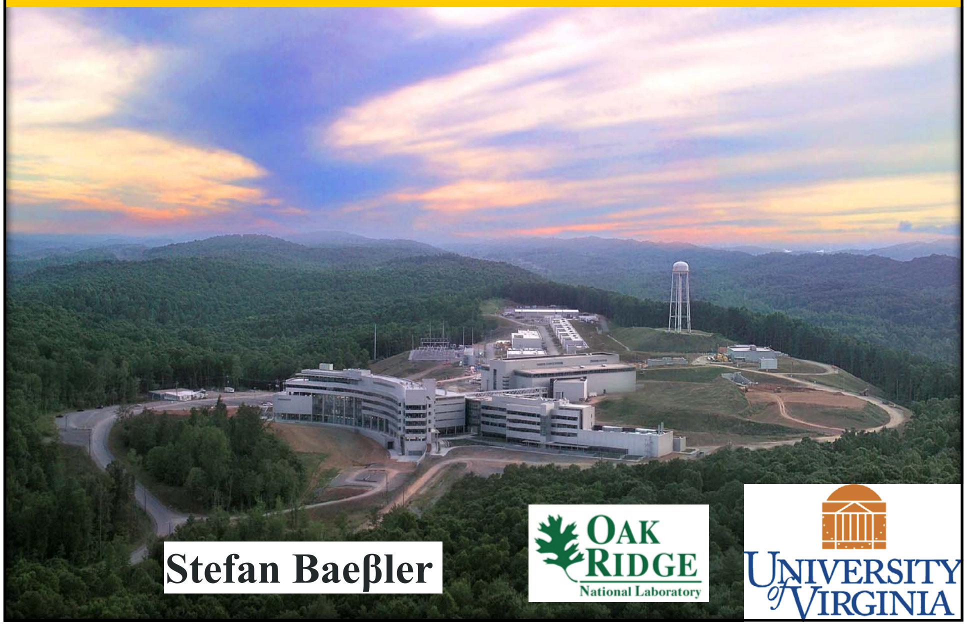
Fundamental Physics with Neutrons



Stefan Baeβler

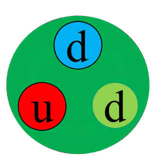
Oak Ridge National Laboratory

University of Virginia

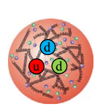
The physicist's view of a neutron

Different physicist's have different views:

For most experiments, it is a point (with some properties: mass and spin).



For neutron beta decay, it has (at least) the structure given by its valence quarks.



With more resolution, more structure appears

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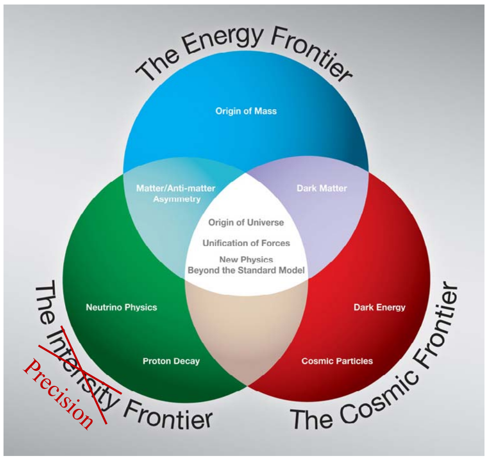
What is our interest?

Answer: We want to find the fundamental laws of physics .

How? Fermilab's view to this is:



David MacFarlane, Director of Particle Physics and Astrophysics division, SLAC

"The Intensity Frontier involves many diverse lower-energy precision experiments; and its discovery potential, being less direct, is therefore harder to understand."

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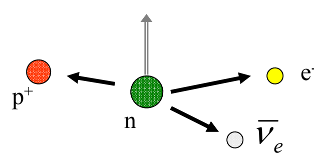

1. Production of Low Energy Neutrons
2. Experiments with Low Energy Neutrons:
   - Neutron Beta Decay
   - Spectroscopy of gravitationally bound quantum states
   - Weak Hadronic Interaction in neutron capture on hydrogen
3. Future plans

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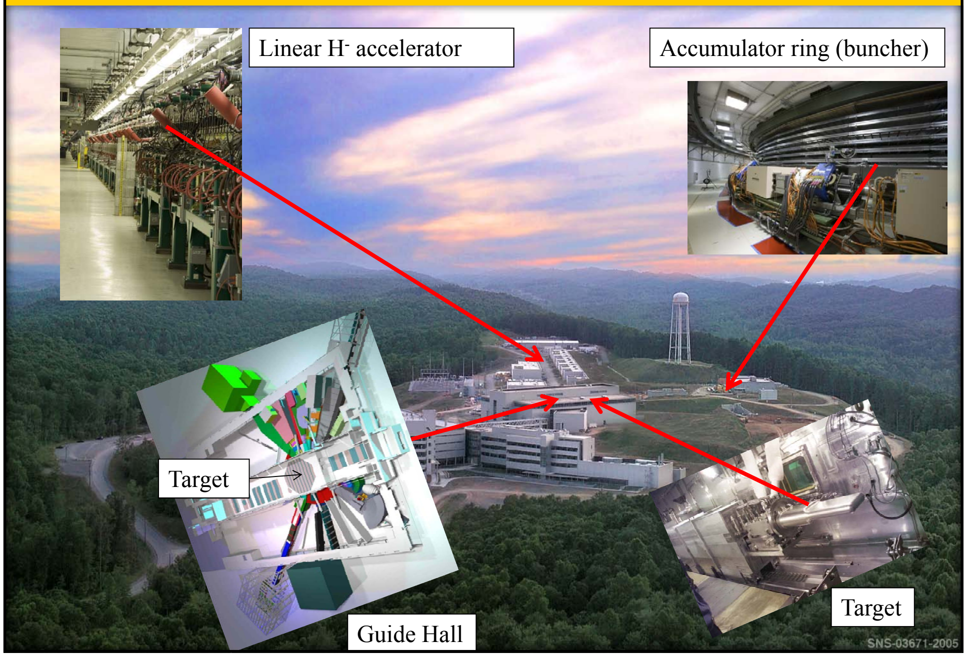
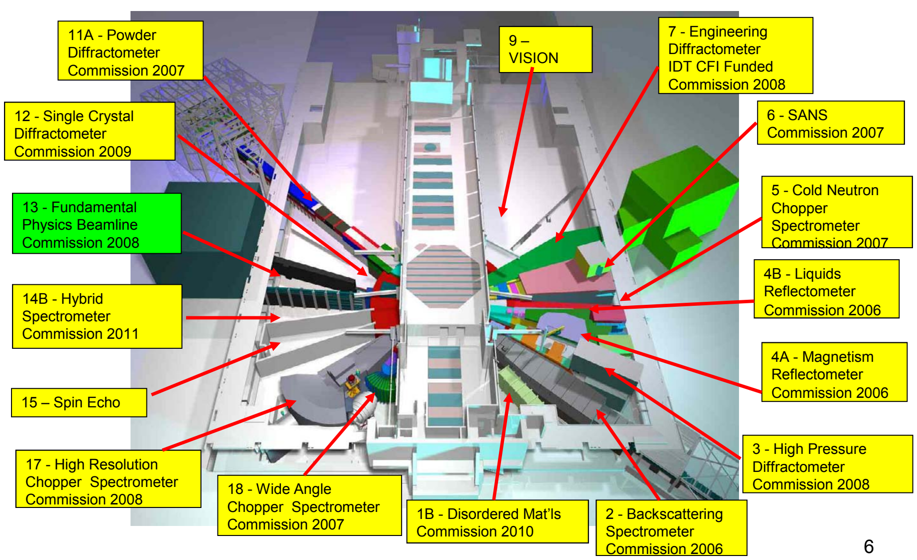
The Spallation Neutron Source SNS in Oak Ridge, TN



Usage of neutrons @ SNS



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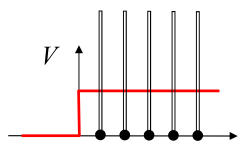
Interactions of low energy neutrons with matter

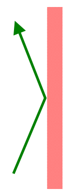
Transport (cold neutrons)

$$V_{\text{Fermi}} = \frac{2\pi\hbar^2}{m_n}\sum_i b_i \delta(x - x_i)$$

$$\lambda \text{ big:} \quad V_{\text{Fermi}} \sim \frac{2\pi\hbar^2}{m_n}\langle nb \rangle$$

$\sim$ 100 neV





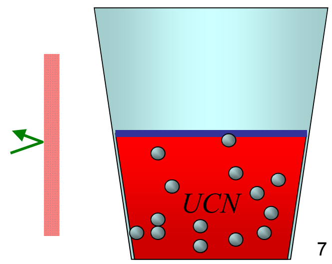
Storage (ultracold neutrons)

Typical properties:

Energy: $E_{\text{UCN}} \sim 100$ neV

Velocity: $v_{\text{UCN}} \sim 5$ m/s

Height: $h_{\text{UCN}} \sim 1$ m



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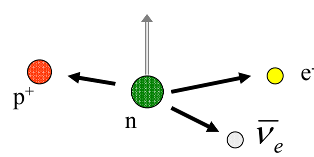

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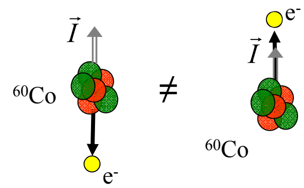
Beta Decay in the Standard Model

Fermi's golden rule:

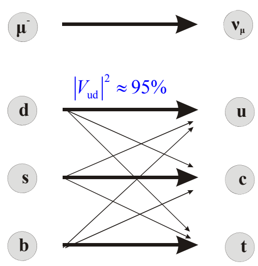
decay probability $\Gamma_{i\to f} = \frac{2\pi}{\hbar}\left|\langle f|H_{\text{weak}}|i\rangle\right|^2 \rho$



Parity Violation found by Wu et al, 1956

$$H_{\text{weak}} = \frac{G_F V_{ud}}{\sqrt{2}} \langle p | 1\cdot\gamma^\mu + \lambda\gamma^\mu\gamma^5 | n\rangle \langle e^- | \gamma_\mu - \gamma_\mu\gamma_5 | \nu_e\rangle + \text{h.c.}$$

1. Quark mixing



2. Nucleon structure effects

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

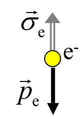
$g_A = G_F \cdot V_{ud} \cdot \lambda$

(No nuclear structure effects)

3. Helicity

… of elementary fermions: $-p/E$,

… of elementary anti-fermions: $+p/E$



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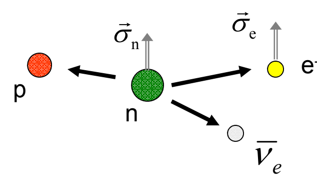
Observables in Neutron Beta Decay

Jackson et al., PR 106, 517 (1957):

Observables in Neutron beta decay, as a function of generally possible coupling constants (assuming only Lorentz-Invariance)



$$d\Gamma \propto \rho(E_e)\cdot\left(1+3|\lambda|^2\right)\cdot\left\{1 + a\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + \vec{\sigma}_n\cdot\left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e\times\vec{p}_\nu}{E_e E_\nu}\right)\right\}$$

Fierz interference term $b = 0$

Beta-Asymmetry $A = -2\frac{|\lambda|^2 + \text{Re}\,\lambda}{1+3|\lambda|^2}$

Neutrino-Electron-Correlation $a = \frac{1-|\lambda|^2}{1+3|\lambda|^2}$

Neutron lifetime $\tau_n^{-1} = \frac{2\pi}{\hbar} G_F^2 V_{ud}^2 \left(1+3|\lambda|^2\right)\int\rho(E_e)$

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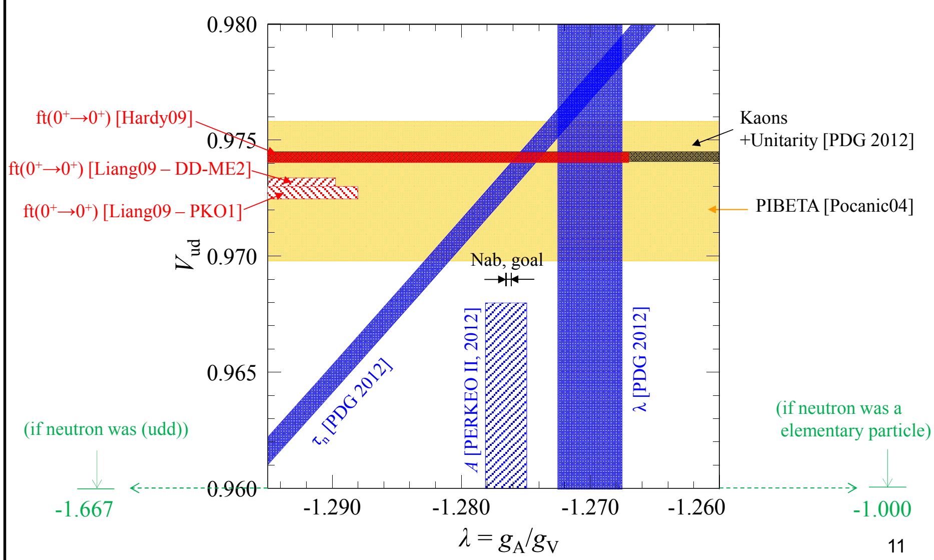
Search for Standard Model Parameters



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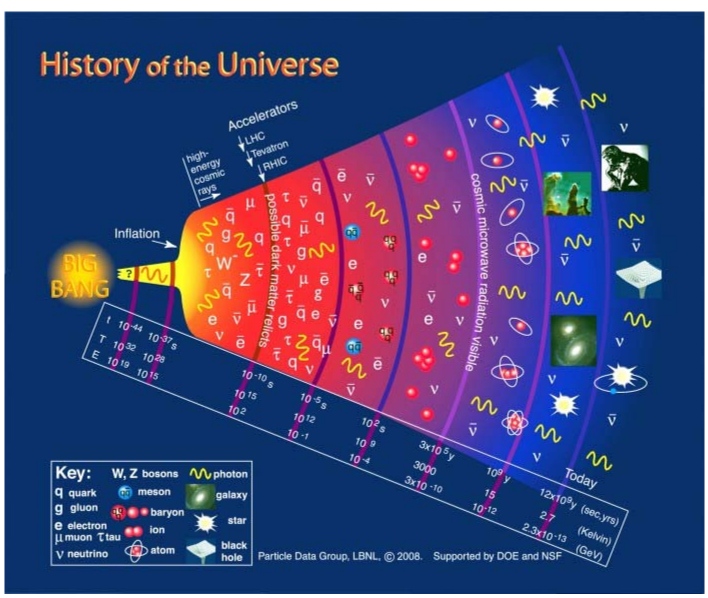

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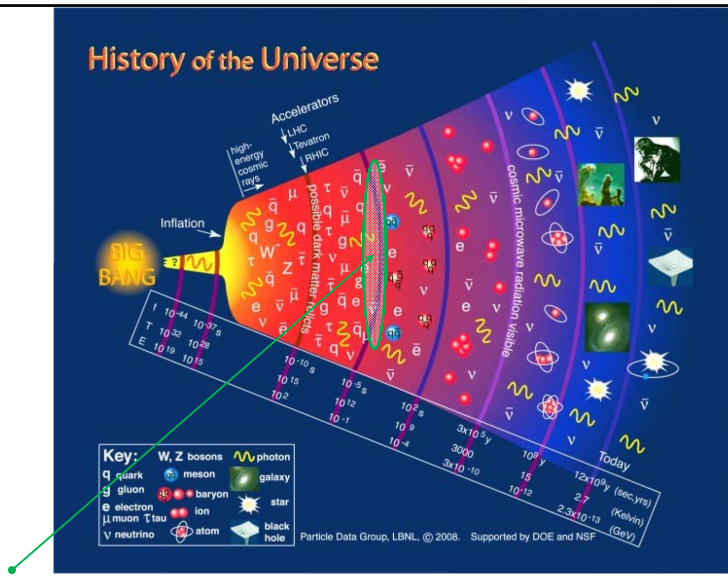

$\boldsymbol{T}$~**1 GeV**: quarks combine to form nucleons: $u+u+d \rightarrow p, u+d+d \rightarrow n, q+\overline{q'} \rightarrow \pi, \rho^0, \ldots$
Problem: If nucleons were formed as many as anti-nucleons (CP-symmetry), nucleons and anti-nucleons would have annihilated and disappeared.
Solution: Need (more) CP violation in theory

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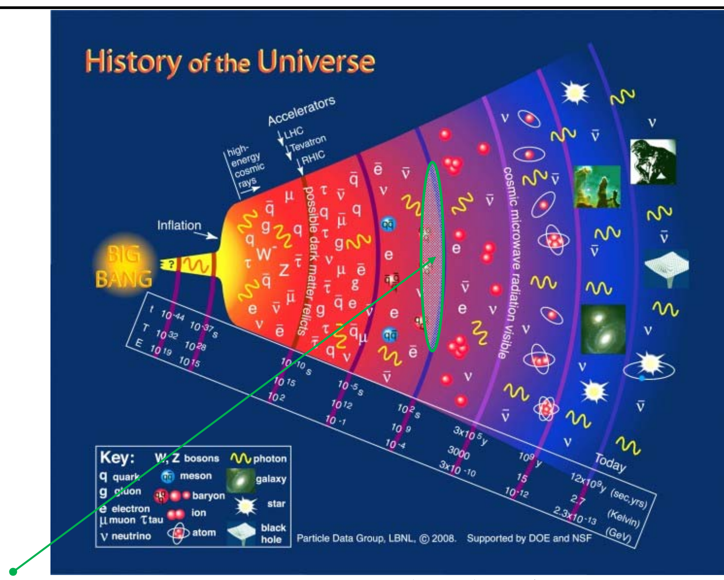
Experiments: Measure electric dipole moments, e.g. of neutron



$\boldsymbol{T} \geq \mathbf{0.3}$ **MeV**: nucleons on thermal equilibrium: $\frac{n}{p} \sim e^{(m_n - m_p)/T} \rightarrow \frac{1}{7}$
$\boldsymbol{T} < \mathbf{0.3}$ **MeV**: heavier nuclei form:

$$p+n \rightarrow d+\gamma, p+d \rightarrow {}^3He+\gamma, n+{}^3He \rightarrow {}^4He+\gamma, \ldots$$

(This is **primordial nucleosynthesis**, it stops at mass 5 and 8)
We find element abundances from nuclear and particle physics!

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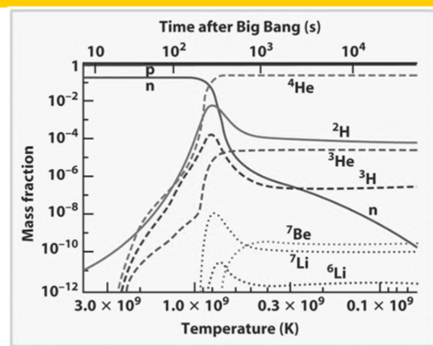
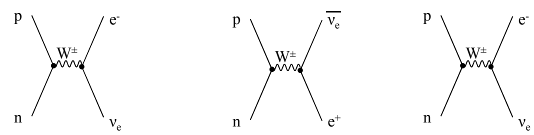
Neutron beta decay data in Primordial Nucleosynthesis



Reactions in equilibrium



$n + \nu_e \leftrightarrow p + e^-$ $\quad n + e^+ \leftrightarrow p + \bar{\nu}_e$ $\quad n \leftrightarrow p + e^- + \bar{\nu}_e$

Experimental input from fundamental physics with neutrons:
Stronger coupling constants in n ↔ p reactions (as determined by neutron lifetime)
⇒ Phase transition later ⇒ nucleon density lower after phase transition ⇒ less ^{4}He, more d

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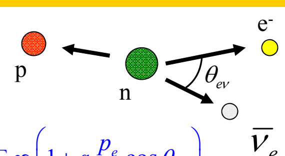
Idea of the cos $\theta_{e\nu}$ spectrometer Nab @ SNS

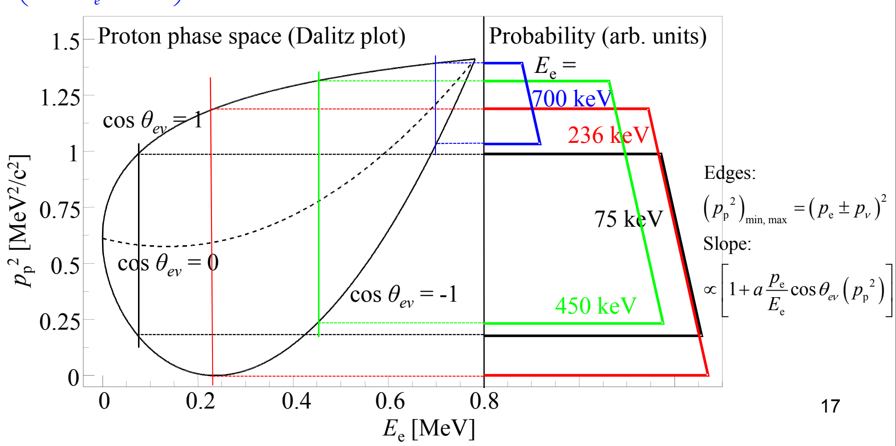


$$d\Gamma \propto \left(1 + a\frac{p_e}{E_e}\cos\theta_{e\nu}\right)$$

Kinematics in Infinite Nuclear Mass Approximation:

- Energy Conservation: $E_\nu = E_{e,\max} - E_e$
- Momentum Conservation

$$p_p^{\,2} = p_e^{\,2} + p_\nu^{\,2} + 2 p_e p_\nu \cos\theta_{e\nu}$$



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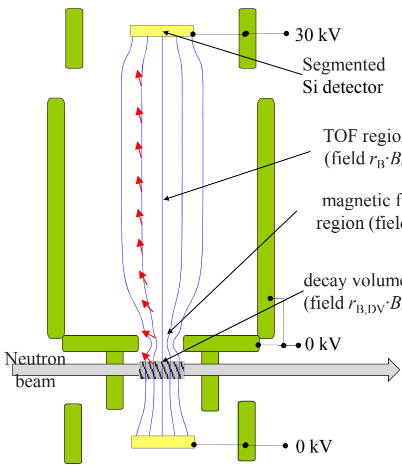
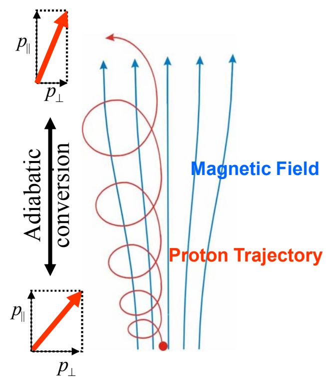
Nab spectrometer principle: measurement of E_e and t_p





- Measurement of E_e and t_p for each event; protons only in upper detector
- Background suppression through coincidences of electron and proton.
- Long flight path improves spectrometer

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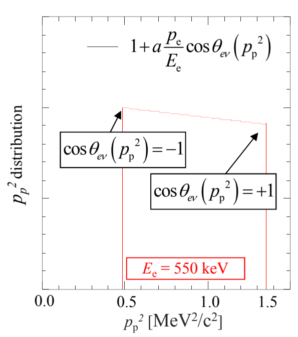
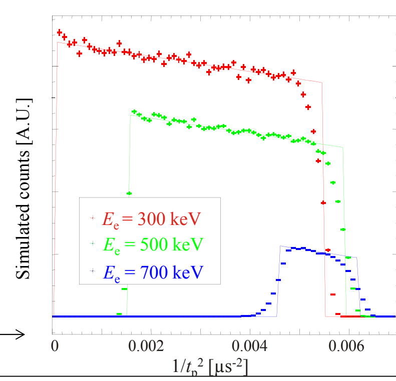
Extraction of *a* in Nab





$$t_p = \frac{m_p}{p_p}\int \frac{dz}{\cos\theta_p(z)}$$

$$\frac{\sin^2\theta_p(z)}{\sin^2\theta_{p,0}} = \frac{B(z)}{B_0}$$

Nab spectrometer simulations:

- J. Brown (2nd prize at Undergraduate Research Symposium 2011), T. Niu, D. van Petten (Mitchell Fellowship), S.B.
- E. Frlez, L. P. Alonzi, D. McLaughlin, D. Pocanic (all UVa)
- J. D. Bowman (ORNL)

and the correlation coefficient *a*.

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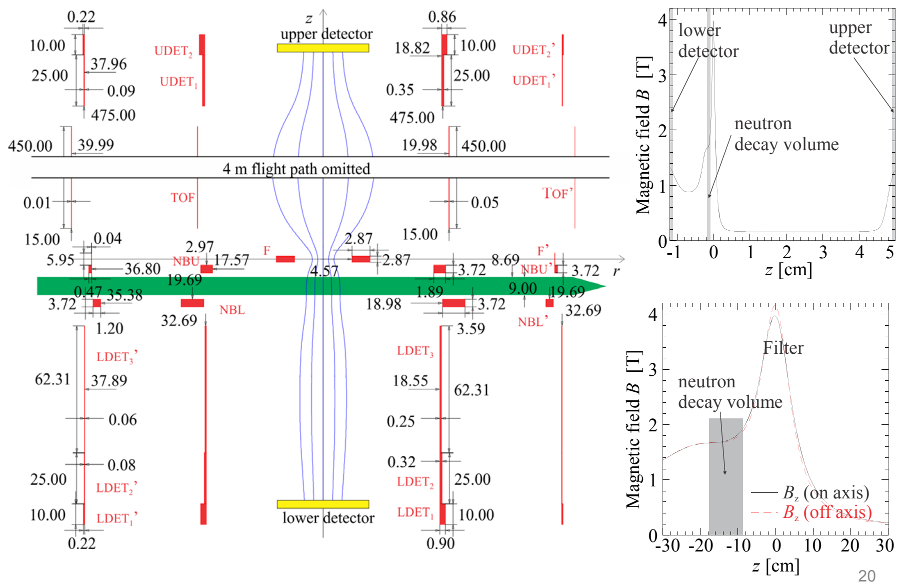
Nab: Spectrometer Magnet System



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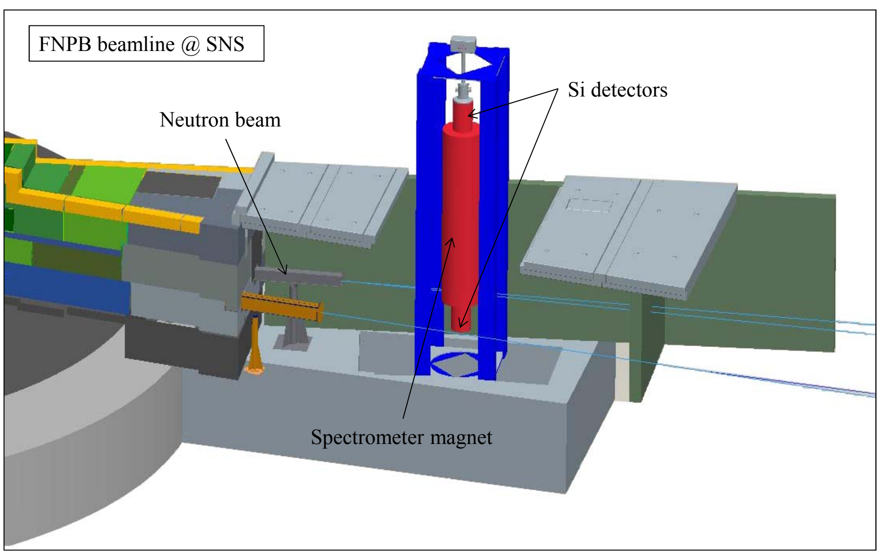
Nab setup at Spallation Neutron Source (SNS)



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Uncertainty budget

PLANNED statistical uncertainty budget:

lower E_e cutoff	none	100 keV	100 keV	300 keV
upper t_p cutoff	**none**	**none**	**40 µs**	**40 µs**
Δ_a	2.4/√N	2.5/√N	2.5/√N	2.6/√N
Δ_a (E_{cal}, l variable)	2.5/√N	2.6/√N	2.7/√N	2.7/√N
Δ_a (E_{cal}, l variable, inner 70% of data)	4.1/√N	4.1/√N	**4.1/√N**	4.1/√N

About 2×10^9 events can be detected in 6 weeks (Decay volume $V = 246$ cm^3, decay density $n_d = 20$ cm^{-3}, 12.7 % of decay protons go to upper detector, 80% duty factor)

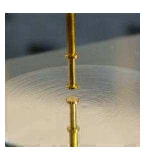
→ $(\Delta a/a)_{stat} < 1\times10^{-3}$ can be reached

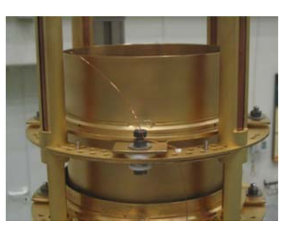
Compare to $\Delta a/a$ = 5 % of existing experimental results

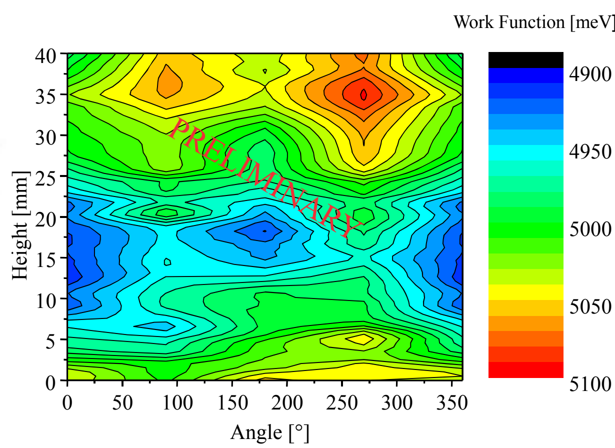
PLANNED systematic uncertainty budget:

Experimental parameter	Systematic uncertainty Δa/a
Magnetic field	
... curvature at pinch	$5\cdot10^{-4}$
… ratio $r_B = B_{TOF}/B_0$	$2.5\cdot10^{-4}$
… ratio $r_{B,DV} = B_{DV}/B_0$	$3\cdot10^{-4}$
Length of the TOF region	(*)
Electrical potential inhomogeneity:	
… in decay volume / filter region	$5\cdot10^{-4}$
… in TOF region	$1\cdot10^{-4}$
Neutron Beam:	
… position	$4\cdot10^{-4}$
… profile (including edge effect)	$2.5\cdot10^{-4}$
… Doppler effect	small
Unwanted beam polarization	can be made small
Adiabaticity of proton motion	$1\cdot10^{-4}$
Detector effects:	
… Electron energy calibration	(*)
… Electron energy resolution	$5\cdot10^{-4}$
… Proton trigger efficiency	$2.5\cdot10^{-4}$
Residual gas	small
Background	small
Accidental coincidences	small
Sum	**$1\cdot10^{-3}$**

Kelvin Probe: First results from early work on *a*SPECT







In collaboration with Prof. I. Baikie, KP Technologies

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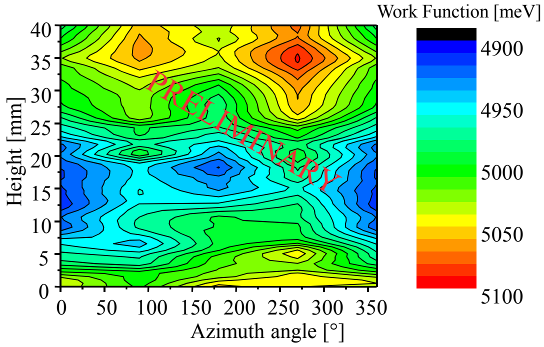
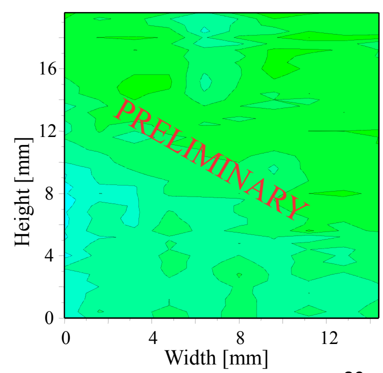
Now: Better coating



In collaboration with Prof. I. Baikie, KP Technologies

(arbitrary offset added)



Thanks to:
Rachel Hodges (undergraduate research prize)
Sean McGovern (M. Sc., 2010)
Henry Bonner,
Xuying Tong
(all UVa)
Gertrud Konrad
(University of Mainz)

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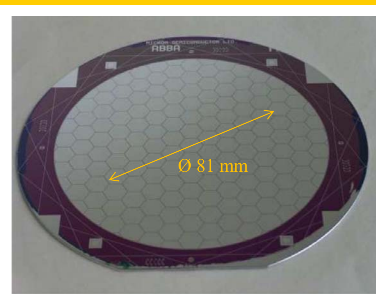
Silicon detector for Nab / abBA / PANDA

Front side



Back side

Segmented ion-implanted silicon detector with fast readout electronics:

- Thickness 2 mm (less for testing)
- Thin dead layer of < 100 nm silicon (measured!):

  Energy loss for 30 keV protons: < 11 keV (measured!)
- 127 channels

  Sufficiently small count rate/pixel,

  Allows to find electron and correlated proton.

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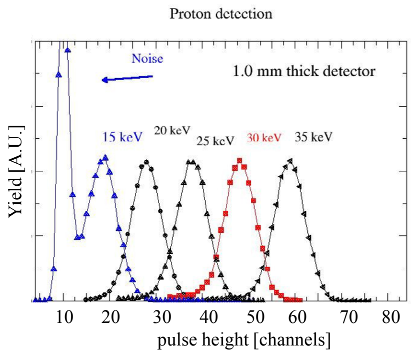
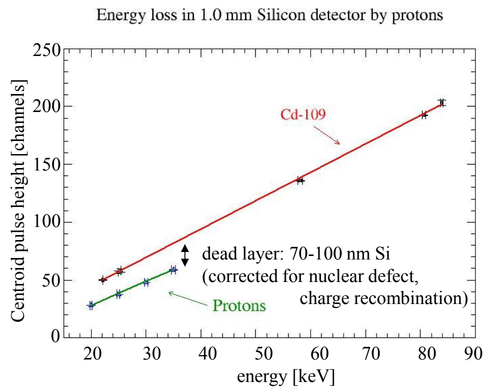
Si detector properties: proton detection





A. Salas-Bacci, P. McGaughey, Dinko Pocanic, S.B. et al @ NCSU proton source (A. Young et al.)

Threshold	lost protons	efficiency slope
8 keV	0.19%	110(30) ppm/keV
10 keV	0.20%	131(31) ppm/keV
12 keV	0.21%	165(32) ppm/keV
14 keV	0.28%	304(76) ppm/keV

For uncertainty in *a*, we assume a threshold of 10 keV and direct measurement of efficiency slope to 50%.

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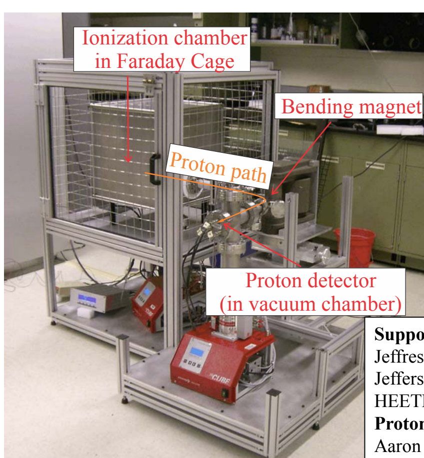
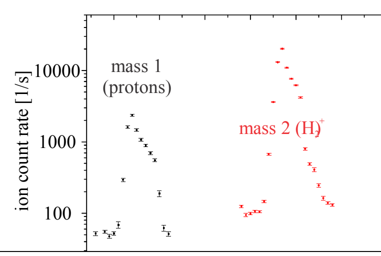
Proton source for detector tests (and advanced lab)



Commissioning results:



Support:
Jeffress Memorial Trust
Jefferson Trust
HEETF
Proton source team:
Aaron Ross (Mitchell fellowship), Ryan Slater, Zia Tompkins,
Americo Salas Bacci, Panaiot Zotev, S.B., Dinko Pocanic
(all UVa)
Martin Schlegel (DAAD fellowship), Y. Kahvaz

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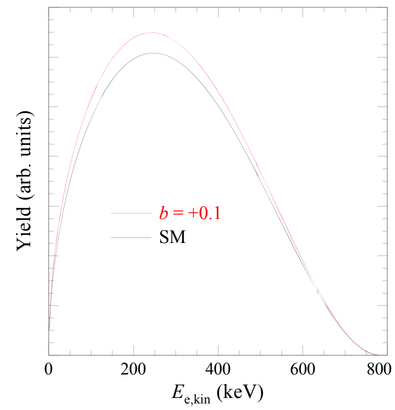
The determination of the Fierz Interference term

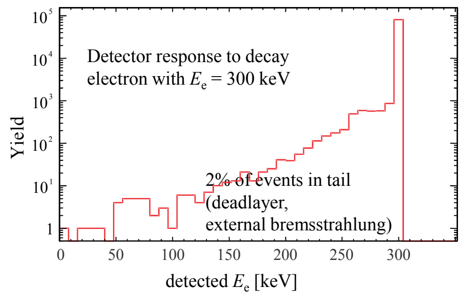
$$dw \propto \rho(E_e) \cdot \left(1 + 3|\lambda|^2\right) \cdot \left\{1 + b\frac{m_e}{E_e}\right\}$$

Electron spectrum:



Systematic uncertainties:

1. Electron energy determination



2. Background

Goal: Δb ~ 3×10⁻³

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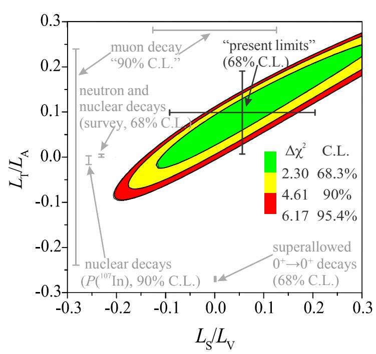
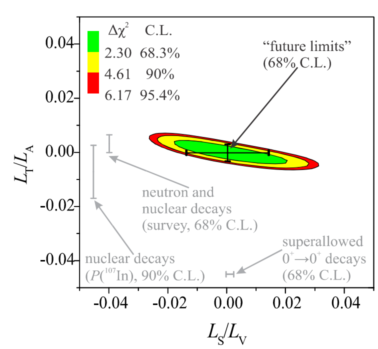
Sensitivity to left-handed S-T couplings



Present limits (n decay data)
SM is in the origin of this plot



Future limits, assuming a = -0.1059(1), A = -0.1186(1) , B = 0.9807(30), C = -0.23785(24), τ_n = 882.2(13) s, b = 0±0.003

Model-dependent predictions: Supersymmetry, leptoquarks, …

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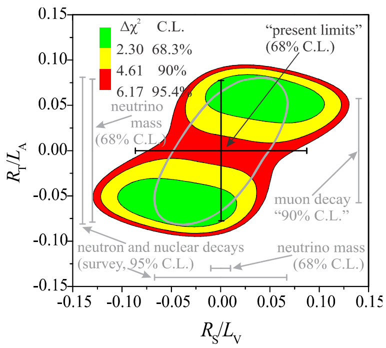
Analysis similar to G. Konrad, S.B. et al., ArXiv:1007.3027

Sensitivity to right-handed S-T couplings



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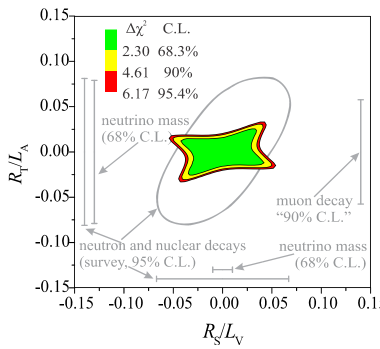

Future limits,
assuming a = -0.1059(1), A = -0.1186(1) ,
B = 0.9807(30), C = -0.23785(24), τ_n = 882.2(13) s

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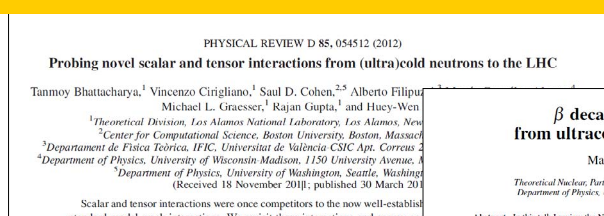
Analysis similar to G. Konrad, S.B. et al., ArXiv:1007.3027

Relevance in the LHC aera



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

Probing novel scalar and tensor interactions from (ultra)cold neutrons to the LHC

Tanmoy Bhattacharya,[1] Vincenzo Cirigliano,[1] Saul D. Cohen,[2,5] Alberto Filipuz…
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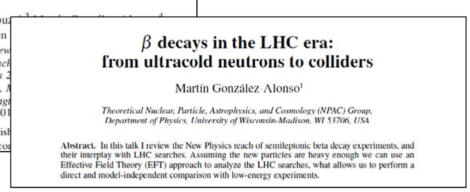
(Received 18 November 2011; published 30 March 201…)

Scalar and tensor interactions were once competitors to the now well-establish… standard model weak interactions. We revisit these interactions and survey co…



β decays in the LHC era: from ultracold neutrons to colliders

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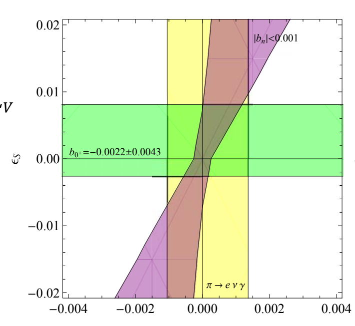
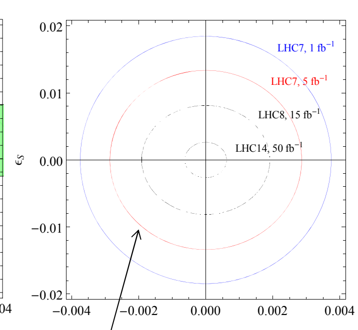
Abstract. In this talk I review the New Physics reach of semileptonic beta decay experiments, and their interplay with LHC searches. Assuming the new particles are heavy enough we can use an Effective Field Theory (EFT) approach to analyze the LHC searches, what allows us to perform a direct and model-independent comparison with low-energy experiments.

$O(1) \cdot L_S/L_V$



$O(1) \cdot L_T/L_A$



CMS-Search for $W' \to l + \nu$ after pp collisions

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The Nab collaboration

R. Alarcon[a], L.P. Alonzi[b] , S.B.[b,c] (Project Manager), S. Balascuta[a], L. Barrón-Palos [n], J.D. Bowman[c] (Co-Spokesmen), M.A. Bychkov[b], J. Byrne[d], J.R. Calarco[e], T. Chupp, T.V. Cianciolo[c], C. Crawford[f], E. Frlež[b], M.T. Gericke[g], F. Glück[h], G.L. Greene[c,i], R.K. Grzywacz[i], V. Gudkov[j], D. Harrison[g], F.W. Hersman[e], T. Ito[k], M. Makela[k], J. Martin[l], P.L. McGaughey[k], S. McGovern[b], S. Page[g], S.I. Penttilä[c] (On-site Manager), D. Počanić[c] (Co-Spokesmen), K.P. Rykaczewski[c], A. Salas-Bacci[b], Z. Tompkins[b], D. Wagner[f], W.S. Wilburn[k], A.R. Young[m]

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Tasks of UVa group: Spectrometer design, Superconducting magnet, Electrodes, Magnetometry, Proton Source

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From the 2011 NSAC report about priorities in "Fundamental Physics with Neutrons"

Scientific Priorities

The principal *scientific* priorities found by the subcommittee, ranked in descending order, are:

- I. The search for a neutron electric dipole moment with the nEDM experiment.
- II. Continuation of the UCNA experiment to obtain improved precision on λ, the ratio of the weak axial-vector to vector coupling constants of the neutron.
- III. Completion of the NPDGamma experiment to obtain a precision measurement of the weak isovector nucleon-nucleon-pion coupling constant.
- IV. Investment in the Nab apparatus with the main goal to determine λ to unprece[…] UCNA.
- V. Continuation of the NIST experiment to perform the most precise cold beam-based measurement of the neutron lifetime.

The only experiment that requires new funding

We estimate that these five high priority initiatives might be accommodated within a scenario of funding at constant level of effort, though moderate additional funding may be required. The ranking indicates the priority with which each effort should be supported, in the event of funding below the constant level of effort. The priority of UCNA and NPDGamma should be considered comparable for this purpose.

(Constant effort is discussed in more detail on a later slide…)

Dec 1, 2011 NSAC Neutron Physics Subcommittee Report 6

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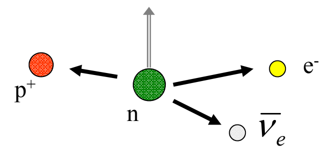

1. Production of Low Energy Neutrons
2. Experiments with Low Energy Neutrons:
   - Neutron Beta Decay
   - Spectroscopy of gravitationally bound quantum states
   - Weak Hadronic Interaction in neutron capture on hydrogen
3. Future plans

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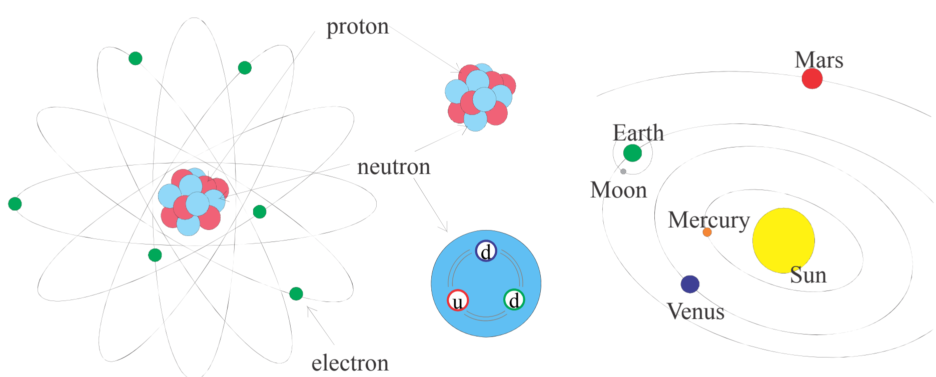
Bound States in Physics



Responsible for binding:
Electromagnetic interaction | Strong interaction | Gravitational interaction

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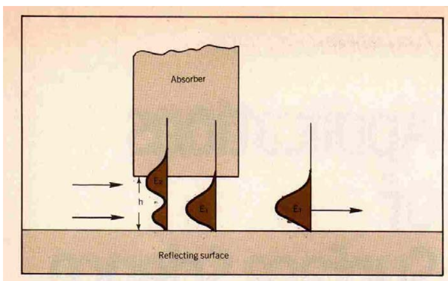
Gravitationally Bound states – The idea

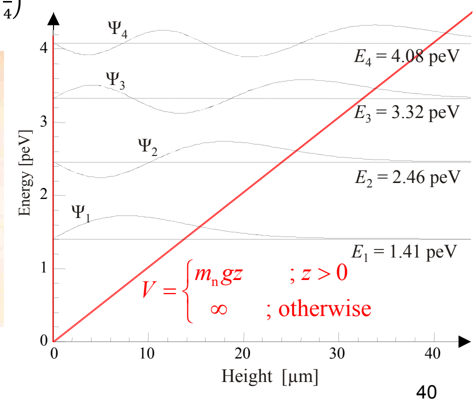
$$-\frac{\hbar^2}{2m_n}\frac{\partial^2}{\partial z^2}\Psi(z) + V(z)\Psi(z) = E_z\Psi(z)$$

$$\Psi(z) \propto \mathrm{Ai}\left(\frac{z-z_k}{l_0}\right);\ z_k = l_0 \cdot \lambda_k;\ E_{z,k} = m_n g l_0 \cdot \lambda_k$$

with $\lambda_k = 2.34, 4.09, 5.52, 6.79, \ldots \sim \frac{3\pi}{2}\left(k-\frac{1}{4}\right)^{2/3}$



V.I. Lushikov,
Physics Today, June 1977



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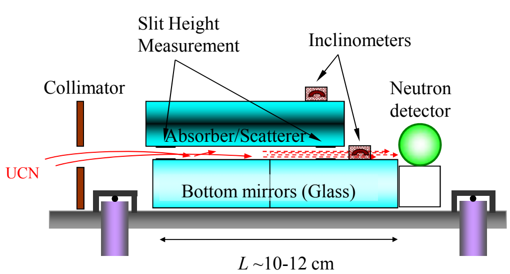
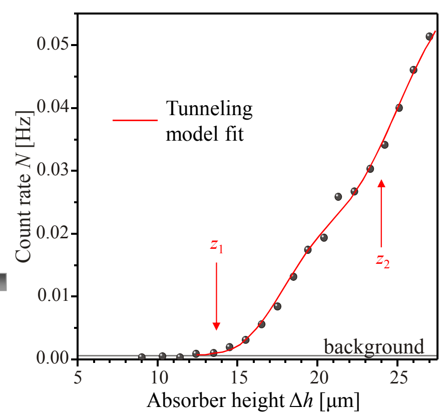
Detection of the size of the quantum states





Results (corrected for non-parallelism):

$z_1 = 12.2 \pm 0.7\text{(stat)} \pm 1.8\text{(syst)}\ \mu\text{m}$

$z_2 = 21.6 \pm 0.7\text{(stat)} \pm 2.2\text{(syst)}\ \mu\text{m}$

Comparison to theory, undisturbed wave functions:

$z_1 = 13.7\ \mu\text{m},\ z_2 = 24.0\ \mu\text{m}$

V.V. Nesvizhevsky, H. Abele, S. B. et al., EPJC 40, 479 (2005)

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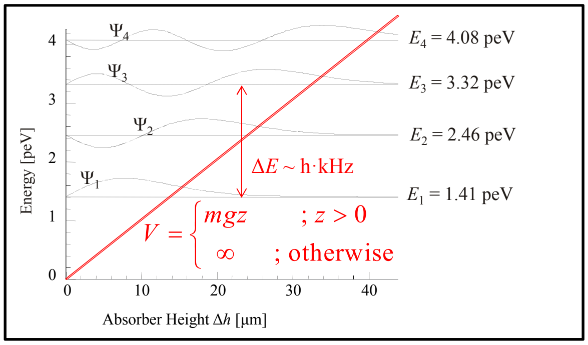
Development of gravity resonance spectroscopy



Accuracy of position-type observables: ~ 10%

Improvement: do **spectroscopy**

Induce state transitions through:

- **Oscillating magnetic field gradients**
- **Vibrations (→ QuBounce, H. Abele et al.)**
- Oscillating Masses

Granit
Gravitational Neutron Induced Transitions

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Resonance transitions = Rabi oscillations

Schroedinger equation: $$H = \underbrace{\frac{\hbar^2}{2m_n}\frac{\partial^2}{\partial z^2} + m_n g z}_{H_0\text{, defines } |N\rangle\text{ , } E_N = \hbar\omega_N} + V(z)\cdot\cos\omega t$$

Ansatz: $$|\psi(t)\rangle = \sum_{N=1} a_N(t) e^{-i\omega_N t} |N\rangle \quad \text{with } H_0|N\rangle = \hbar\omega_N |N\rangle$$

Insert in Schroedinger equation, restrict to 2 states "1" and "3":

$$\hbar\Omega_{13} = \langle 1|V(z)|3\rangle \qquad \omega_{13} = \omega_3 - \omega_1 \qquad \hbar\Omega_{11} = \langle 1|V(z)|1\rangle$$

$$i\hbar\frac{da_3(t)}{dt} = \Omega_{13} a_1(t) e^{-i\omega_{13}t}\cos\omega t + \Omega_{33} a_3(t)\cos\omega t$$

$$\hbar\Omega_{33} = \langle 3|V(z)|3\rangle$$

$$i\hbar\frac{da_1(t)}{dt} = \Omega_{13} a_3(t) e^{+i\omega_{13}t}\cos\omega t + \Omega_{11} a_1(t)\cos\omega t$$

Neglect fast self coupling and fast oscillating terms:

Rabi formula: $$P_{3\to 1}\left(\tau_{\text{passage}}\right) = \Omega_{13}^2 \frac{\sin^2\left(\sqrt{(\omega-\omega_{13})^2 + \Omega_{13}^2}\,\frac{\tau_{\text{passage}}}{2}\right)}{(\omega-\omega_{13})^2 + \Omega_{13}^2}$$

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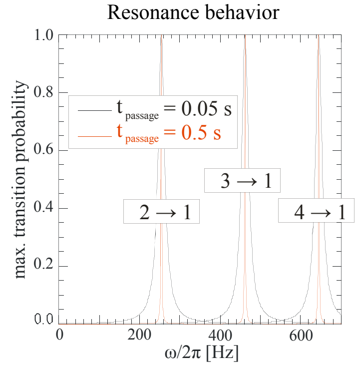
Resonance transitions = Rabi oscillations

Rabi formula:

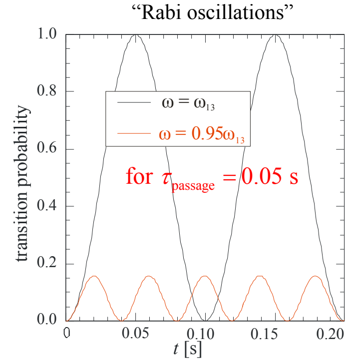
$$P_{3\to 1}\left(\tau_{passage}\right)=\Omega_{13}{}^{2}\,\frac{\sin^{2}\left(\sqrt{\left(\omega-\omega_{13}\right)^{2}+\Omega_{13}{}^{2}}\;\frac{\tau_{passage}}{2}\right)}{\left(\omega-\omega_{13}\right)^{2}+\Omega_{13}{}^{2}}$$

Transition probability at maximum for $\omega=\omega_{13}$ and $\Omega_{13}\cdot\tau_{passage}=\pi$

Resonance behavior



"Rabi oscillations"



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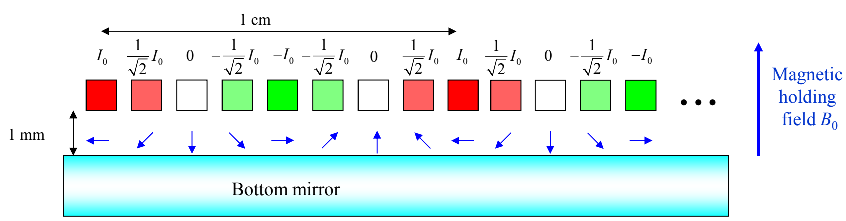
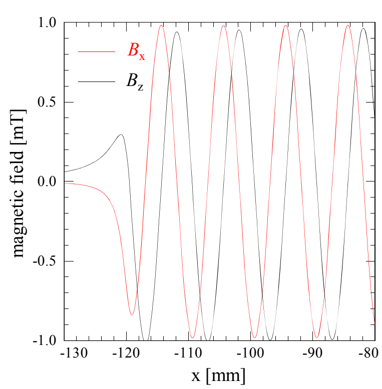
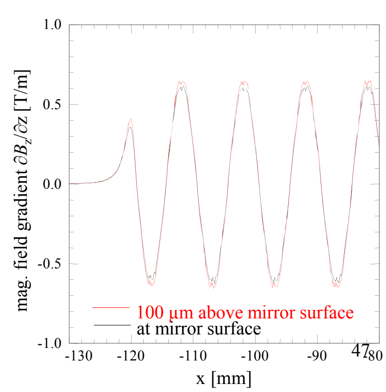
Oscillating potential: Fluctuating magnetic field







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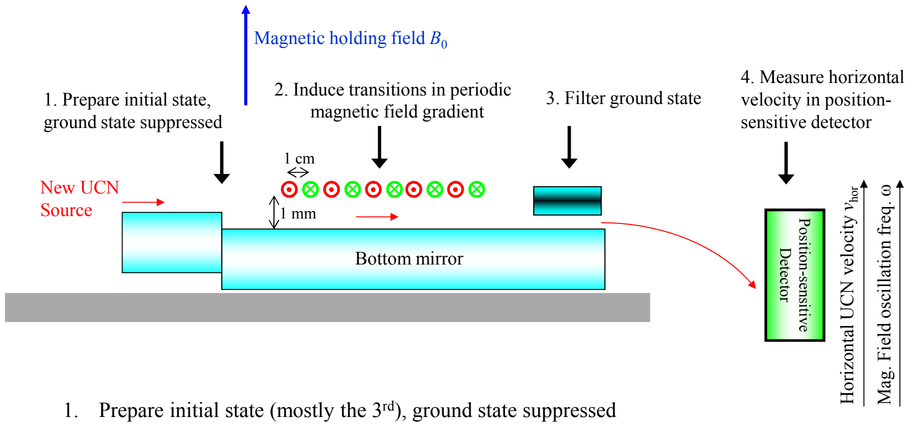
First setup to detect magnetically induced resonance transitions in flow-through mode



1. Prepare initial state (mostly the 3rd), ground state suppressed
2. Induce Transitions 3→1 in time-dependent magnetic field gradient
3. Filter ground state
4. Detect neutrons in dependence of free fall height

   (corresponding to horizontal velocity, corresponding to oscillation frequency)

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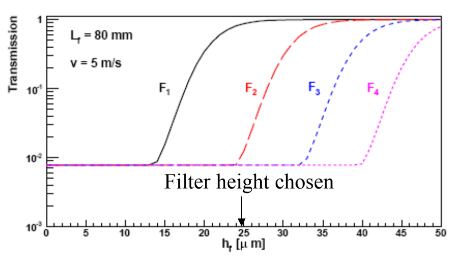
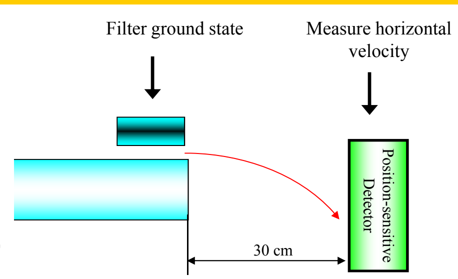
Velocity-selective detection



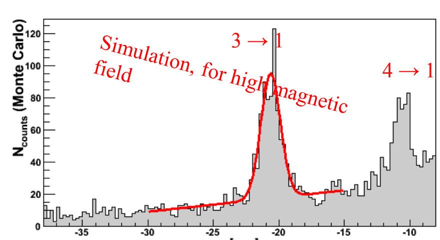


Monte-Carlo-Simulation, takes into account:

- 10000 incoming neutrons per incoming state
- Background: 10% in ground state
- Filter: 80 mm long, slit height: 25 µm
- Wave function evolves in free fall
- Detector resolution: 0.2 mm

Not simulated: Interference effects, Stern-Gerlach shift

Main systematic effect: Geometry



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G. Pignol et al., Thesis UJF Grenoble, 2009

Systematic effects

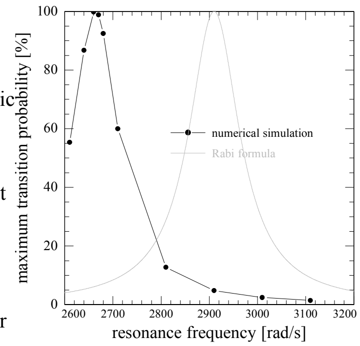
- **3D description**
  The previous discussion assumes time-dependent fields (so: reference frame of the incoming neutron). In reality, loss of energy in the vertical component is transferred into gain of energy in the horizontal component. We have proven that at estimated precision of $\Delta\omega_{13}/\omega_{13} \sim 10^{-3}$, both descriptions are equivalent.

S.B. et al., CRP 12, 707 (2011)

- **Depolarization:**
  Need magnetic holding field of $B_0 = 13$ Gauss in order to stabilize spin.
- **Stern-Gerlach shift:**
  At moderate magnetic field, interplay between magnetic holding field $\overrightarrow{B_0}$ and rotating field with amplitude $|\vec{B}|$ and associated field gradient $\frac{\partial B_z}{\partial x}$ with amplitude β_x leads to spin-dependent frequency shift, that to the first non-vanishing order is given as

$$\Delta\omega_{13}/\omega_{13} \sim \pm \frac{\hbar\gamma_n}{6m_n g}\beta_x \cdot \frac{B}{B_0} + \cdots$$

  The sign of this term depends on the spin state, and our system can act as a UCN polarizer.
  In addition, the there is a slowing down of the transition frequency.



S.B. et al., to be published

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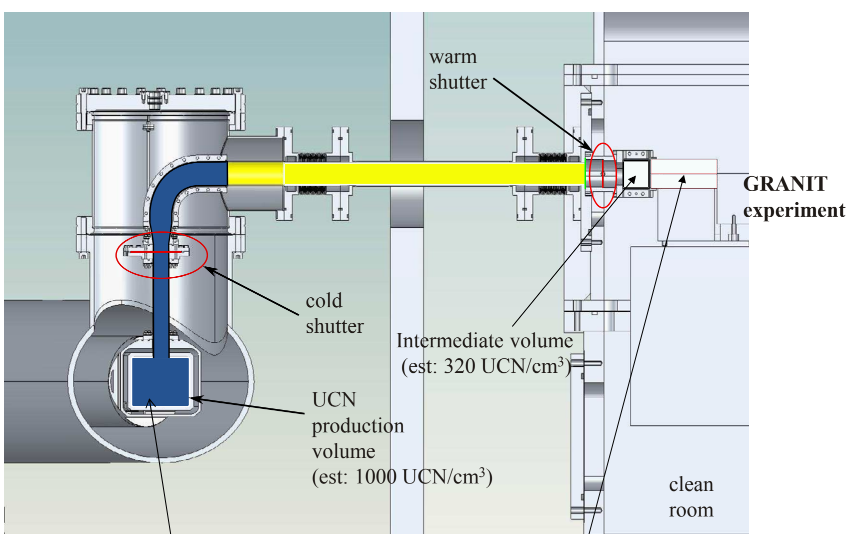
Installation of GRANIT: New UCN Source



O. Zimmer et al, arXiV:0708.1373v2

O. Zimmer et al, PRL 107, 134801 (2011)

Collimator channel optimization:
A. Mietke, V. Nesvizhevsky, S.B., et al., CRP 12, 729 (2012)

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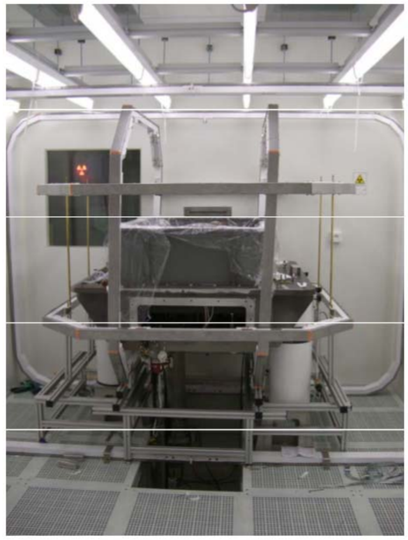
Installation of GRANIT: In the clean room



UVa contributors:
J. Prince, A. Mietke (DAAD fellowship), D. Morton, S.B. (vice spokesperson)

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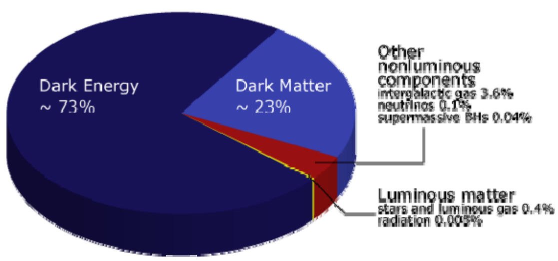
probably dual use, interest for a UCN reflectometer

Search for Chameleon fields



Quintessence: Hypothetical scalar field φ that explains the accelerated expansion of the universe.

E.g., Potential density $V(\varphi) = \text{const} + \frac{\Lambda^{4+n}}{\varphi^n} + \ldots$ with $\Lambda = 2.4$ meV, $\varphi = \varphi(t)$

Chameleon field: Scalar field of the type above, position dependent, with a hypothetical coupling to matter (density ρ) of the type:

$$V(\varphi) = \text{const} + \frac{\Lambda^{4+n}}{\varphi^n} + \frac{\beta}{M_{Pl}}\rho\varphi \text{ with } \varphi = \varphi(t, \vec{x})$$

Relevant properties:
- Non-linear interaction, no superposition principle
- Self-shielding of macroscopic bodies: only outer shell of macroscopic bodies contributes to the force between macroscopic bodies (this evades constraints from torsion balance experiments)

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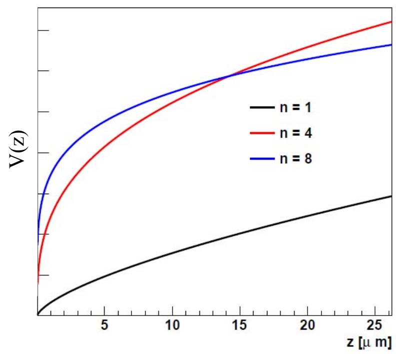
Search for Chameleon fields

Chameleon field above mirror, for high β:

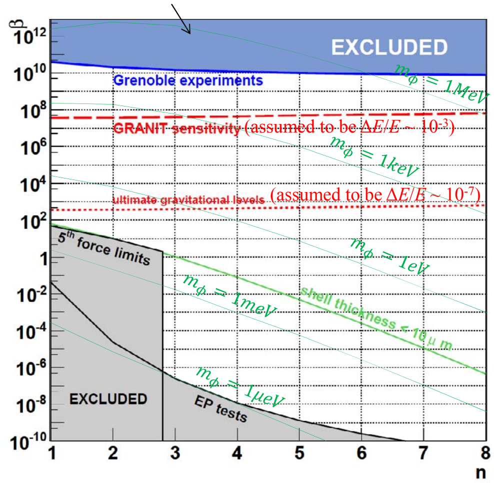
$$\varphi(z) = \Lambda\left(\frac{\Lambda z}{\hbar c}\right)^{2/2+n}$$

Consequence:

$$V(z) = \frac{\beta}{M_{\mathrm{Pl}}} m\varphi$$



Excluded, high β would cause extra quantum state of UCN



P. Brax, G. Pignol, PRL 107, 111301 (2011)

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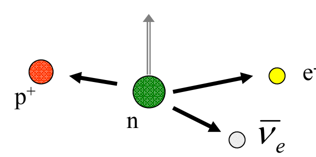

1. Production of Low Energy Neutrons
2. Experiments with Low Energy Neutrons:
   - Neutron Beta Decay
   - Spectroscopy of gravitationally bound quantum states
   - Weak Hadronic Interaction in neutron capture on hydrogen
3. Future plans

Granit

Gravitational Neutron Induced Transitions

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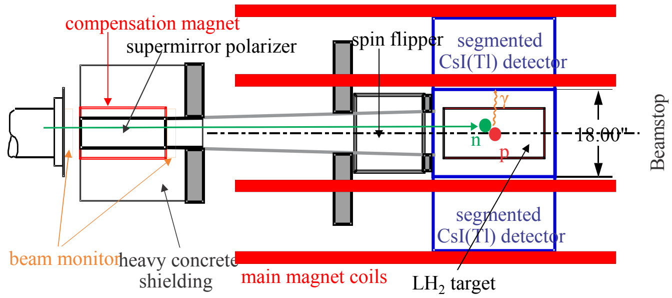
npdgamma

Weak Hadronic Interaction in neutron capture on hydrogen:



UVa contribution:
- A. Mietke, J. Schaedler, S. Schroeder (DAAD fellowships), J. Prince, S.B. (EC member and magnetic field subsystem manager)
- E. Askanazi, J. Hall, E. Frlez, D. Pocanic

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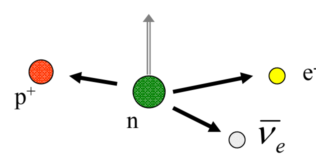

1. Production of Low Energy Neutrons
2. Experiments with Low Energy Neutrons:
   - Neutron Beta Decay
   - Spectroscopy of gravitationally bound quantum states
   - Weak Hadronic Interaction in neutron capture on hydrogen
3. Future research plans:
   - G-2: Responsibility for trolley magnetic field measurement in g-2 at Fermilab
   - nEDM: Purification of Helium, PULSTAR
   - Nab: can be used with polarized neutron beam (abBA, PANDA), ~2020
   - GRANIT: Use trapping mode to achieve ultimate accuracy

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Summary

- Fundamental physics with neutrons has many ways to make important discoveries
- Precision measurements take time
- Nab experiment promises to determine the coupling constants of weak interaction with high precision, allowing for Standard Model Tests and Searches for "Beyond the Standard Model"-physics
- GRANIT looks for new short-range interactions.

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