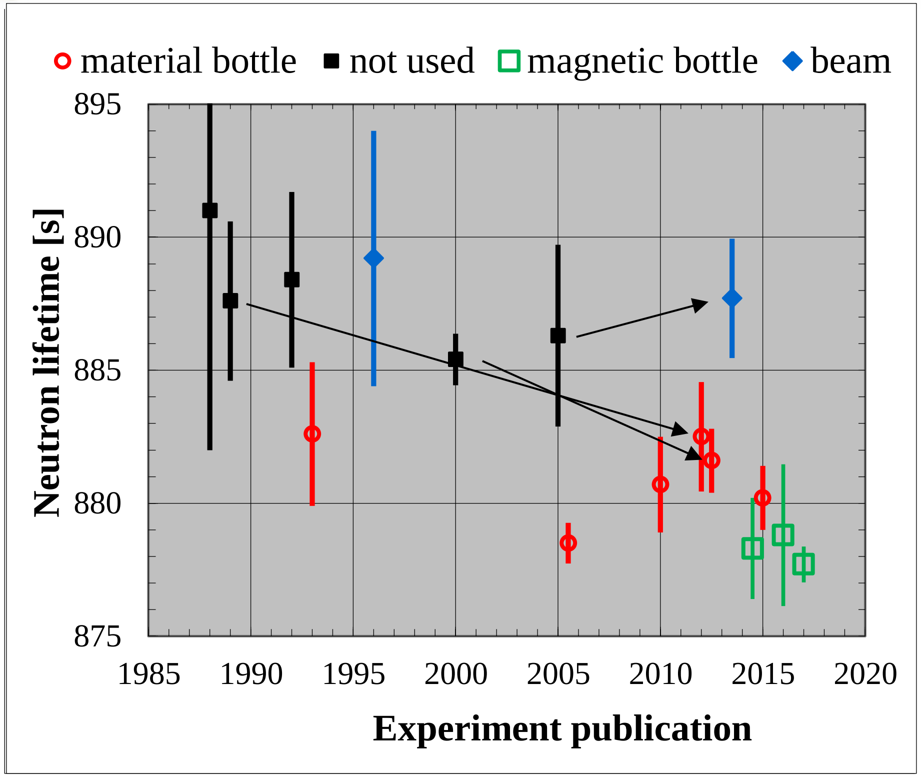
Beam: Decay rate: $\frac{dN}{dt} = \frac{N}{\tau_n}$

Bottle: Neutron counts : $N = N_0 e^{-\frac{t}{\tau_{eff}}}$

with $\frac{1}{\tau_{eff}} = \frac{1}{\tau_n} + \frac{1}{\tau_{wall}}$

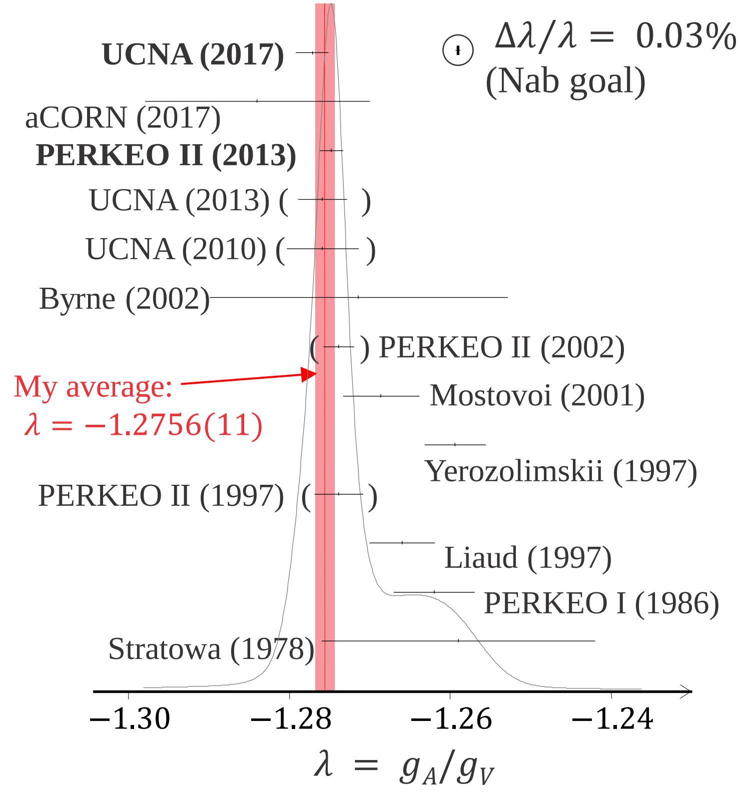






Motivation for Nab

Determination of ratio $\lambda = g_A/g_V$ from
$A = -2(\mathrm{Re}\,\lambda + |\lambda|^2)/(1+3|\lambda|^2)$ or
$a = (1-|\lambda|^2)/(1+3|\lambda|^2)$:

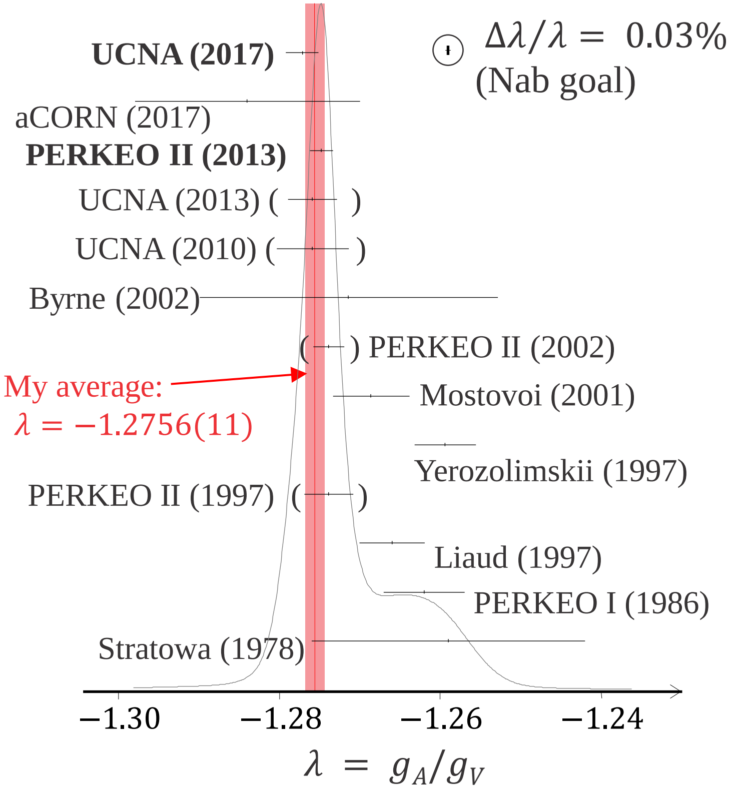


$\Delta\lambda/\lambda = 0.03\%$ (Nab goal)

My average: $\lambda = -1.2756(11)$

Motivation for Nab

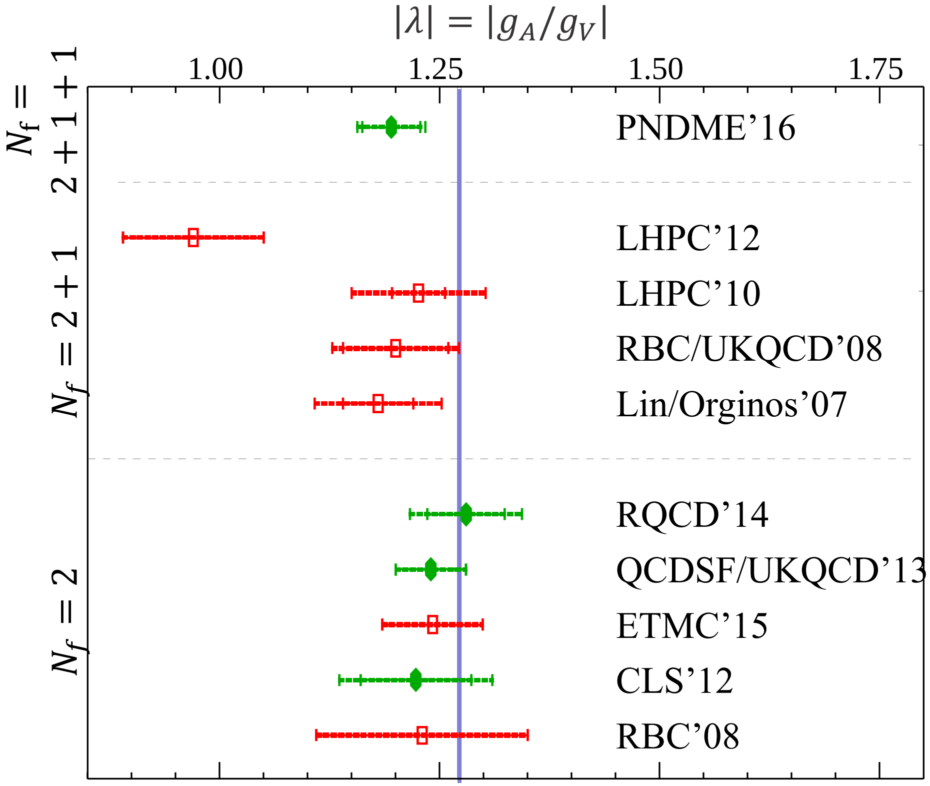
Determination of ratio $\lambda = g_A/g_V$ from
$A = -2(\mathrm{Re}\,\lambda + |\lambda|^2)/(1 + 3|\lambda|^2)$ or
$a = (1 - |\lambda|^2)/(1 + 3|\lambda|^2)$:



$\Delta\lambda/\lambda = 0.03\%$ (Nab goal)

My average: $\lambda = -1.2756(11)$

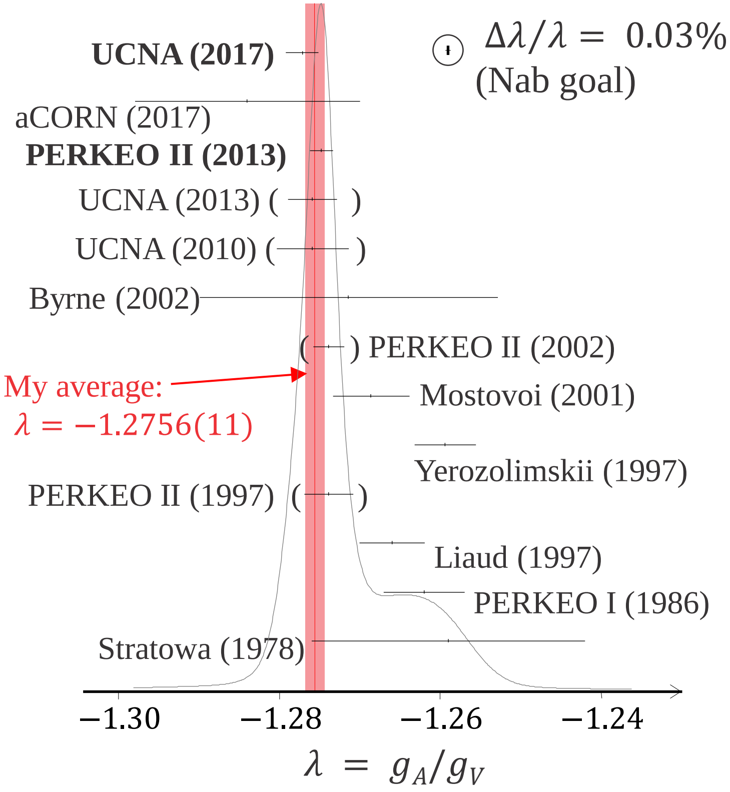
Note: λ should be fixed by standard model. However, precision of its calculation from first principles is insufficiently precise:



Most recent 2+1+1 flavor Lattice-QCD result from PNDME: T. Bhattacharya et al., PRD 94, 054508 (2016)

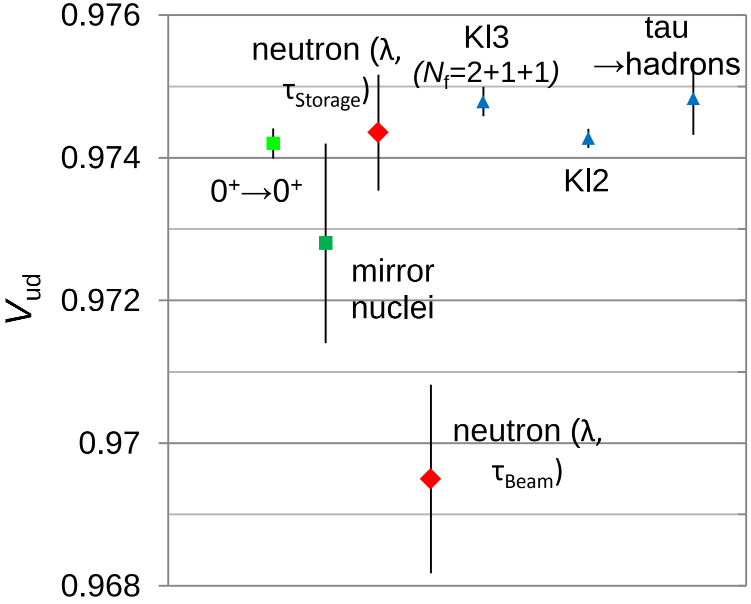
Motivation for Nab

Determination of ratio $\lambda = g_A/g_V$ from
$A = -2(\mathrm{Re}\,\lambda + |\lambda|^2)/(1 + 3|\lambda|^2)$ or
$a = (1 - |\lambda|^2)/(1 + 3|\lambda|^2)$:



$\Delta\lambda/\lambda = 0.03\%$ (Nab goal)

2. Goal: Test of unitarity of Cabibbo-Kobayashi-Maskawa (CKM) matrix from
$|V_{ud}|^2\tau_n(1 + 3\lambda^2) = 4908.7(19)$ s and
$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$



For neutron data to be competitive, want:
$\Delta\tau_n/\tau_n \sim 0.3$ s
$\Delta\lambda/\lambda \sim 0.03\%$

What if the test of CKM unitarity fails?

Like all precision measurements, a failure of the unitarity test would not point to a single cause: Various possibilities exist, among those are:

1. Heavy quarks:

$$\begin{pmatrix} d' \\ s' \\ b' \\ D' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{uD} \\ V_{cd} & V_{cs} & V_{cb} & V_{cD} \\ V_{td} & V_{ts} & V_{tb} & V_{tD} \\ V_{Ed} & V_{Es} & V_{Eb} & V_{ED} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \\ D \end{pmatrix}$$

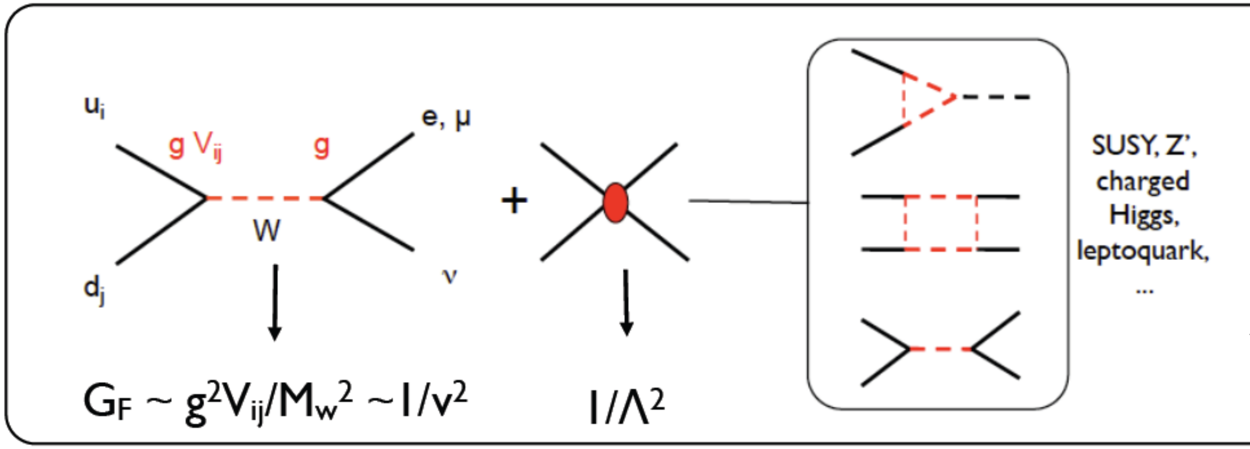
$$|V_{uD}|^2 = 1 - |V_{ub}|^2 - |V_{us}|^2 - |V_{ud}|^2$$

W. Marciano, A. Sirlin, PRL 56, 22 (1986)
P. Langacker, D. London, PRD 38, 886 (1988)

2. Exotic muon decays:

   All determinations of V_{ud} use G_F from muon lifetime. If the muon had additional decay modes ($\mu \to X + Y + \cdots$), G_F (and V_{ud}) would be determined wrong. E.g., $\mu^+ \to e^+ + \bar{\nu}_e + \nu_\mu$ (wrong neutrinos) would be very relevant for neutrino factories. K.S. Babu and S. Pakvasa, hep-ph/0204236

3. (Semi-)leptonic decays of nuclei through something other than exchange of $W^\pm$ bosons:

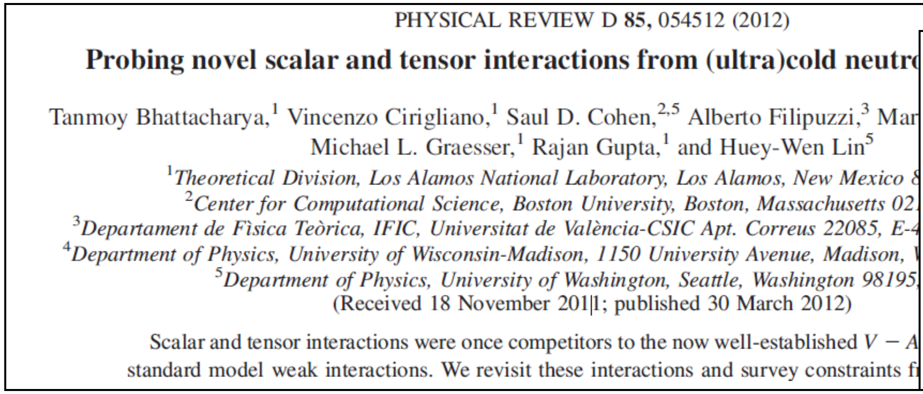


Specific models: E.g.
W. Marciano, A. Sirlin, PRD 35, 1672 (1987).
R. Barbieri et al., PLB 156, 348 (1985)
K. Hagiwara et al., PRL 75, 3605 (1995)
A. Kurylov, M. Ramsey-Musolf, PRL 88, 071804 (2000)

Energy scale of new physics: $\Lambda \geq 11$ TeV V. Cirigliano et al., NPB 830, 95 (2010)

Scalar(S) and tensor(T) interactions in beta decay

Other searches for Beyond Standard Model Physics: S,T interactions (fermions with “wrong” helicity), e.g. through W’ bosons; weak magnetism; second class currents; …



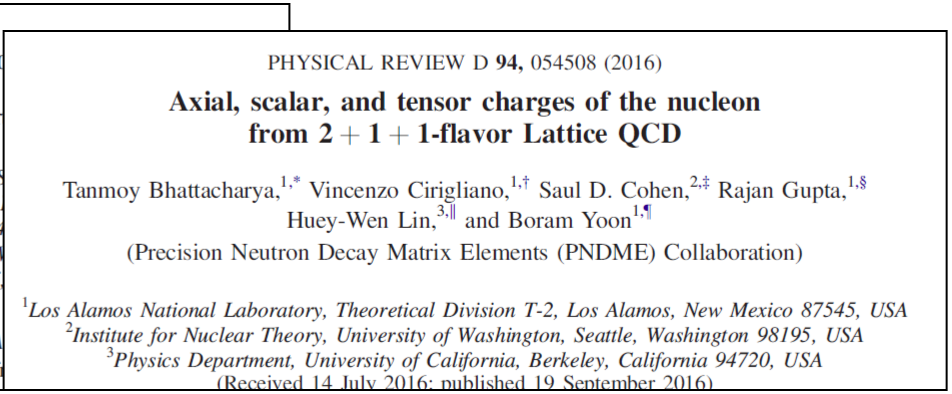
PHYSICAL REVIEW D **85,** 054512 (2012)

Probing novel scalar and tensor interactions from (ultra)cold neutr

Tanmoy Bhattacharya,[1] Vincenzo Cirigliano,[1] Saul D. Cohen,[2,5] Alberto Filipuzzi,[3] Mar
Michael L. Graesser,[1] Rajan Gupta,[1] and Huey-Wen Lin[5]
[1]*Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico*
[2]*Center for Computational Science, Boston University, Boston, Massachusetts 02*
[3]*Departament de Fìsica Teòrica, IFIC, Universitat de València-CSIC Apt. Correus 22085, E-*
[4]*Department of Physics, University of Wisconsin-Madison, 1150 University Avenue, Madison,*
[5]*Department of Physics, University of Washington, Seattle, Washington 98195*

(Received 18 November 2011; published 30 March 2012)

Scalar and tensor interactions were once competitors to the now well-established $V-A$
standard model weak interactions. We revisit these interactions and survey constraints f



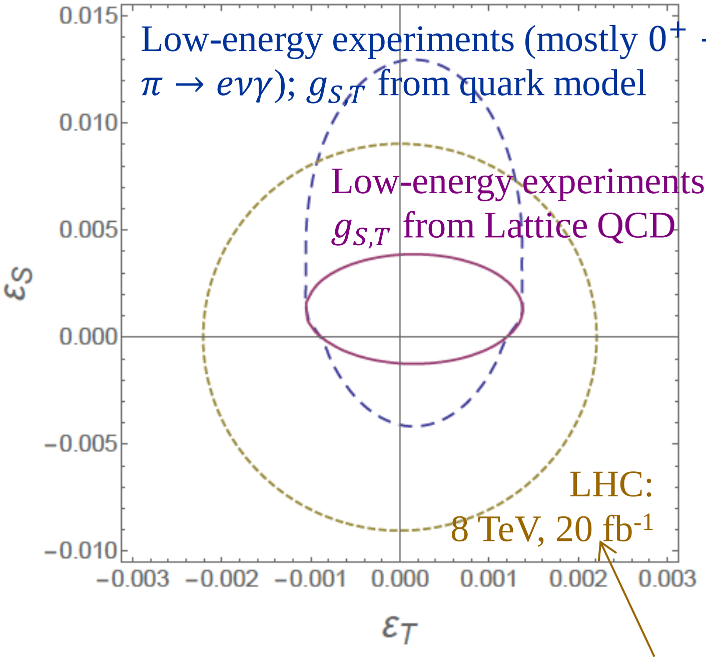
PHYSICAL REVIEW D **94,** 054508 (2016)

Axial, scalar, and tensor charges of the nucleon from 2 + 1 + 1-flavor Lattice QCD

Tanmoy Bhattacharya,[1,*] Vincenzo Cirigliano,[1,†] Saul D. Cohen,[2,‡] Rajan Gupta,[1,§]
Huey-Wen Lin,[3,∥] and Boram Yoon[1,¶]
(Precision Neutron Decay Matrix Elements (PNDME) Collaboration)

[1]*Los Alamos National Laboratory, Theoretical Division T-2, Los Alamos, New Mexico 87545, USA*
[2]*Institute for Nuclear Theory, University of Washington, Seattle, Washington 98195, USA*
[3]*Physics Department, University of California, Berkeley, California 94720, USA*

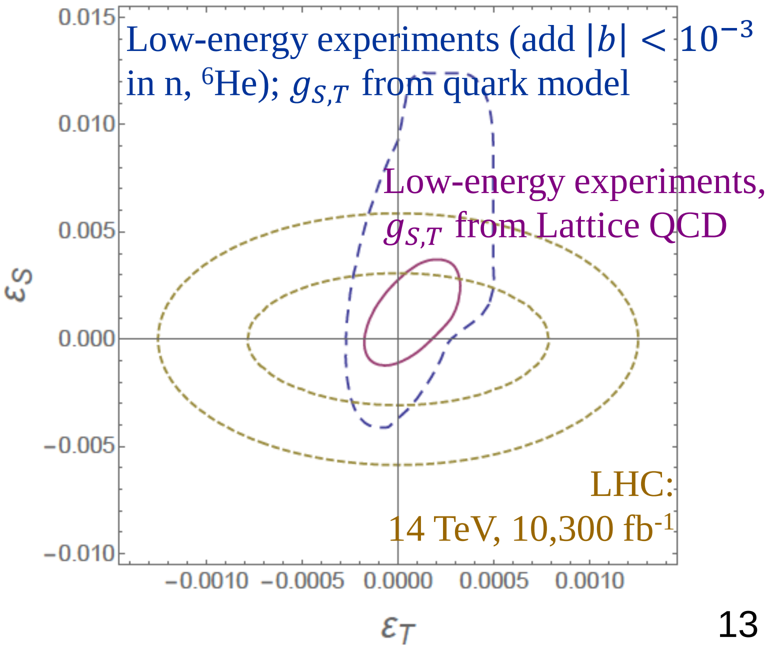
(Received 14 July 2016; published 19 September 2016)



Low-energy experiments (mostly $0^+ \to 0^+$, $\pi \to e\nu\gamma$); $g_{S,T}$ from quark model

Low-energy experiments, $g_{S,T}$ from Lattice QCD

LHC:
8 TeV, 20 fb^{-1}



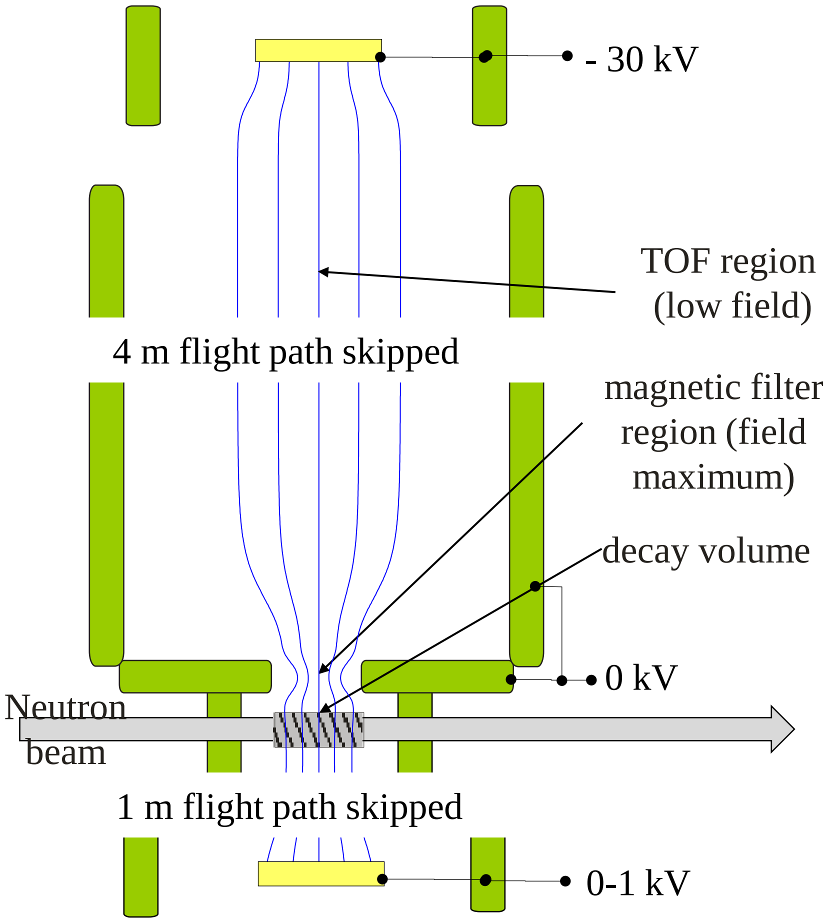
Low-energy experiments (add $|b| < 10^{-3}$ in n, ^{6}He); $g_{S,T}$ from quark model

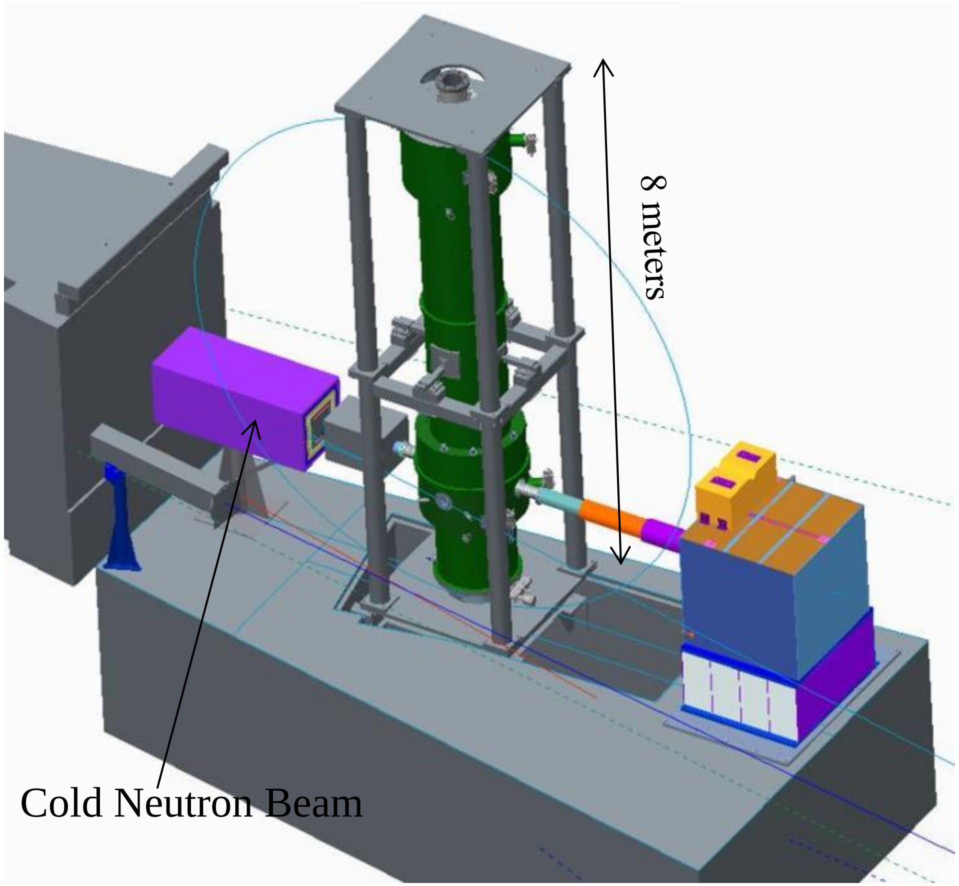
Low-energy experiments, $g_{S,T}$ from Lattice QCD

LHC:
14 TeV, 10,300 fb^{-1}

LHC-Search for $pp \to e + \nu +$ other stuff and $pp \to e + e +$ other stuff

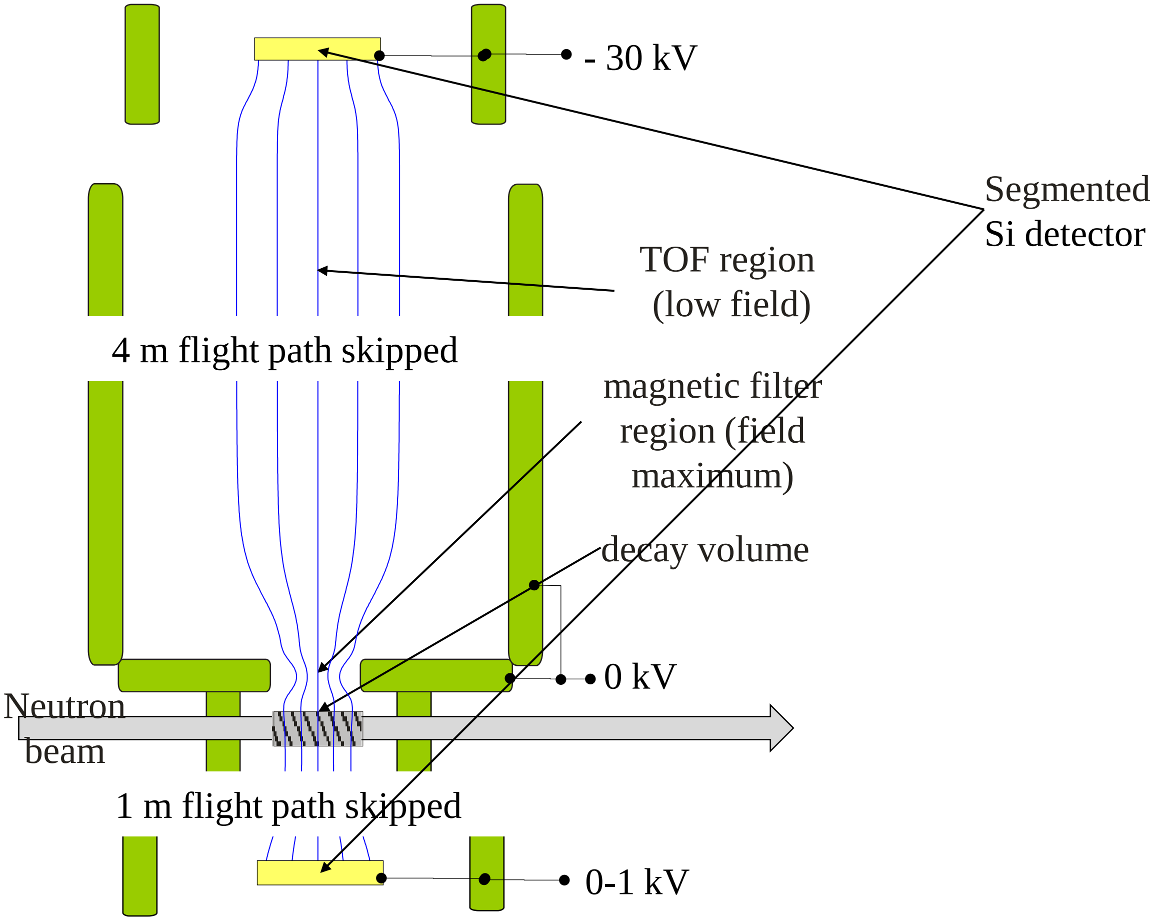
Nab spectrometer @ FNPB @ SNS





Fundamental Neutron Physics Beamline (FNPB) @ Spallation Neutron Source (SNS)

Nab spectrometer operation



- 30 kV

Segmented
Si detector

TOF region
(low field)

4 m flight path skipped

magnetic filter
region (field
maximum)

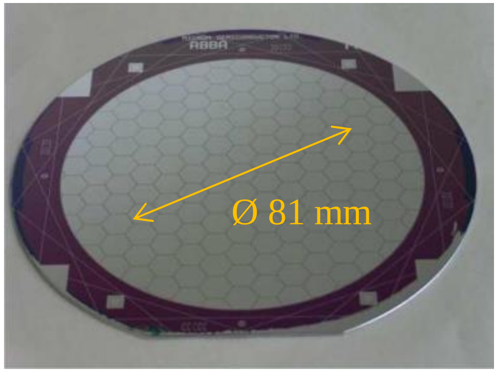
decay volume

0 kV

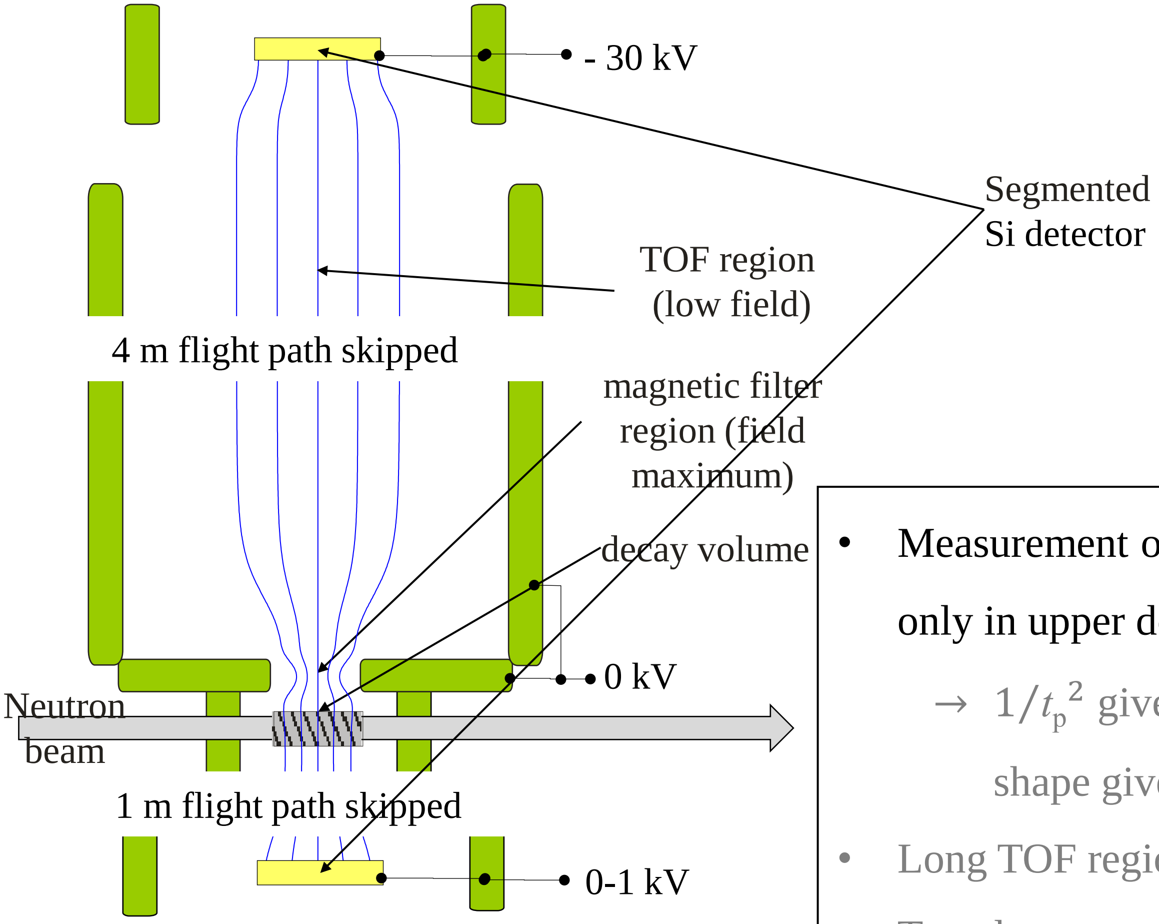
Neutron
beam

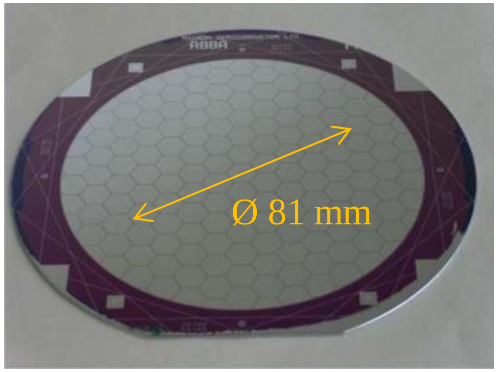
1 m flight path skipped

0-1 kV



Nab spectrometer operation

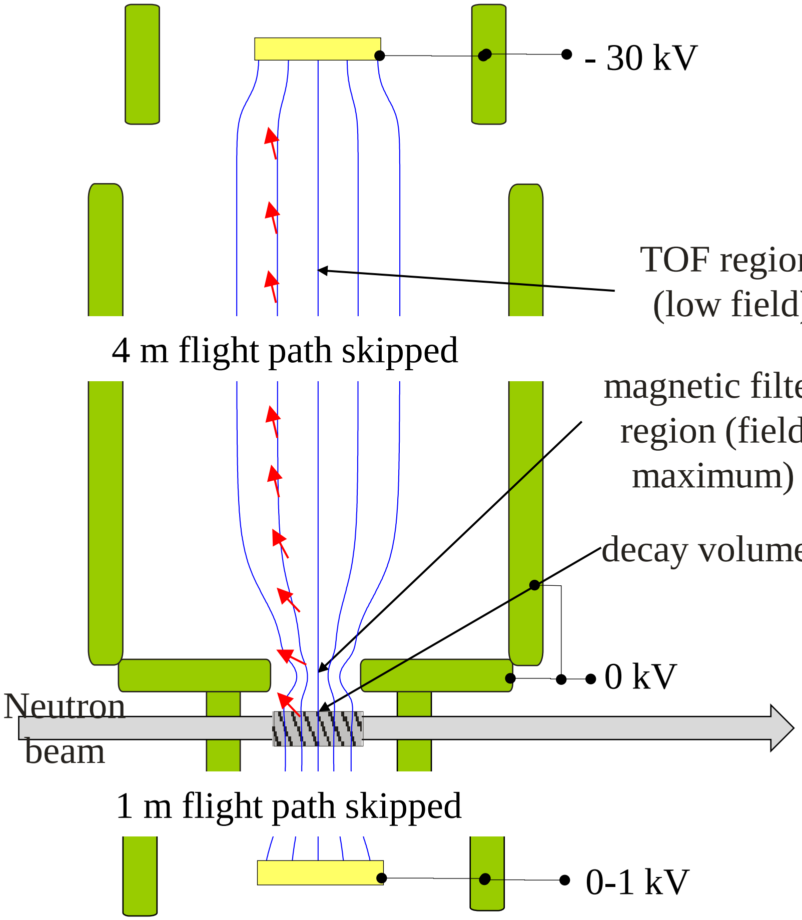


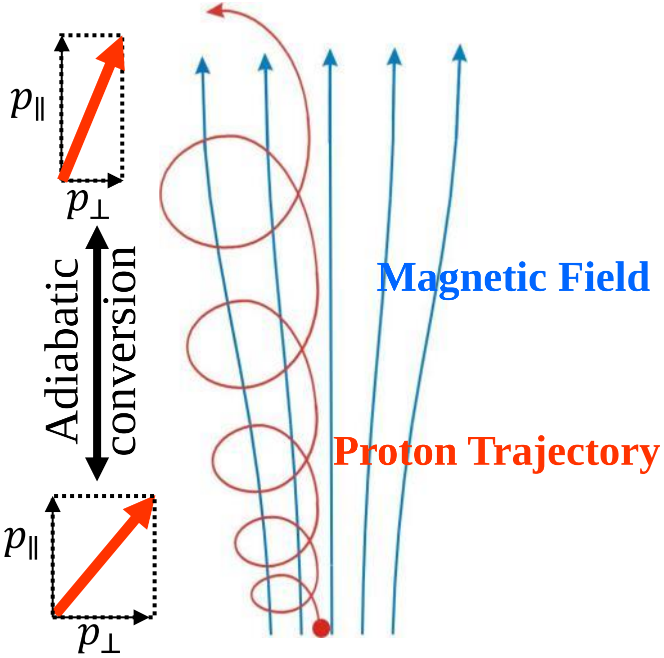


- Measurement of $E_{e,kin}$ and t_p for each event; protons only in upper detector
  - → $1/t_p{}^2$ gives an estimate for $p_p{}^2$, magnetic field shape gives a narrow detector response function
- Long TOF region improves proton TOF resolution
- Two detector geometry allows to suppress electron backscattering

Original configuration: D. Počanić, S. Baeßler, D. Bowman, V. Cianciolo, G. Greene, S. Penttilä et al., NIM A 611, 211 (2009)
Asymmetric configuration: S. Baeßler, D. Počanić, D. Bowman, S. Penttilä et al., arXiv:1209.4663

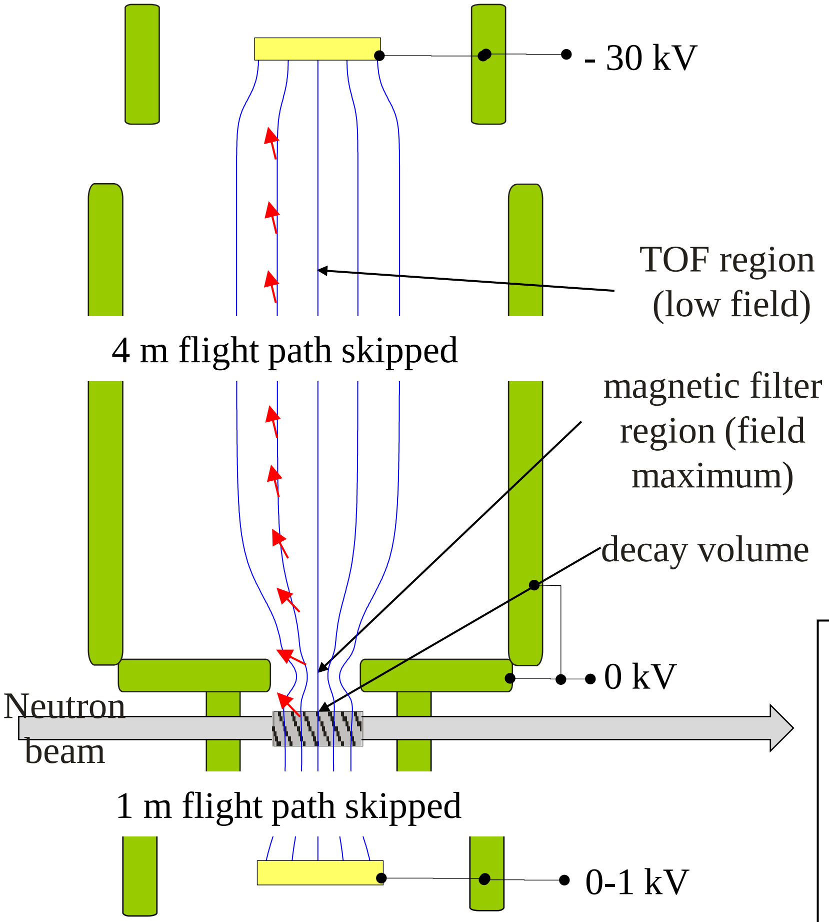
Nab spectrometer principle: measurement of E_e and t_p

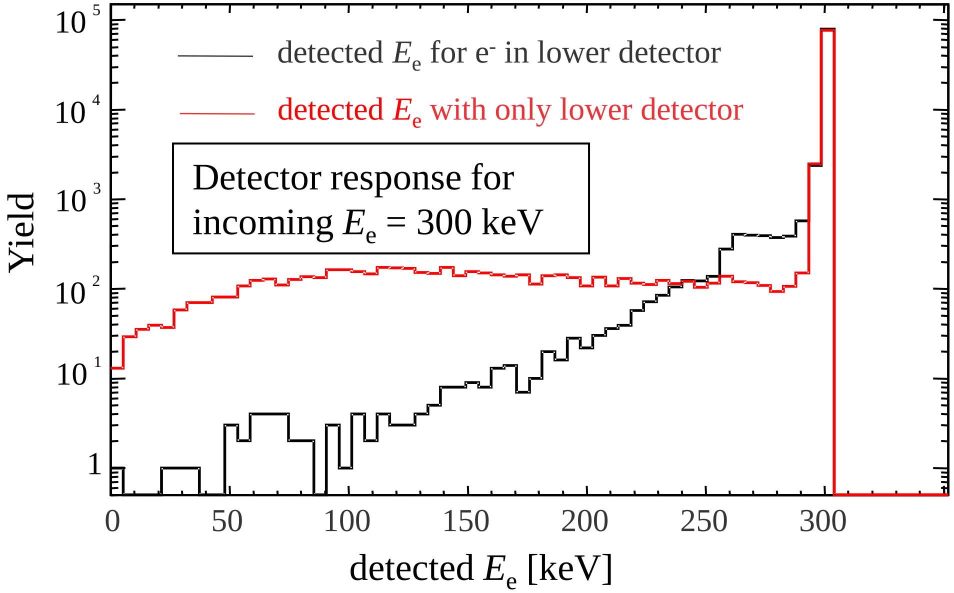




- Measurement of $E_{e,kin}$ and t_p for each event; protons only in upper detector
  - → $1/t_p^2$ gives an estimate for p_p^2, magnetic field shape gives a narrow detector response function
- Long TOF region improves proton TOF resolution
- Two detector geometry allows to suppress electron backscattering

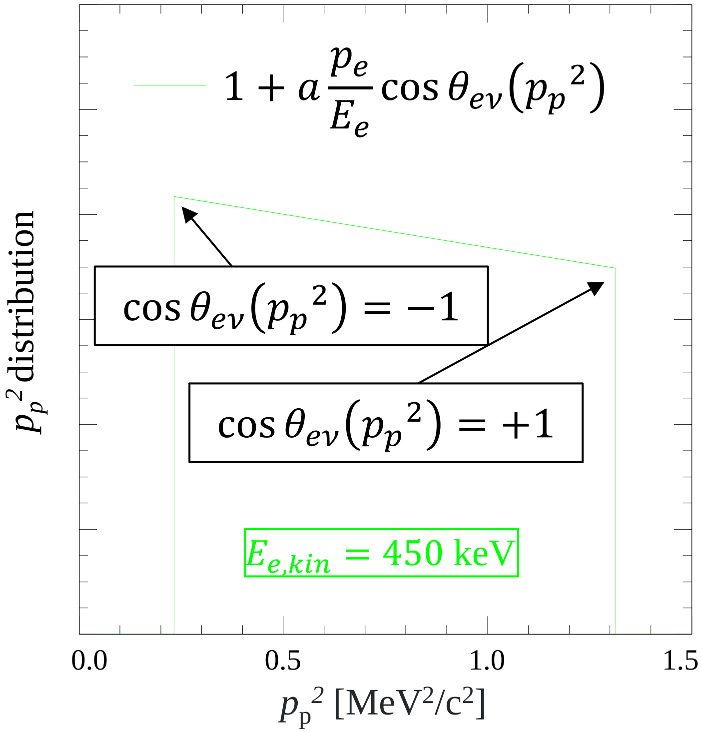
Electron energy measurement with backscattering suppression



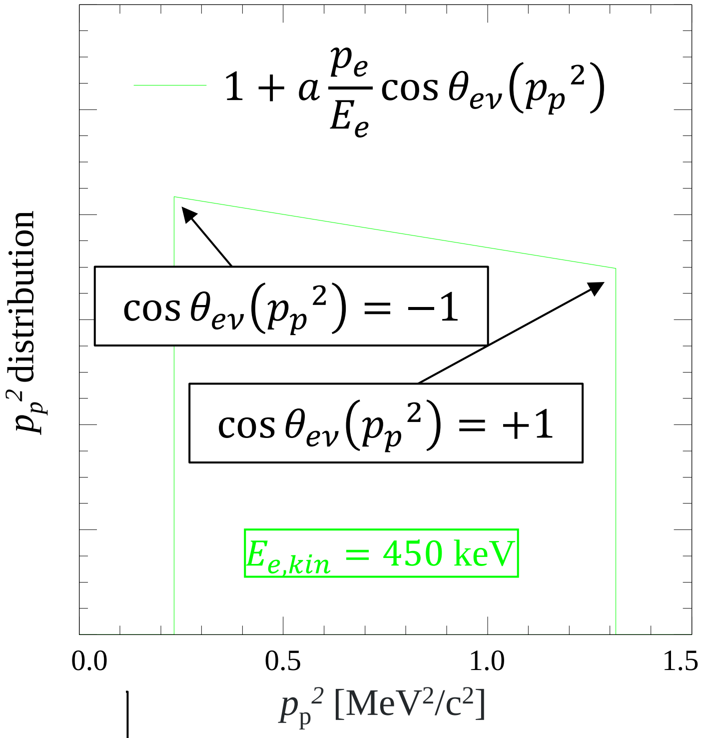


- Measurement of $E_{e,kin}$ and t_p for each event; protons only in upper detector
  - → $1/t_p^2$ gives an estimate for p_p^2, magnetic field shape gives a narrow detector response function
- Long TOF region improves proton TOF resolution
- Two detector geometry allows to suppress electron backscattering

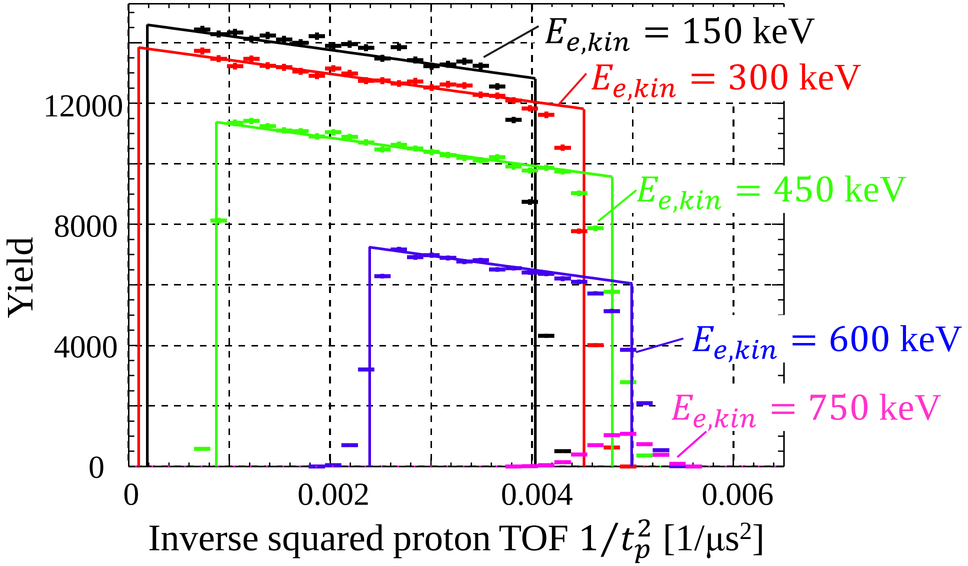
Nab data analysis



Nab data analysis

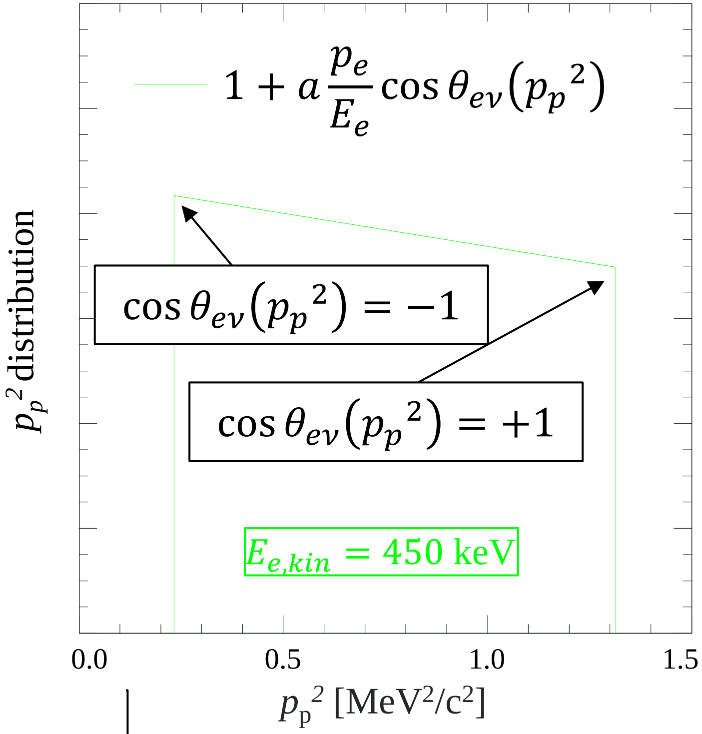


Full GEANT4 spectrometer simulation:

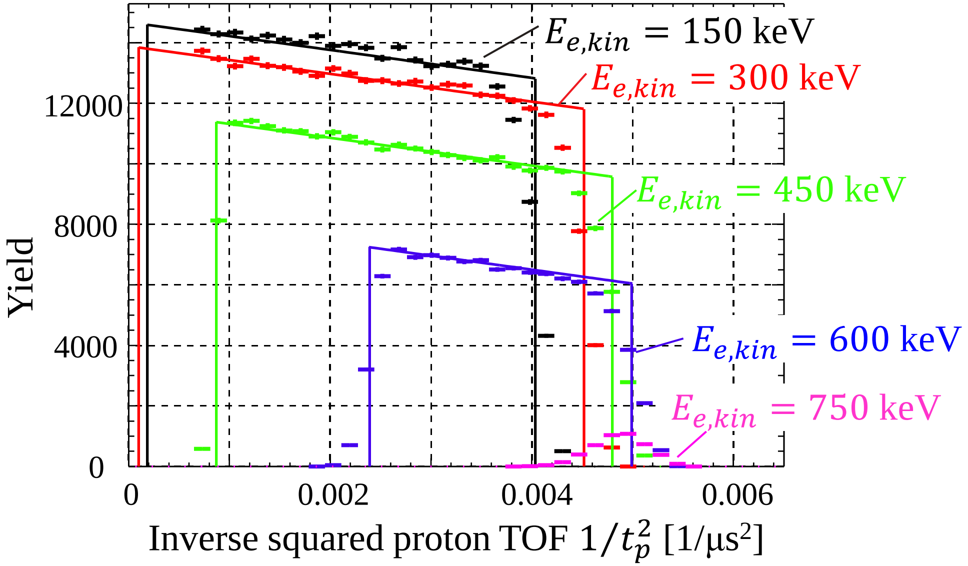


$$t_p = \frac{m_p \cdot \text{spectrometer length}}{p_p - \text{component along } \vec{B}}$$

Nab data analysis



Full GEANT4 spectrometer simulation:



$$t_p = \frac{m_p \cdot \text{spectrometer length}}{p_p\text{−component along }\vec{B}}$$

Data analysis: Use edge to determine or verify the spectrometer TOF response function.

Then, use central part to determine slope and correlation coefficient *a*.

Statistical uncertainty budget for *a* coefficient

Planned statistical uncertainty budget:

lower $E_{e,kin}$ cutoff	**none**	**100 keV**	**100 keV**	**100 keV**
upper t_p cutoff	**none**	**none**	**40 µs**	**30 µs**
Δa (*N*, *a*, *b* variable)	2.4/√N	2.5/√N	2.7/√N	3.0/√N
Δa (*N*, *a*, *b*, E_{cal}, *L* variable)	2.6/√N	2.7/√N	2.9/√N	3.2/√N
Δa (*N*, *a*, *b*, E_{cal}, *L* variable, inner 75% of data)	3.4/√N	3.5/√N	**3.8/√N**	4.3/√N
As above, 10% bg	4.2/√N	4.4/√N	**4.6/√N**	5.0/√N

3.6×10^8 events can be detected in 6 weeks (Decay volume $V = 246$ cm^3, 12.7% of decay protons go to upper detector, 50% efficiency in use of beam time, 1600 decays/s), corresponding to $\left(\frac{\Delta a}{a}\right)_{stat} \sim 2.4\cdot10^{-3}$ for this period.

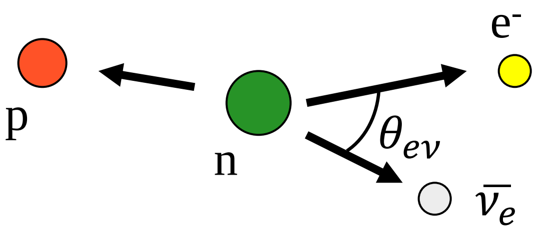
→ $\left(\frac{\Delta a}{a}\right)_{stat} \sim 7\cdot10^{-4}$ **can be reached, but it requires 70 weeks of data taking.**

Compare to $\Delta a/a = 4$ % of best existing experimental results (ACORN 2017), and ~ 1 % planned for ACORN and *a*SPECT

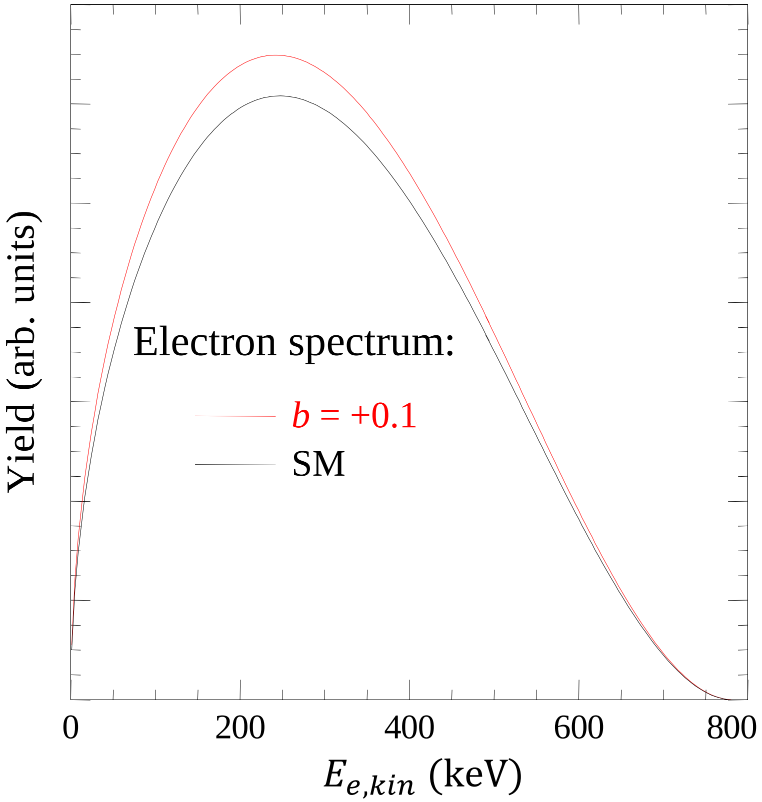
Systematic uncertainty budget for *a* coefficient

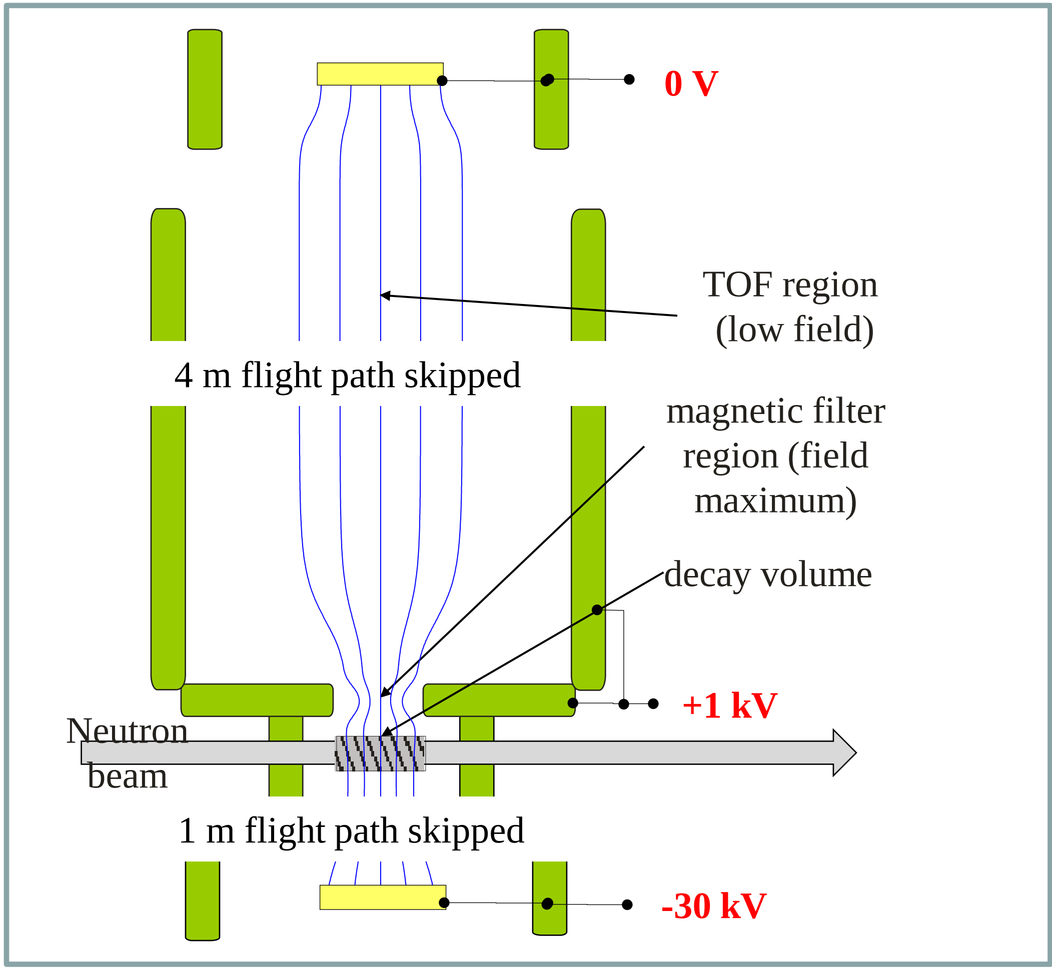
Experimental parameter	Main specification	Systematic uncertainty Δa/a
Magnetic field		
... curvature at pinch	$\Delta\gamma/\gamma = 2\%$ with $\gamma = d^2\, B_z(z)/dz^2/B_z(0)$	**$5.3\cdot10^{-4}$**
… ratio $r_B = B_{TOF}/B_0$	$(\Delta r_B)/r_B = 1\%$	$2.2\cdot10^{-4}$
… ratio $r_{B,DV} = B_{DV}/B_0$	$(\Delta r_{B,DV})/r_{B,DV} = 1\%$	$1.8\cdot10^{-4}$
Length of the TOF region		none
Electrical potential inhomogeneity:		
… in decay volume / filter region	$\lvert U_F - U_{DV}\rvert < 10$ mV	**$5\cdot10^{-4}$**
… in TOF region	$\lvert U_F - U_{TOF}\rvert < 200$ mV	$2.2\cdot10^{-4}$
Neutron Beam:		
… position	$\Delta\overline{z_{DV}} < 2$ mm	$1.7\cdot10^{-4}$
… profile (including edge effect)	Slope at edges < 10%/cm	$2.5\cdot10^{-4}$
… Doppler effect		small
… Unwanted beam polarization	$\lvert\overline{P_n}\rvert \ll 10^{-4}$	can be small
Adiabaticity of proton motion		$1\cdot10^{-4}$
Detector effects:		
… Electron energy calibration	$\Delta E_{e,kin} < 0.2$ keV	$2\cdot10^{-4}$
… Shape of electron energy response	fraction of events in tail to 1%	**$5.7\cdot10^{-4}$**
… Proton trigger efficiency	$\epsilon_p < 100$ ppm/keV	$3.4\cdot10^{-4}$
… TOF shift due to detector/electronics	$\Delta t_p < 0.3$ ns	$3\cdot10^{-4}$
Residual gas	$p < 2\cdot10^{-9}$ torr	$3.8\cdot10^{-4}$
Background / Accidental coincidences		small
Sum		**$1.2\cdot10^{-3}$**

The measurement of the Fierz Interference Term *b*

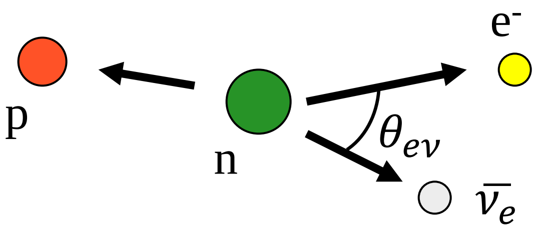


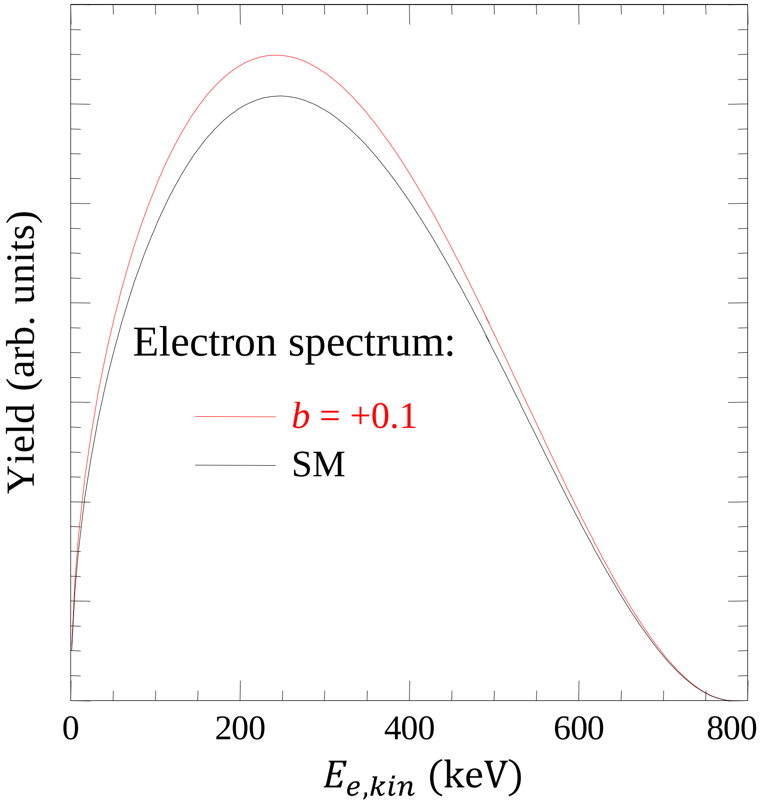
$$d\Gamma \propto \varrho(E_e)\left(1 + a\,\frac{p_e}{E_e}\cos\theta_{e\nu} + b\,\frac{m_e}{E_e}\right)$$





The measurement of the Fierz Interference Term *b*

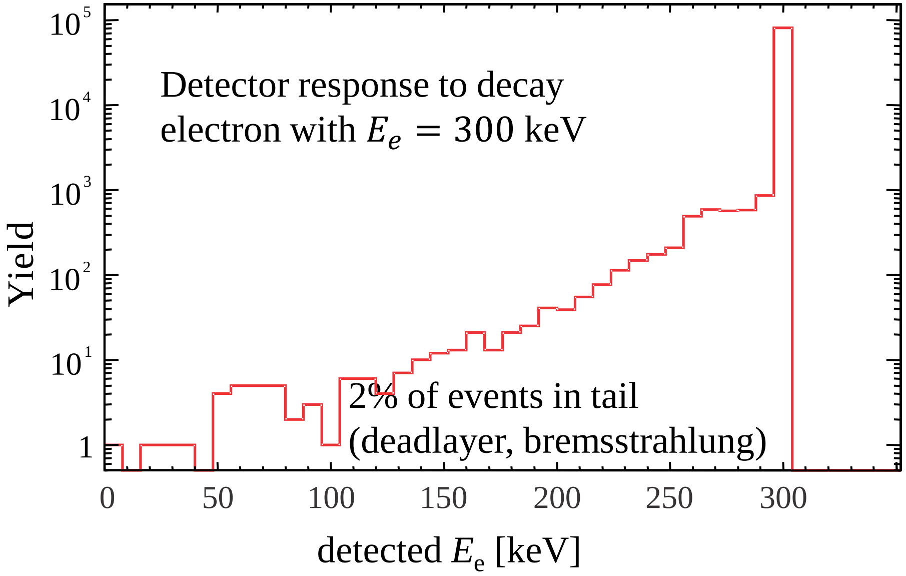




$$d\Gamma \propto \varrho(E_e)\left(1 + a\frac{p_e}{E_e}\cos\theta_{e\nu} + b\frac{m_e}{E_e}\right)$$

Systematic uncertainties:

1. Electron energy determination



2. Most stringent requirement: Non-linearity of 0.01%

3. Background

Goal: $\Delta b \leq 3 \cdot 10^{-3}$

Status of Nab experiment

Fundamental Neutron Physics Beamline
@ Spallation Neutron Source

Status of Nab experiment

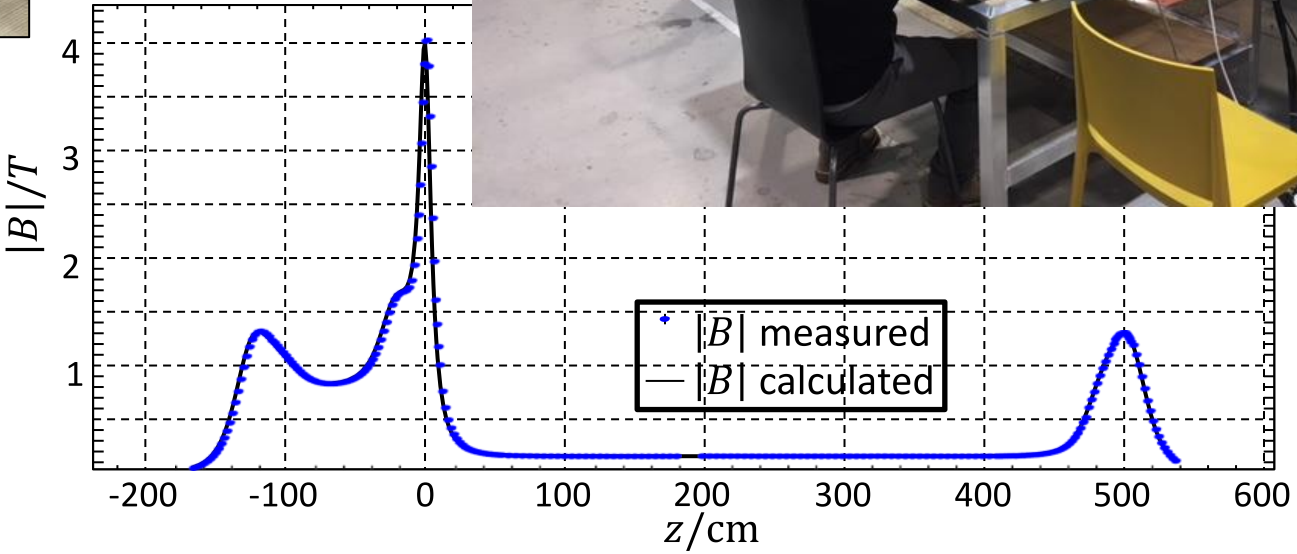
Fundamental Neutron Physics Beamline @ Spallation Neutron Source

Magnet system tested successfully at manufacturer, is expected to arrive at ORNL this Friday.

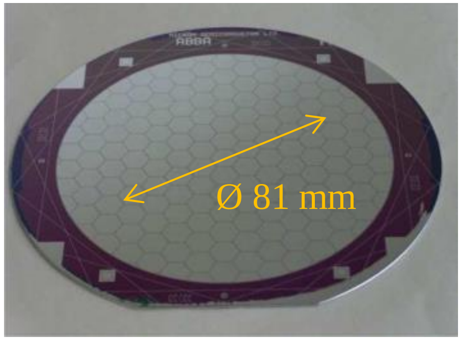
Status of Nab experiment

Fundamental Neutron Physics Beamline
@ Spallation Neutron Source

Magnet system tested successfully at manufacturer, is expected to arrive at ORNL this Friday.

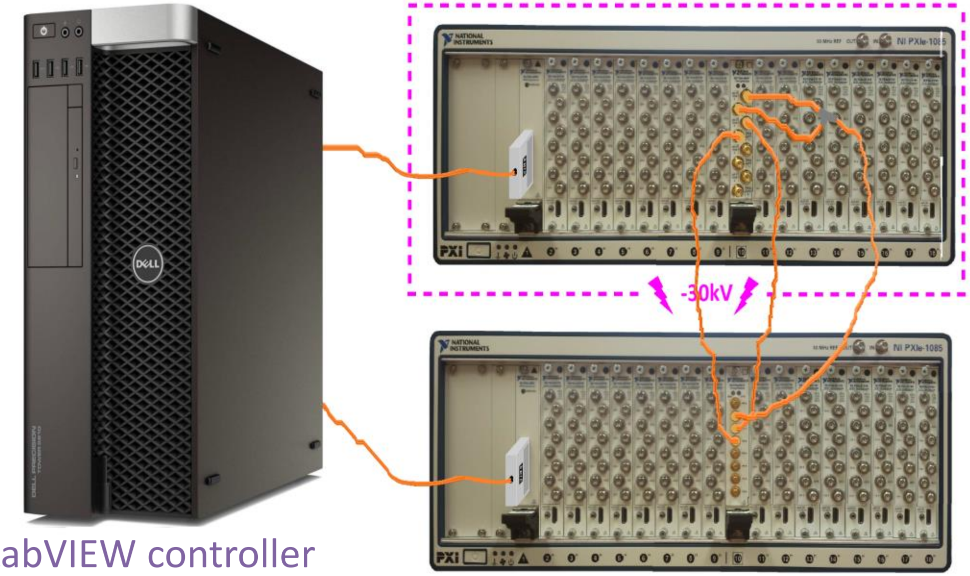


Nab (and UCNB) detector properties



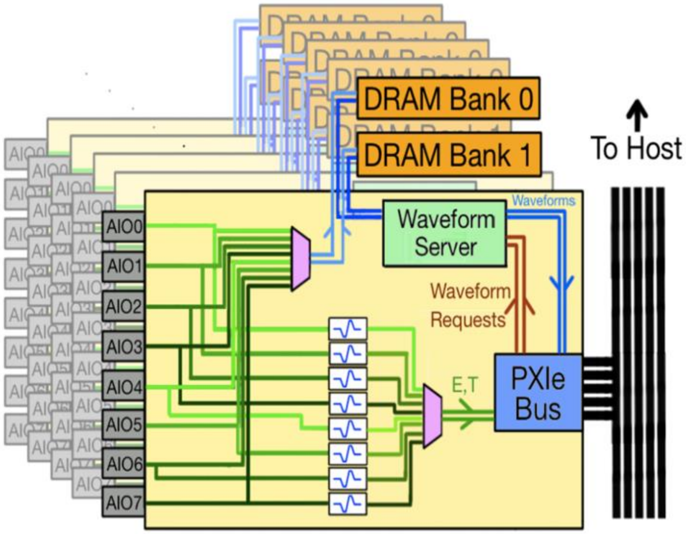
Back side

- DAQ system (**A. Sprow, C. Crawford et al.**): All waveforms recorded. Risetime ~ 40 ns, fall time ~ 4 μs.
- Energy resolution a few keV, threshold ≤ 10 keV
- Noise low enough to detect protons (average deposited energy: 18 keV)
- Bad pixels need investigation



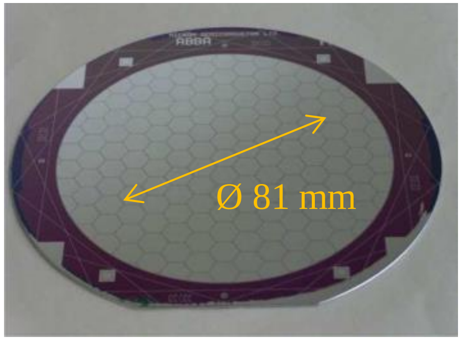
LabVIEW controller
C++ coincidence logic

Optical fiber bus, clock & sync



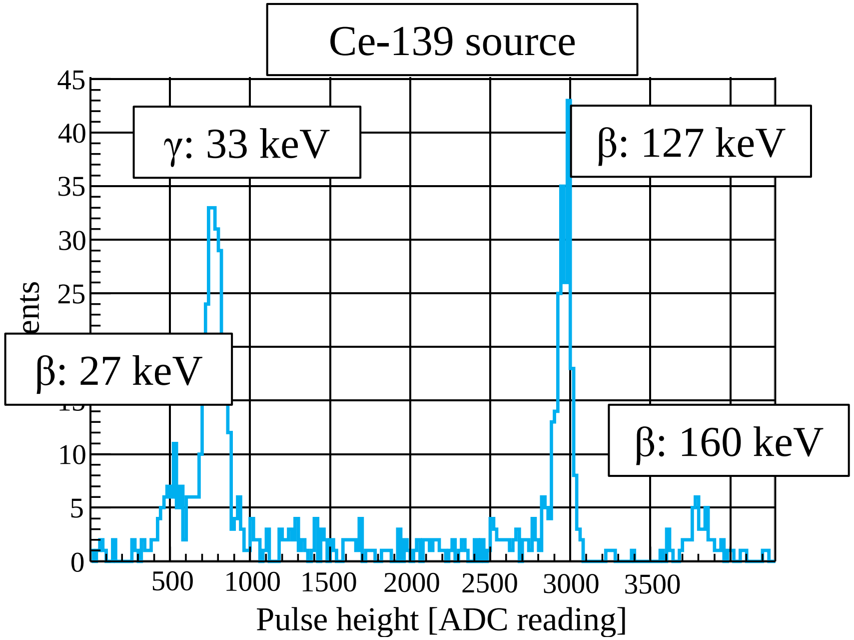
LabVIEW FPGA low-threshold trapezoid trigger on ADC

Nab (and UCNB) detector properties



Back side

- DAQ system (**A. Sprow, C. Crawford et al.**): All waveforms recorded. Risetime ~ 40 ns, fall time ~ 4 μs.
- Energy resolution a few keV, threshold ≤ 10 keV
- Noise low enough to detect protons (average deposited energy: 18 keV)
- Bad pixels need investigation


Ce-139 source

γ: 33 keV

β: 127 keV

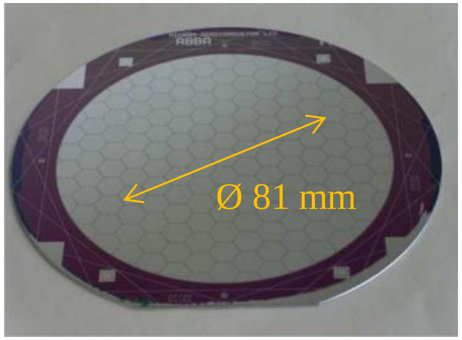
β: 27 keV

β: 160 keV

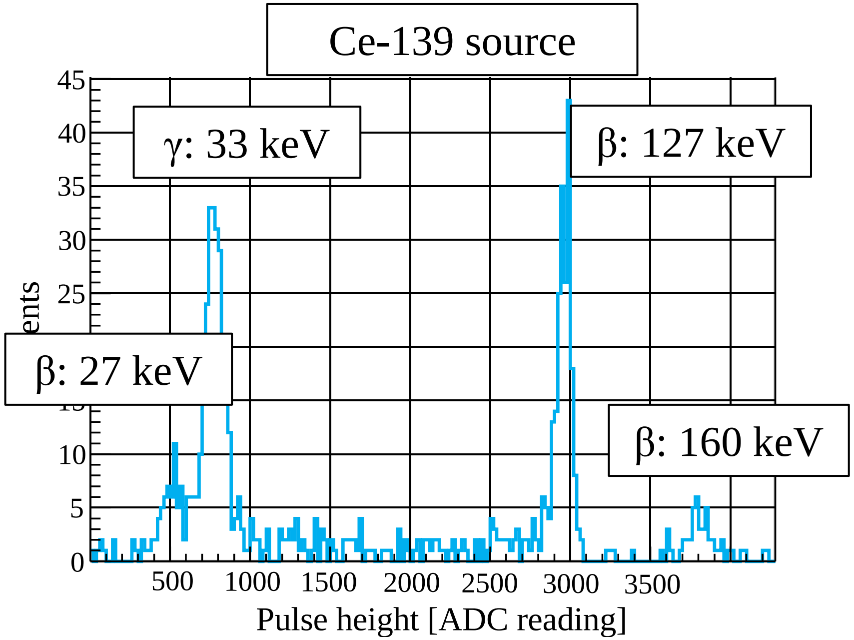
LANL test run with Ce-139 source, Analysis H. Li

Nab (and UCNB) detector properties

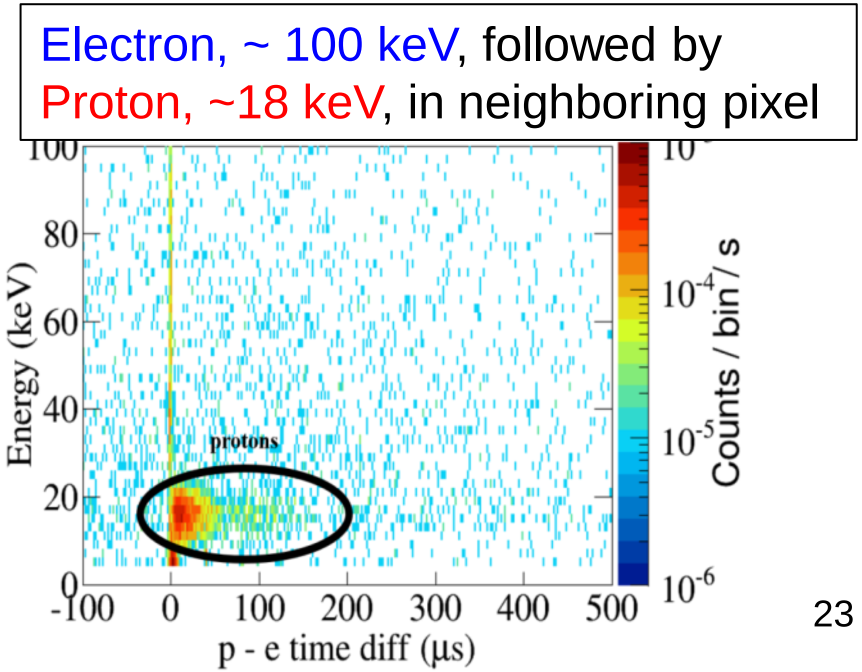
Back side



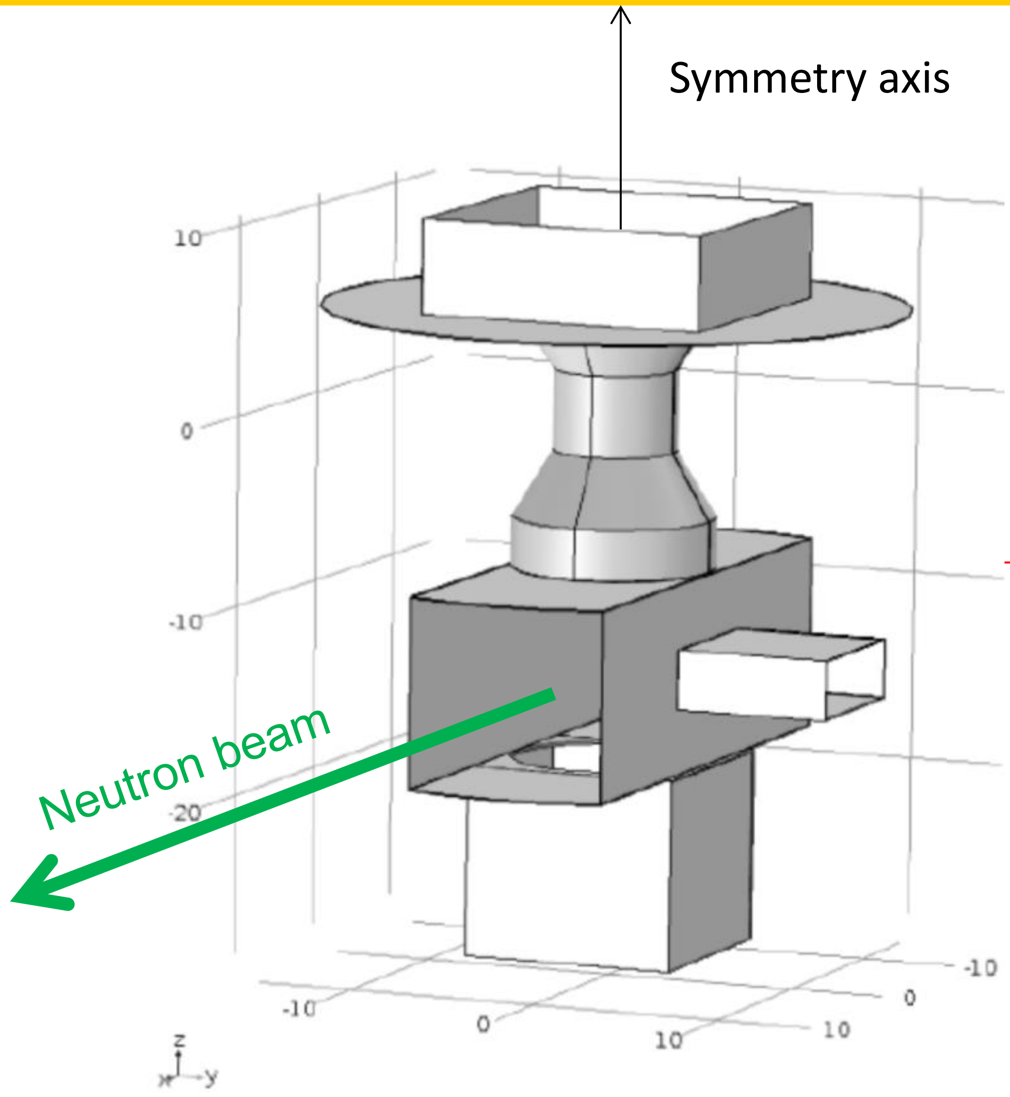
- DAQ system (**A. Sprow, C. Crawford et al.**): All waveforms recorded. Risetime ~ 40 ns, fall time ~ 4 μs.
- Energy resolution a few keV, threshold ≲ 10 keV
- Noise low enough to detect protons (average deposited energy: 18 keV)
- Bad pixels need investigation



LANL test run with Ce-139 source, Analysis H. Li

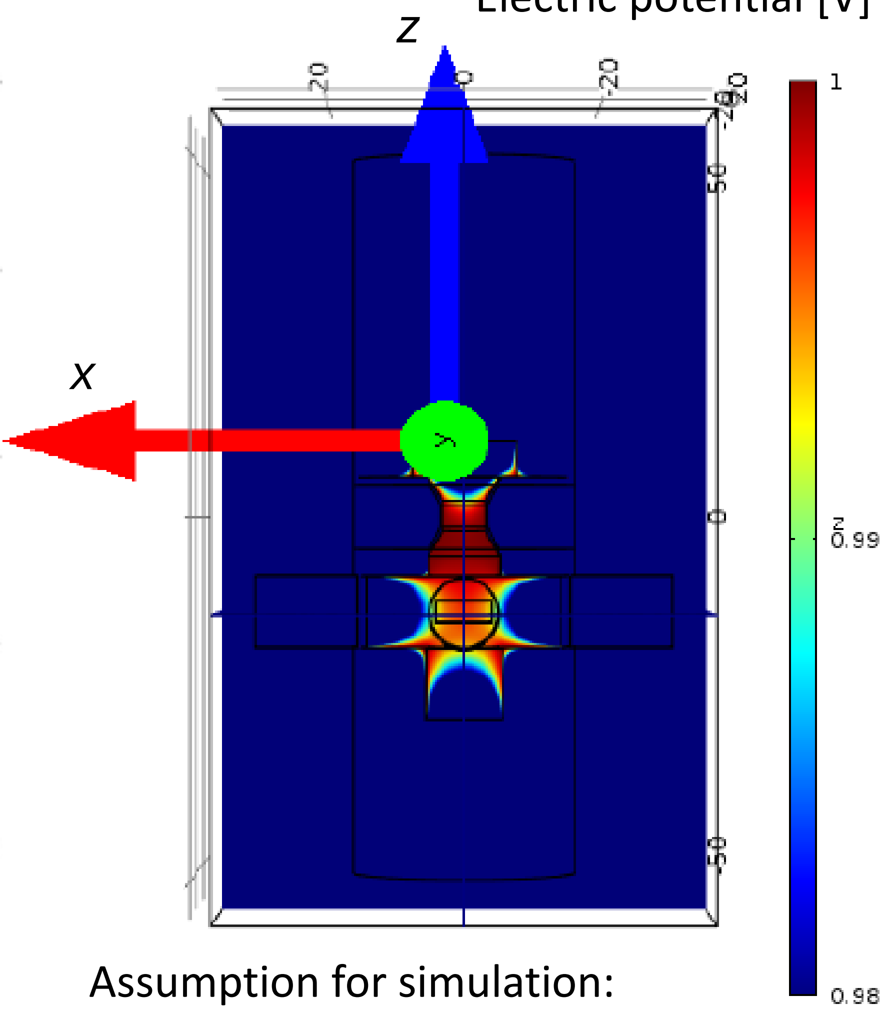


Main electrode system: Simulation of the effect of openings



Symmetry axis

Neutron beam



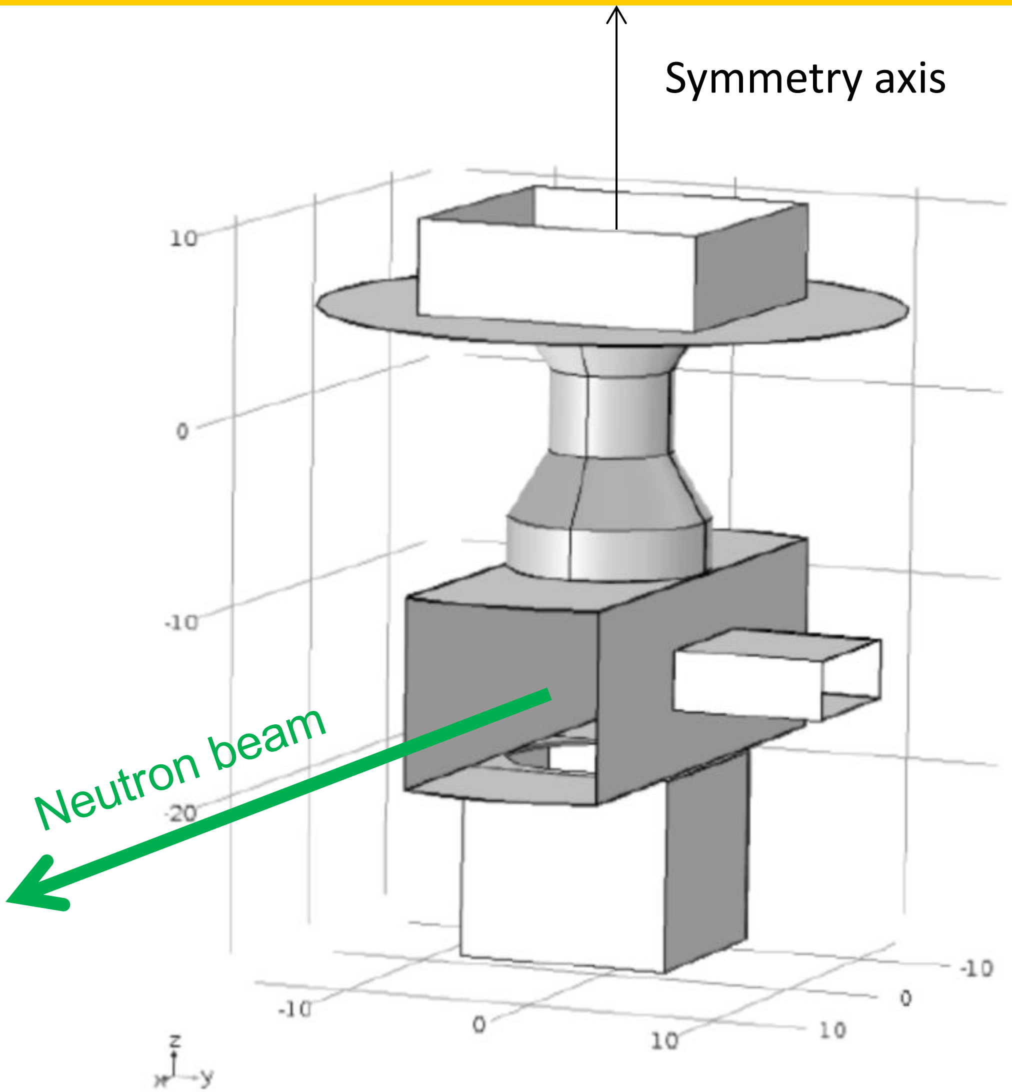
Electric potential [V]

z

x

Assumption for simulation:
Potential of bore tube different
by 1 V from electrodes

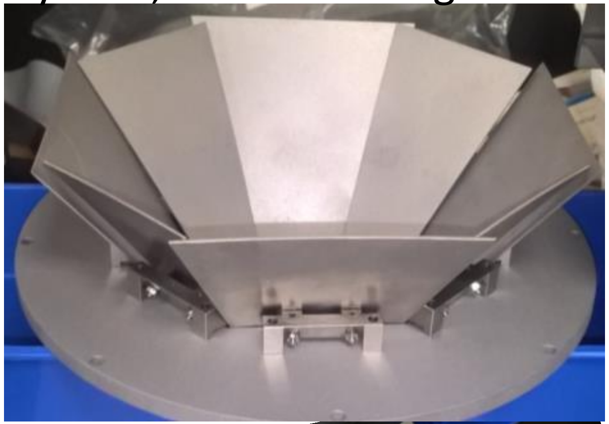
Main electrode system: Fabrication

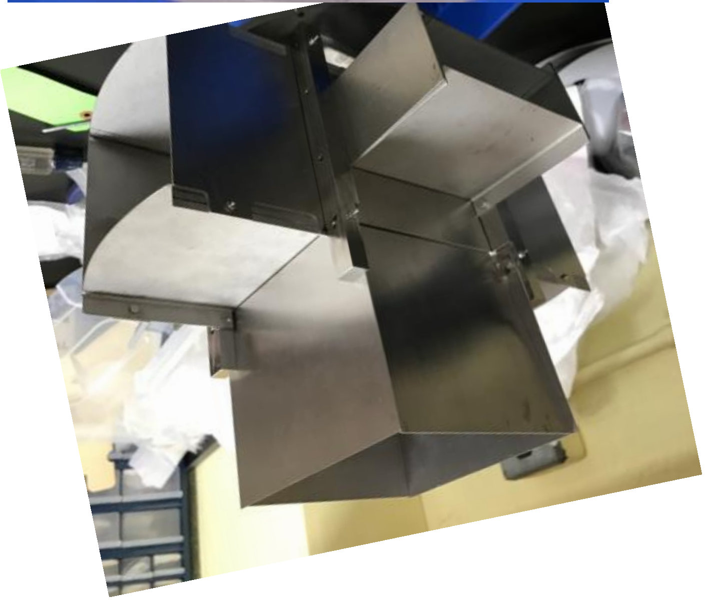


Symmetry axis

Neutron beam

Top and bottom part of electrode system, before coating:





Parts are in hand, and are awaiting cleaning and coating.

Electrode surface coating: What is the issue?

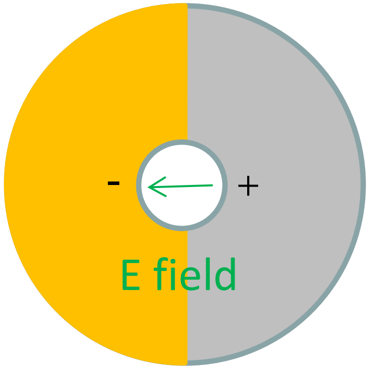
Most undergraduate textbooks: No electric field in empty hole inside conductor…

Electrode surface coating: What is the issue?

Most undergraduate textbooks: No electric field in empty hole inside conductor…

...and I have no objection if the conductor is homogenous.

However, if not:

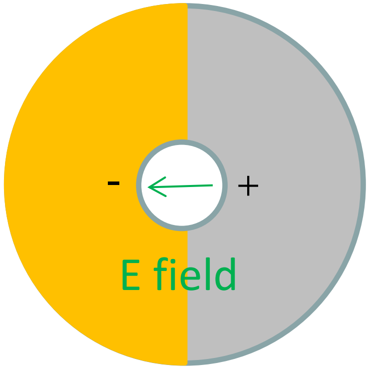


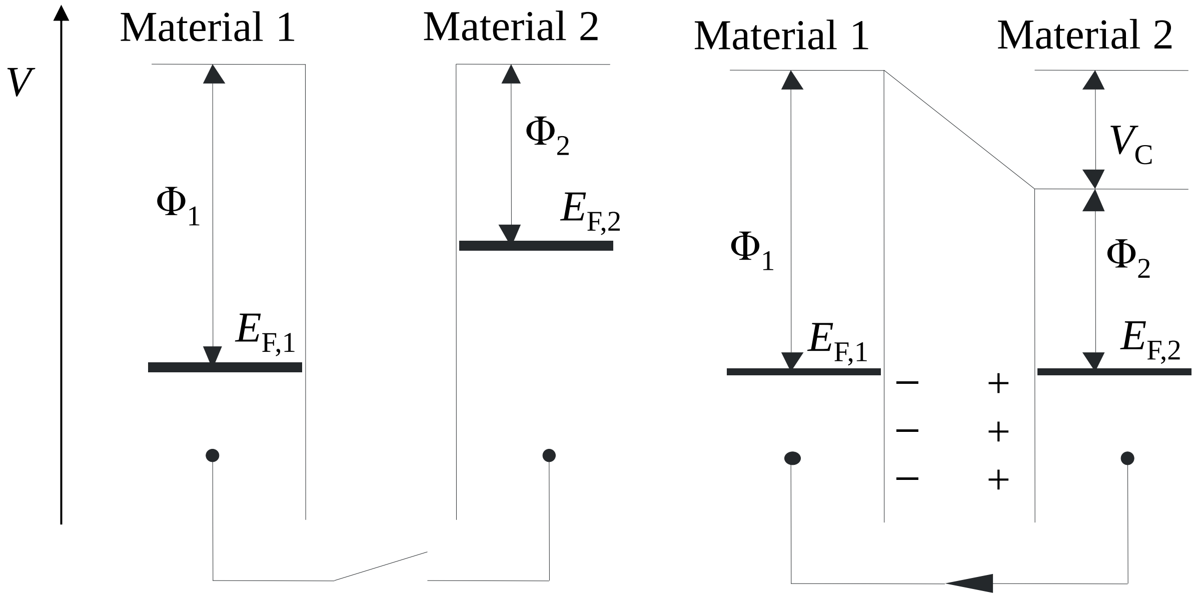
Electrode surface coating: What is the issue?

Most undergraduate textbooks: No electric field in empty hole inside conductor…

...and I have no objection if the conductor is homogenous.

However, if not:



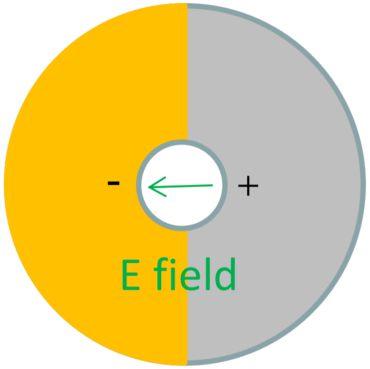


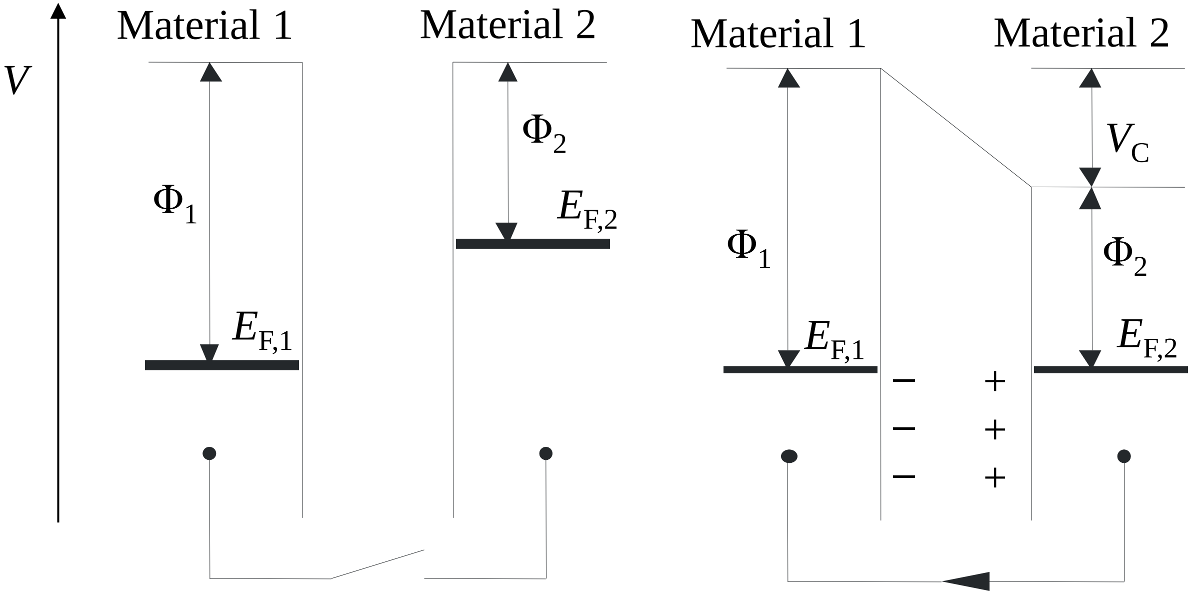
Electrode surface coating: What is the issue?

Most undergraduate textbooks: No electric field in empty hole inside conductor…

…and I have no objection if the conductor is homogenous.

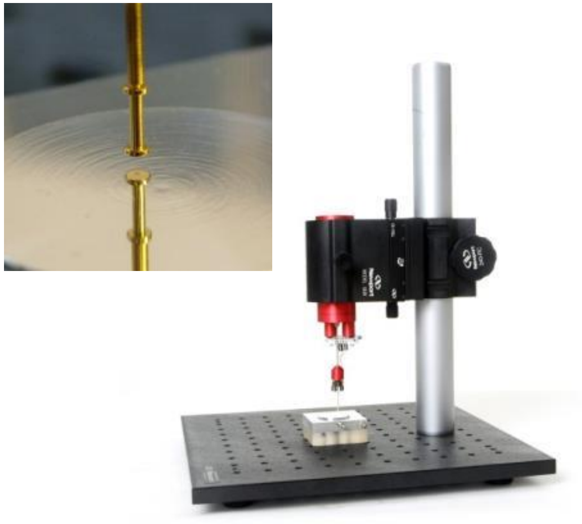
However, if not:

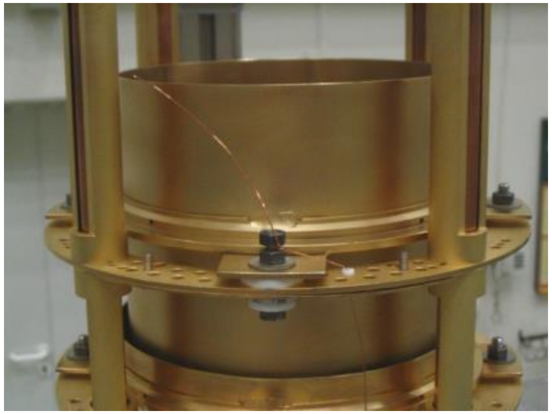


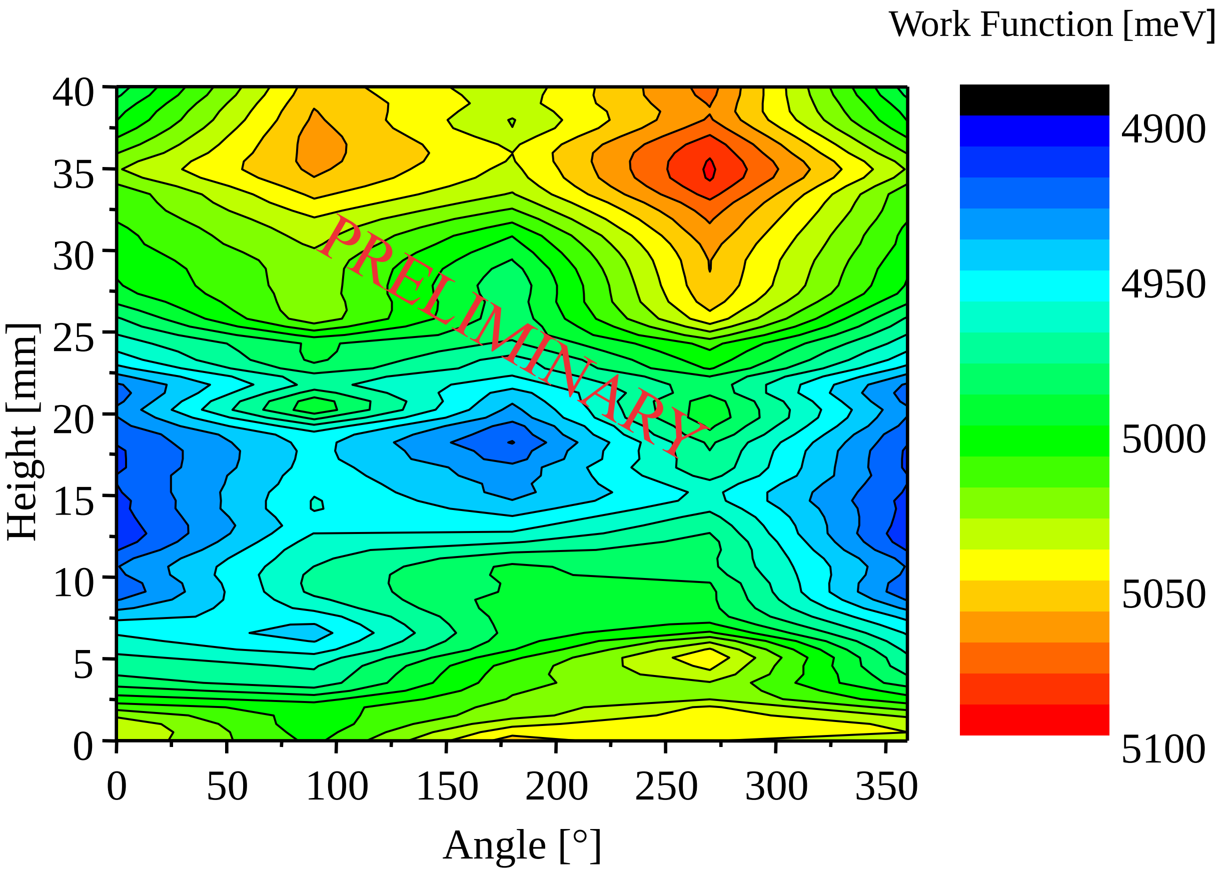


Consequence: Need to establish that electric field is known, or known to be absent, in flight path.

Work function measurements





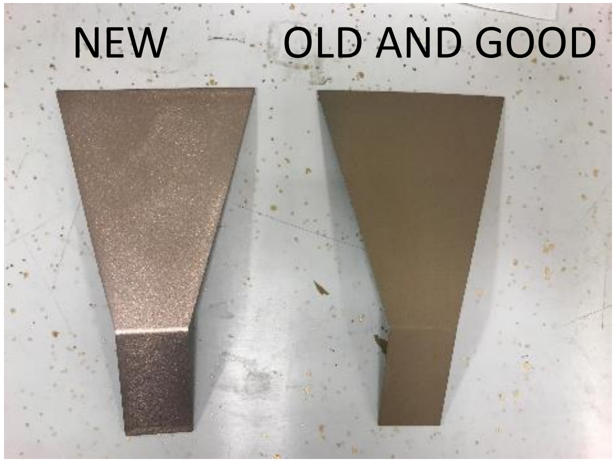


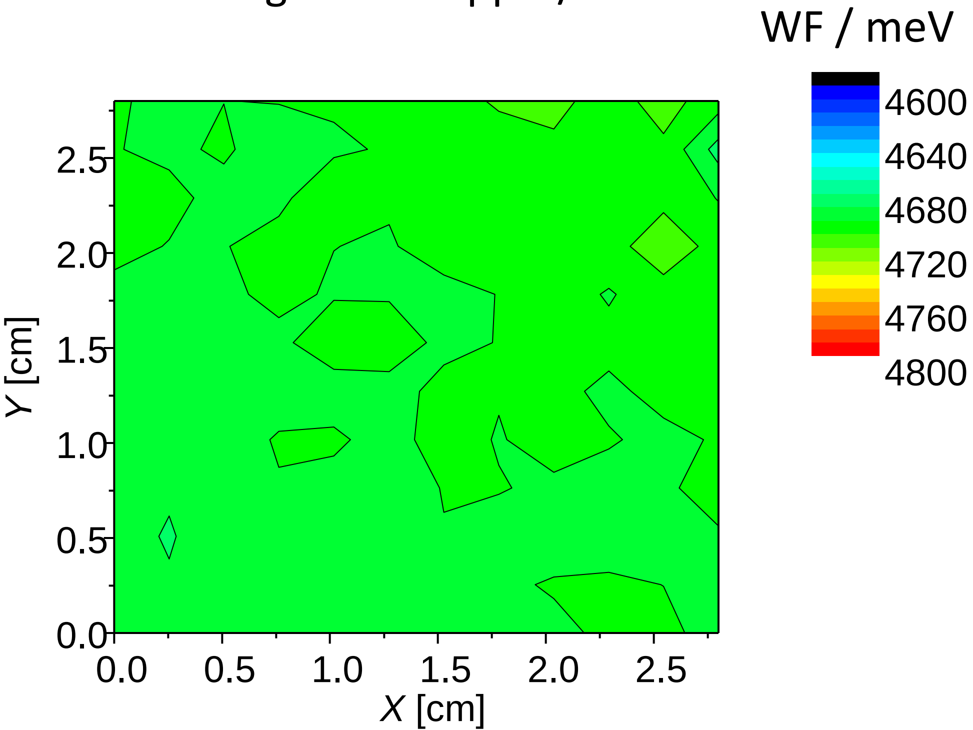
In collaboration with Prof. I. Baikie, KP Technologies

Main electrode system

We previously identified two coating methods that provide good homogeneity of the work function, and are compatible with UHV conditions. A copper/silver spray (which was good always when the coating looked good eye) and a graphite spray (which was mostly good when the coating looked good by eye). We decided to go with copper/silver.

But: Manufacturer changed recipe:





Present status of testing:

- New spray seems to be equally good in terms of work function uniformity ($\sigma < 10$ meV)
- Vacuum test so far inconclusive
- Cryogenic testing not yet done

Next step: Align main electrode substrates, do coating, characterize

The Nab collaboration

Active and recent collaborators:

R. Alarcon[a], S.B.[b,c] (Project Manager), S. Balascuta[a], L. Barrón Palos[n], K. Bass[i], N. Birge[i], A. Blose[f], D. Borissenko[b], J.D. Bowman[c] (Co-Spokesperson), L. Broussard[c], A.T. Bryant[b], J. Byrne[d], J.R. Calarco[c,i], T. Chupp[o], T.V. Cianciolo[c], J.N. Clement[b], C. Crawford[f], W. Fan[b], W. Farrar[b], N. Fomin[i], E. Frlež[b], J. Fry[b], M.T. Gericke[g], M. Gervais[f], F. Glück[h], G.L. Greene[c,i], R.K. Grzywacz[i], V. Gudkov[j], J. Hamblen[e], C. Hayes[m], C. Hendrus[o], T. Ito[k], H. Li[b], C.C. Lu[b], M. Makela[k], R. Mammei[g], J. Martin[l], M. Martinez[a], D.G. Matthews[f], P. McGaughey[k], C.D. McLaughlin[b], P. Mueller[c], D. van Petten[b], S.I. Penttilä[c] (On-site Manager), D. Počanić[c] (Co-Spokesperson), G. Randall[a], N. Roane[b], C.A. Royse[m], K.P. Rykaczewski[c], A. Salas-Bacci[b], E.M. Scott[i], S.K. Sjue[k], A. Smith[b], E. Smith[k], A. Sprow[f], E. Stevens[b], J. Wexler[m], R. Whitehead[i], W.S. Wilburn[k], A.Young[m], B.Zeck[m]

[a] Department of Physics, Arizona State University, Tempe, AZ 85287-1504
[b] Department of Physics, University of Virginia, Charlottesville, VA 22904-4714
[c] Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831
[d] Department of Physics and Astronomy, University of Sussex, Brighton BN19RH, UK
[e] Department of Chemistry and Physics, University of Tennessee at Chattanooga, Chattanooga, TN 37403
[f] Department of Physics and Astronomy, University of Kentucky, Lexington, KY 40506
[g] Department of Physics, University of Manitoba, Winnipeg, Manitoba, R3T 2N2, Canada
[h] KIT, Universität Karlsruhe (TH), Kaiserstraße 12, 76131 Karlsruhe, Germany
[i] Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996
[j] Department of Physics and Astronomy, University of South Carolina, Columbia, SC 29208
[k] Los Alamos National Laboratory, Los Alamos, NM 87545
[l] Department of Physics, University of Winnipeg, Winnipeg, Manitoba R3B2E9, Canada
[m] Department of Physics, North Carolina State University, Raleigh, NC 27695-8202
[n] Universidad Nacional Autónoma de México, México, D.F. 04510, México
[o] University of Michigan, Ann Arbor, MI 48109

Main project funding:

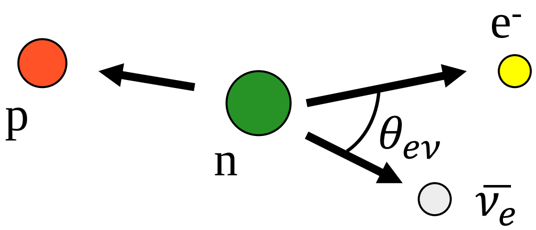
NSF

U.S. DEPARTMENT OF ENERGY
Office of Science

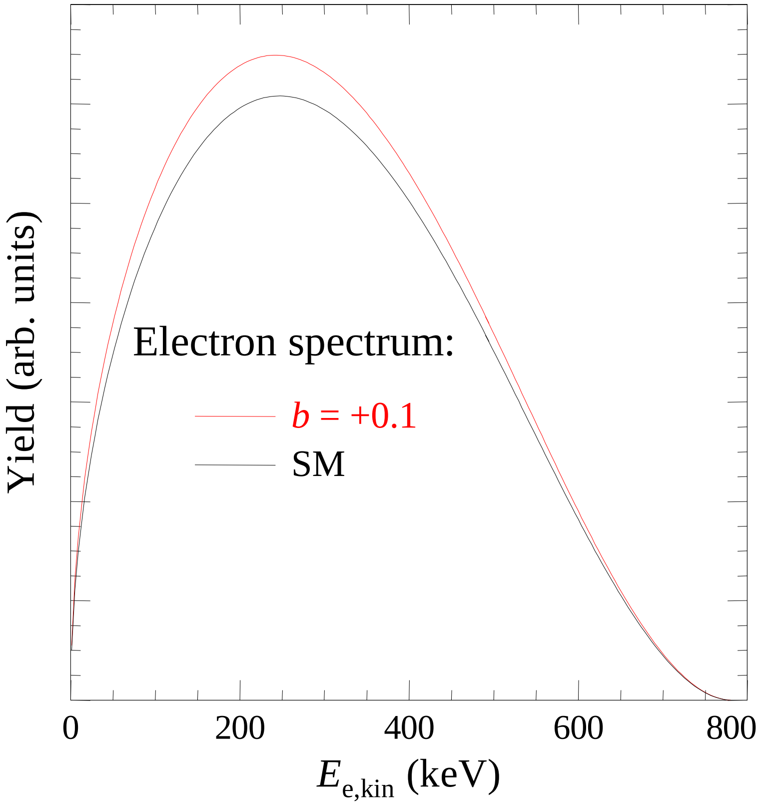
OAK RIDGE
National Laboratory

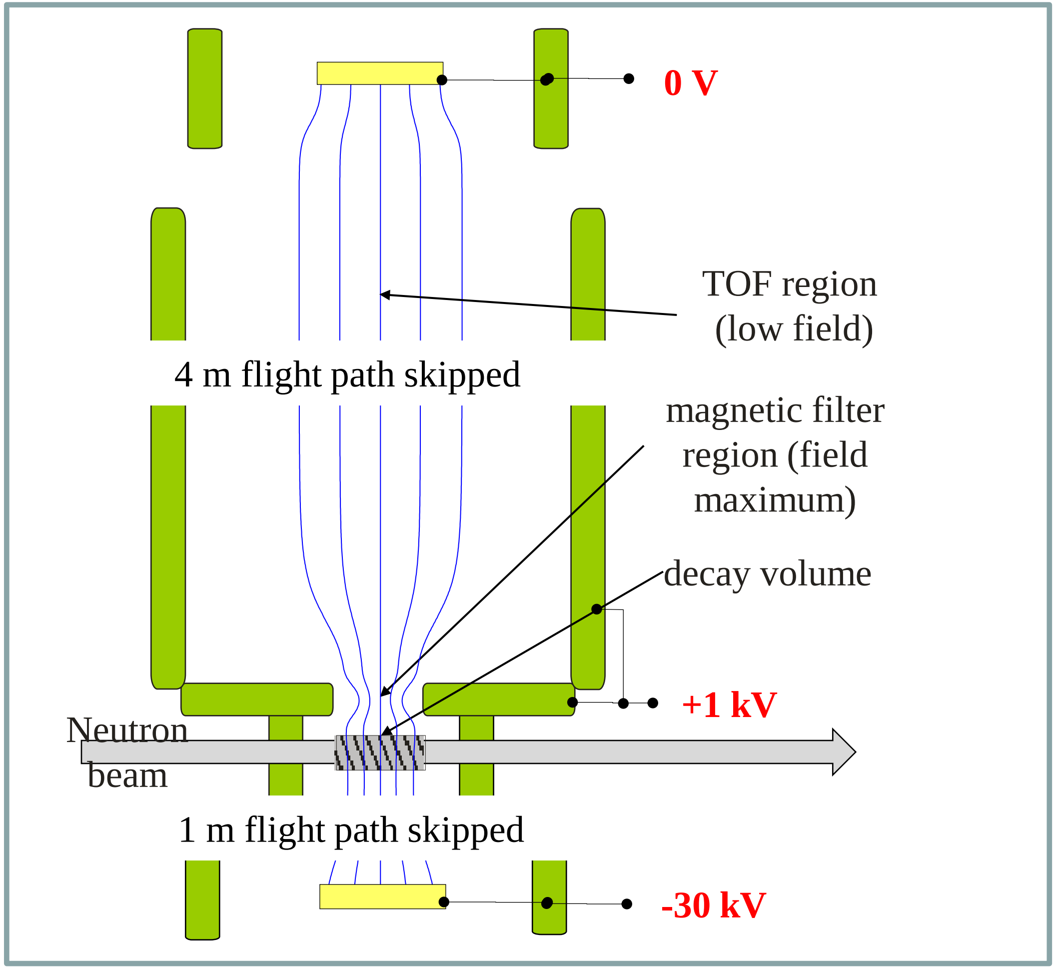
UNIVERSITY of VIRGINIA

The determination of the Fierz Interference term *b*

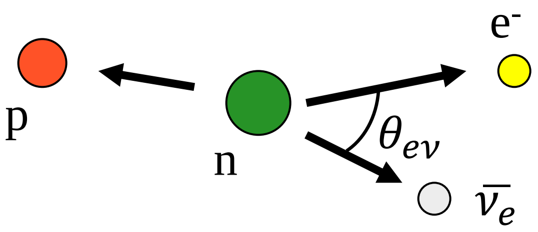


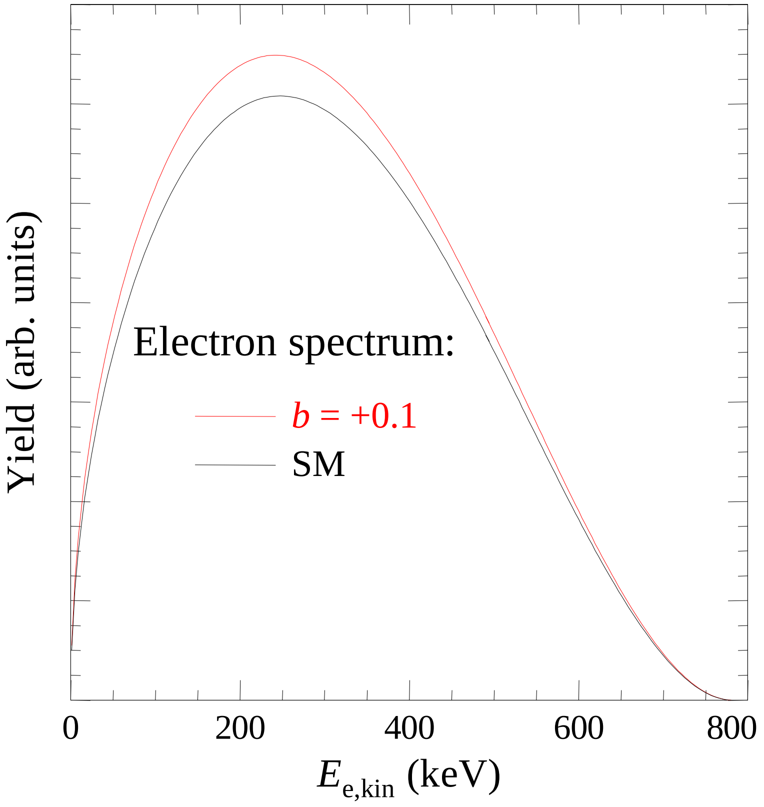
$$d\Gamma \propto \varrho(E_e)\left(1 + a\frac{p_e}{E_e}\cos\theta_{e\nu} + b\frac{m_e}{E_e}\right)$$





The determination of the Fierz Interference term *b*



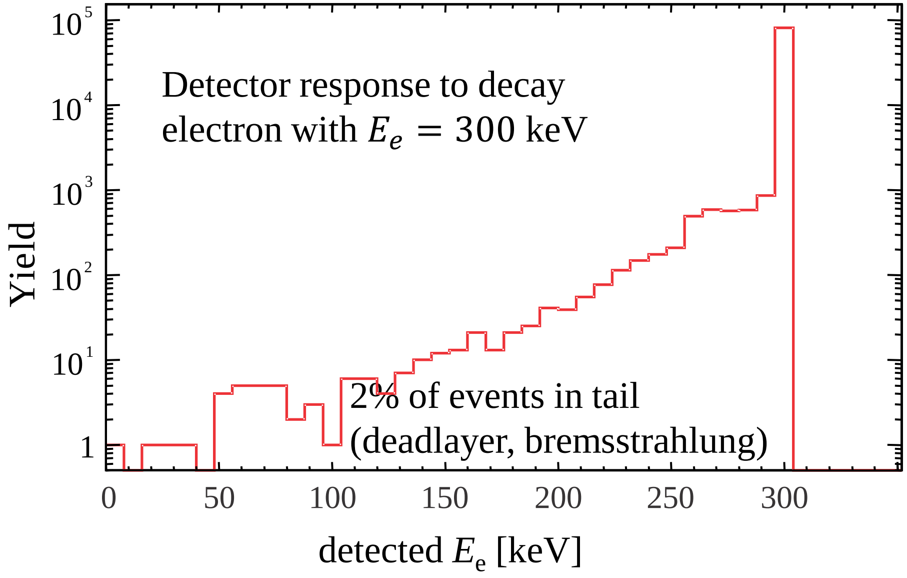


Electron spectrum:

$$d\Gamma \propto \varrho(E_e)\left(1 + a\frac{p_e}{E_e}\cos\theta_{e\nu} + b\frac{m_e}{E_e}\right)$$

Systematic uncertainties:

1. Electron energy determination



Detector response to decay electron with $E_e = 300$ keV

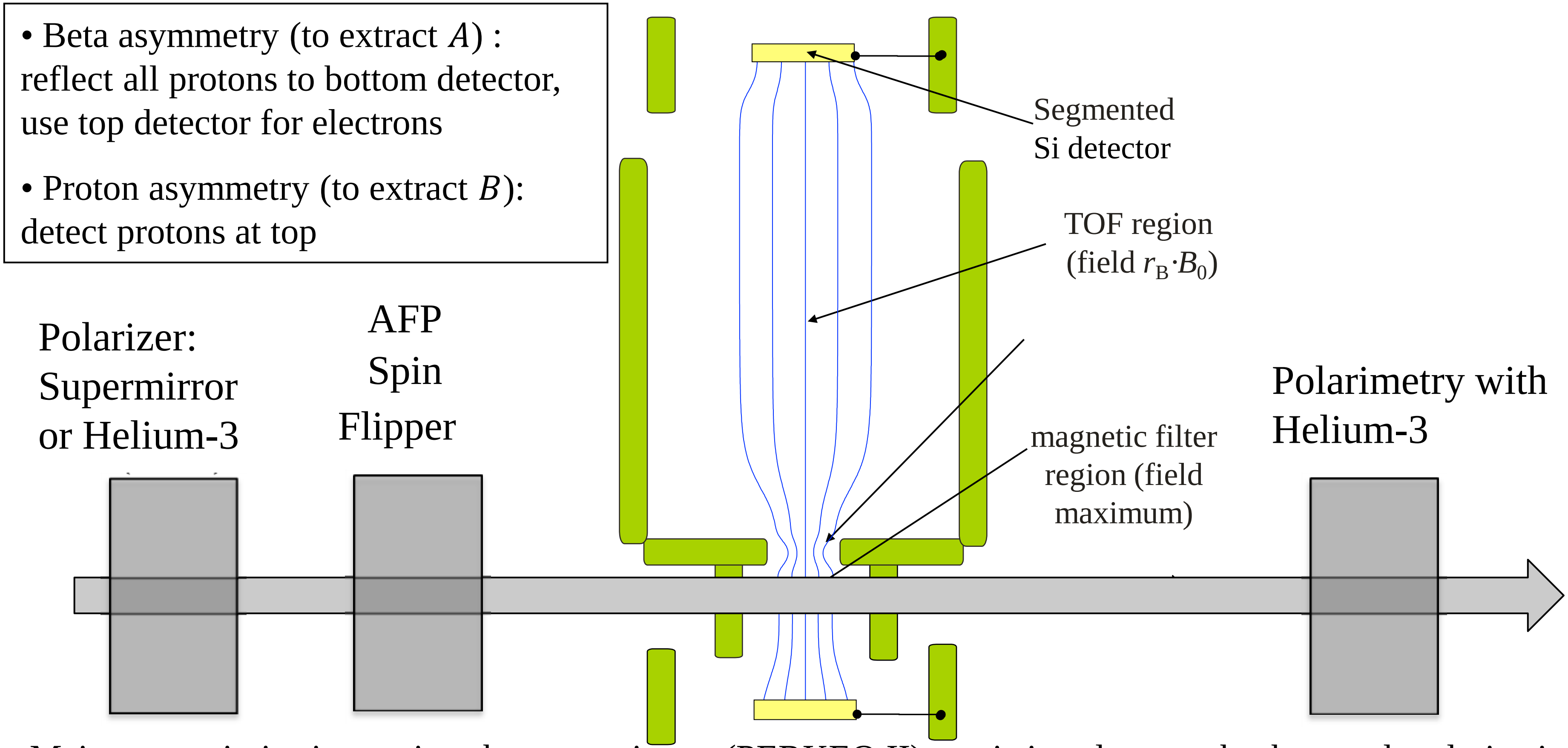
2% of events in tail (deadlayer, bremsstrahlung)

2. Background

Goal: $\Delta b < 3 \cdot 10^{-3}$

Planned continuation (SNS or NIST): Polarized neutrons

- Beta asymmetry (to extract *A*) : reflect all protons to bottom detector, use top detector for electrons
- Proton asymmetry (to extract *B*): detect protons at top



Polarizer: Supermirror or Helium-3

AFP Spin Flipper

Segmented Si detector

TOF region (field $r_B \cdot B_0$)

magnetic filter region (field maximum)

Polarimetry with Helium-3

- Main uncertainties in previous best experiment (PERKEO II): statistics, detector, background, polarization
- Superior detector energy resolution, good enough time resolution
- Keep coincidences to improve background
- Statistics @ SNS or NIST is an issue for *A*
- Polarization measurement seems manageable (XSM or He-3)

Summary

- The Nab collaboration is setting up the Nab spectrometer at the Spallation Neutron Source. Start of commissioning planned in summer 2018. Until tomorrow, the big reason for the delay has been the magnet.

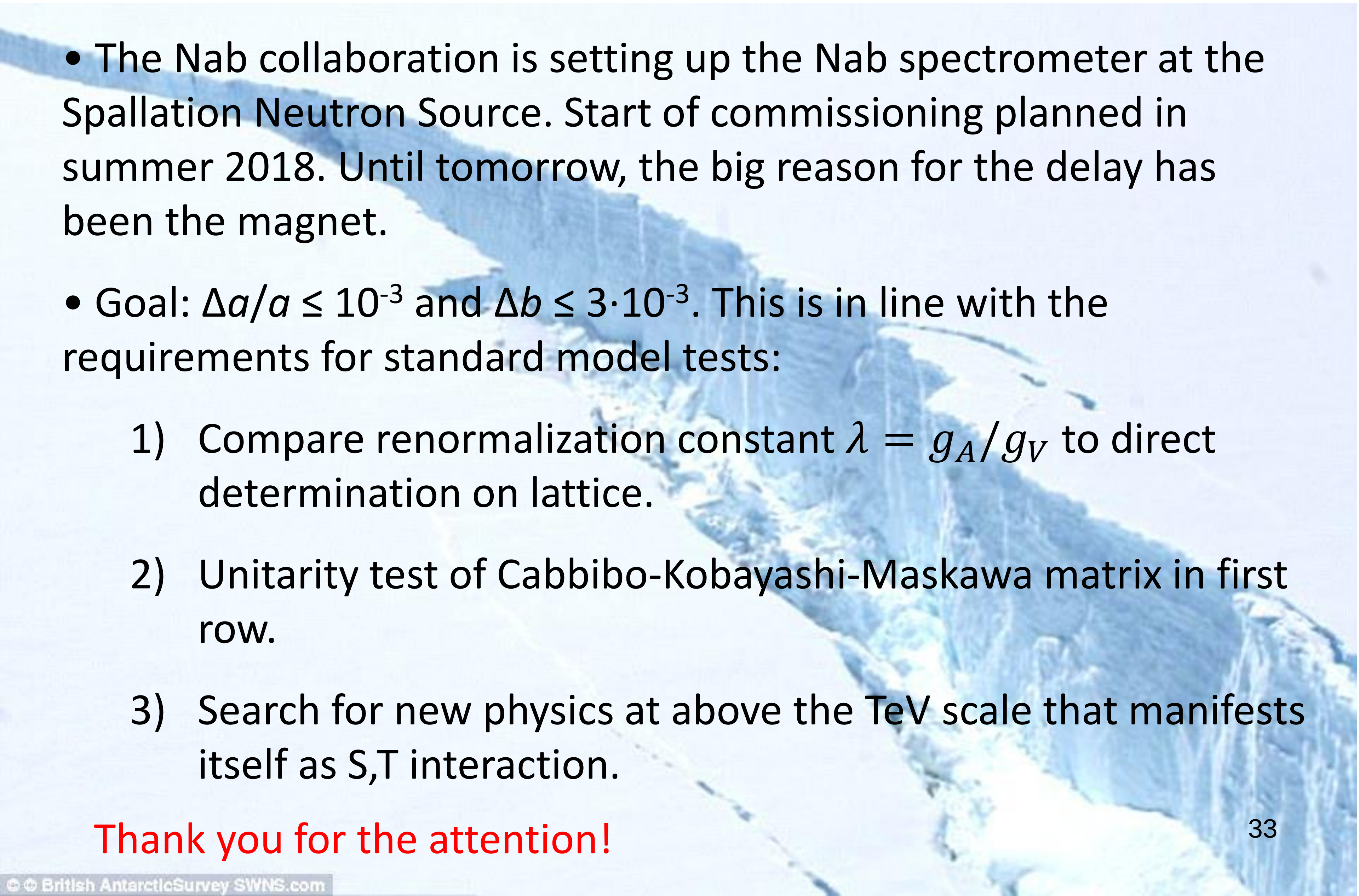
- Goal: $\Delta a/a \leq 10^{-3}$ and $\Delta b \leq 3 \cdot 10^{-3}$. This is in line with the requirements for standard model tests:

  1) Compare renormalization constant $\lambda = g_A/g_V$ to direct determination on lattice.

  2) Unitarity test of Cabbibo-Kobayashi-Maskawa matrix in first row.

  3) Search for new physics at above the TeV scale that manifests itself as S,T interaction.

Thank you for the attention!



© © British AntarcticSurvey SWNS.com