Hadronic Parity Violation with Cold Neutrons

Three experiments (at the SNS):

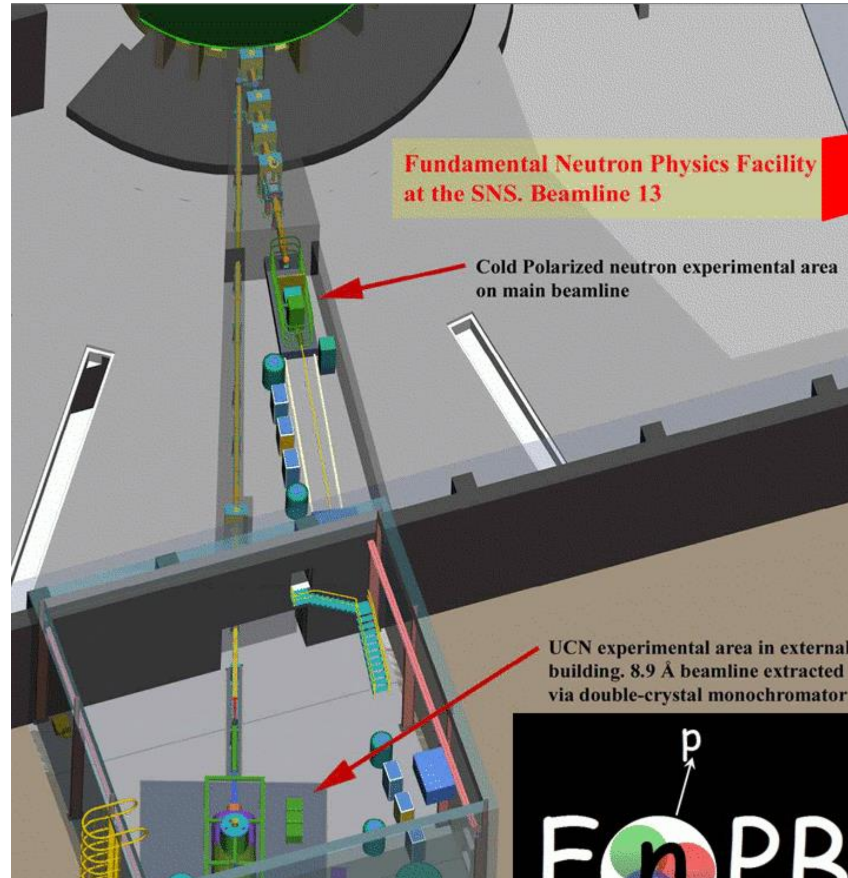
NPDGamma:
Transversely polarized cold neutrons on hydrogen – looks for a directional asymmetry in the number of γ-rays, after decay: $n + p \rightarrow d + \gamma$

n3He:
Longitudinally polarized cold neutrons on helium 3 – looks for a directional asymmetry in the number of protons after breakup: $n + {}^{3}He \rightarrow t + p$

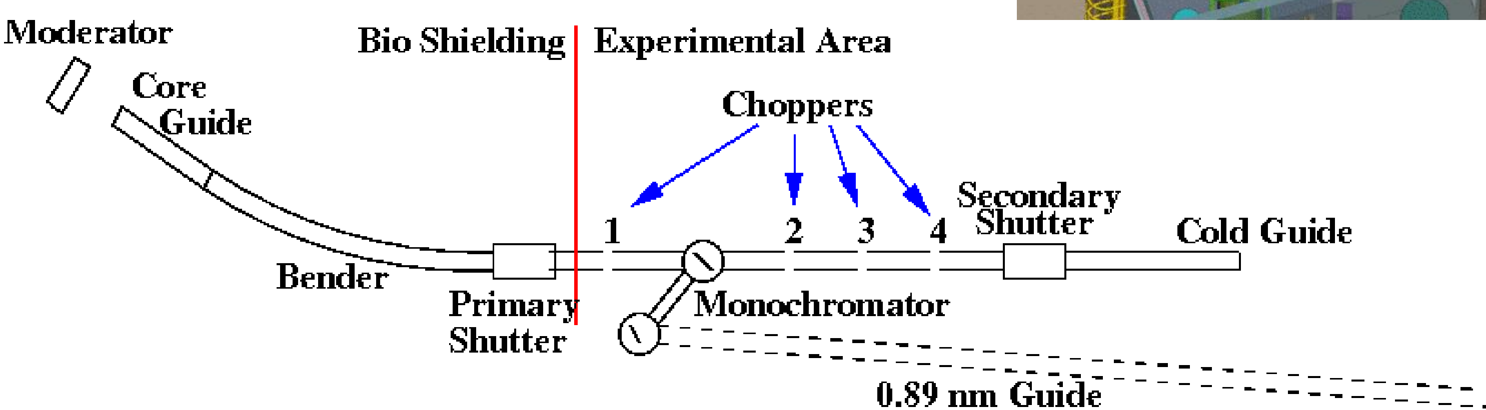
Nab:
Cold neutron beta decay at the SNS. Measuring "little a" and "little b" to high precision, as a test for BSM, and CKM unitarity.

Spallation Neutron Source (SNS)

The Fundamental Neutron Physics Beam (FnPB)

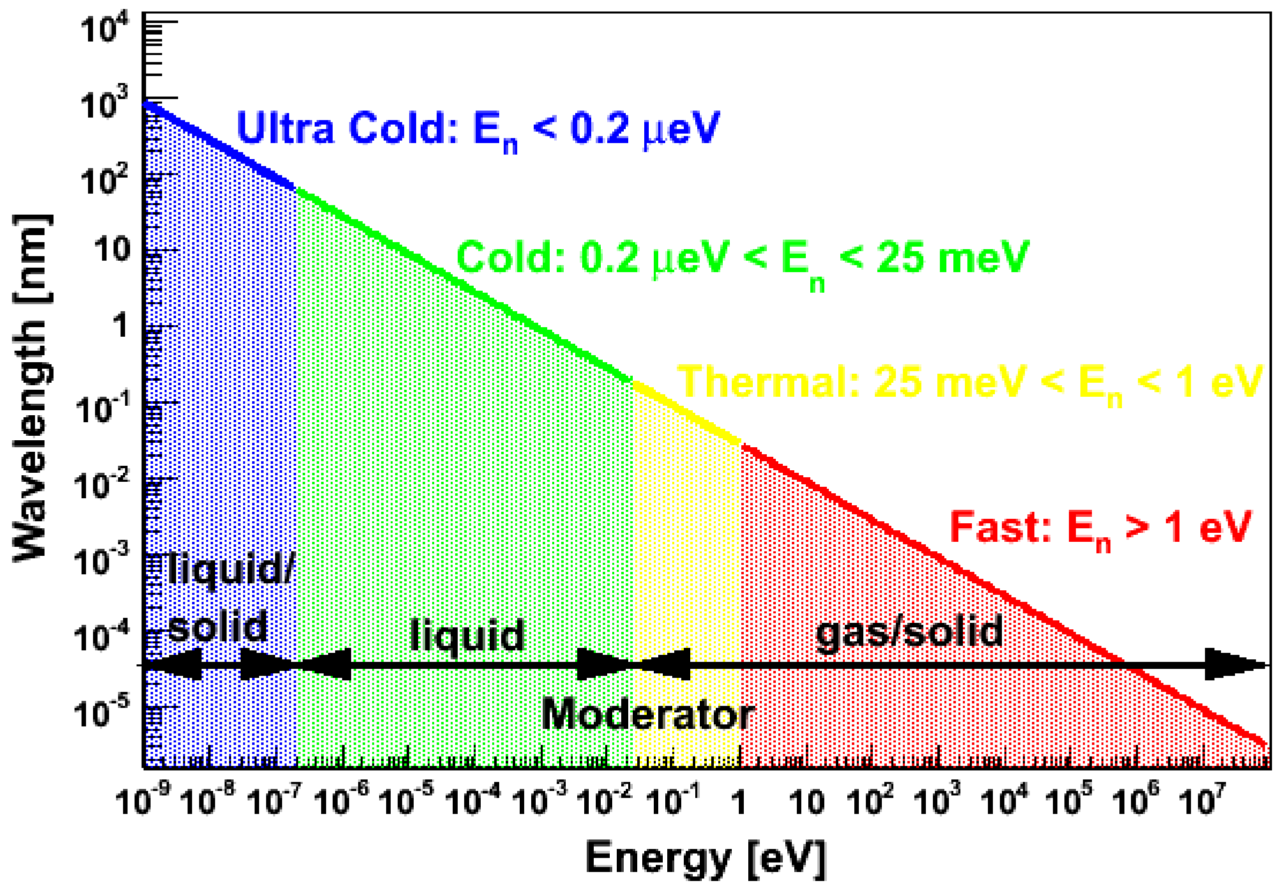


- LH2 moderator
- 17 m long guide ~ 20 m to experiment
- one polyenergetic cold beam line
- one monoenergetic (0.89 nm) beam line
- ~ 40 m to nEDM UCN source
- 4 frame overlap choppers
- 60 Hz pulse repetition



FnPB has a Cold Moderator

$$\lambda \approx \frac{29}{\sqrt{E_k}} fm$$



$$E_k = \frac{\hbar^2 k^2}{2M_n} = k_B T \quad , \quad k = 43.4\sqrt{E_k[MeV]} \;\; MeV/c$$

The NPDGamma

$$\vec{n} + p \rightarrow d + \gamma$$

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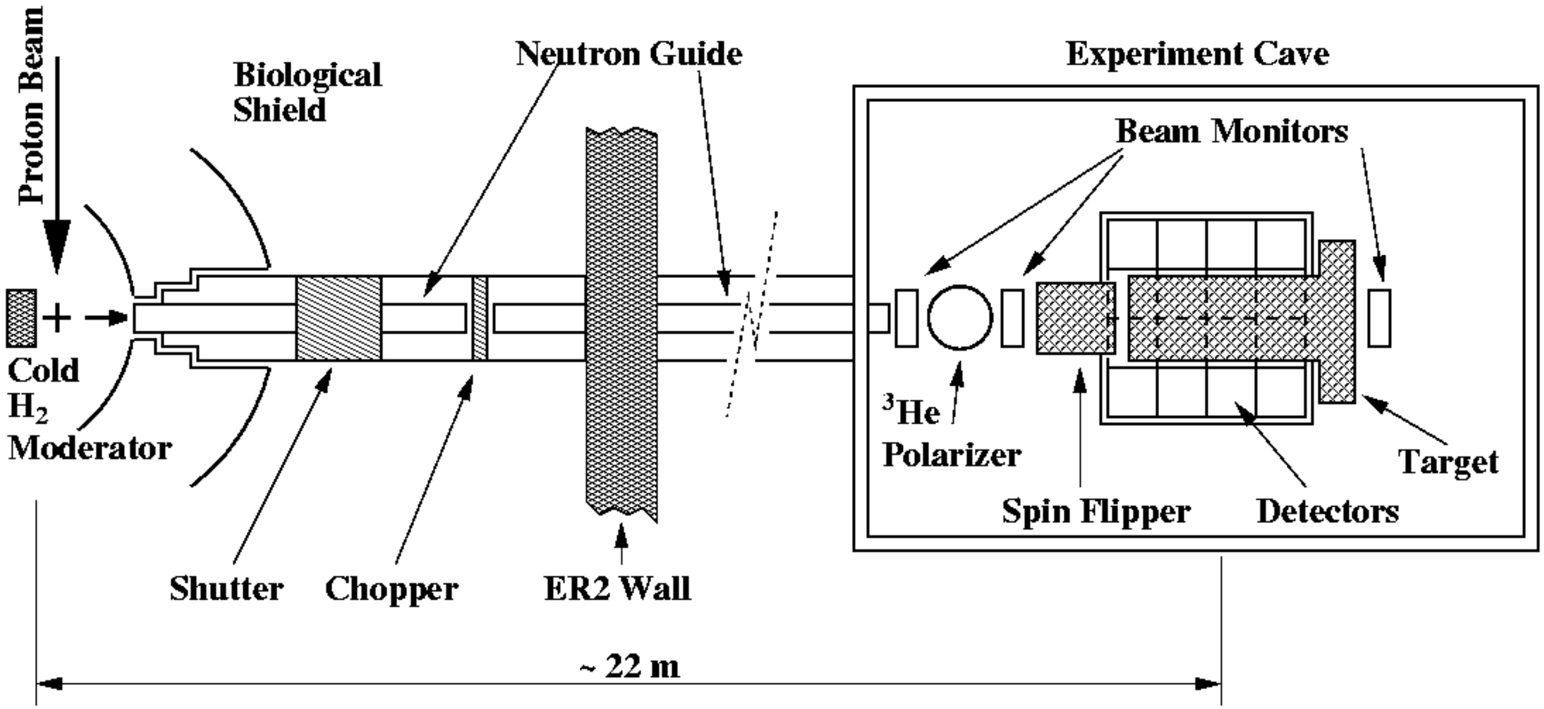
1 Arizona State University
2 Universidad Nacional Autonoma de Mexico
3 University of Virginia
4 Oak Ridge National Laboratory
5 Thomas Jefferson National Laboratory
6 National Institute of Standards and Technology
7 Univeristy of Michigan, Ann Arbor
8 University of Kentucky
9 University of New Hampshire
10 Los Alamos National Laboratory
11 Indiana University
12 University of Tennessee
13 University of California at Berkeley
14 University of Manitoba, Canada
15 KEK, Japan
16 Hamilton College
17 PSI, Switzerland
18 Spallation Neutron Source
19 UC Davis
20 TRIUMF, Canada
21 Bhabha ARC, India
22 Duke University
23 JINR, Dubna, Russia
24 University of Dayton
25 Western Kentucky University

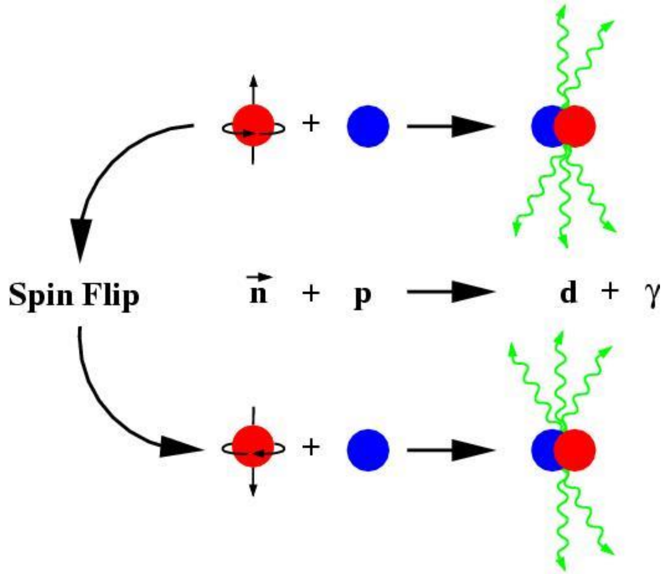
Experimental Setup

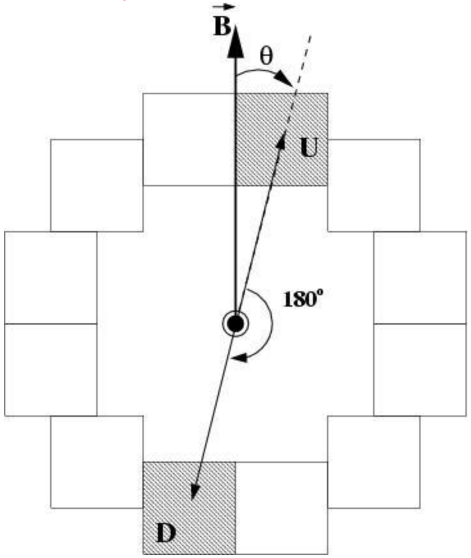
1) Spallation Target
2) Moderator
3) Neutron Beam Line / Guide
4) Neutron Beam Shutter
5) Beam Chopper
6) Neutron Beam Monitors
7) ^{3}He Neutron Spin Filter
8) Neutron Spin Flipper
9) Target
10) Detectors



The NPDGamma Observable

The main NPDGamma observable is the up-down asymmetry in the angular distribution of gamma rays with respect to the neutron spin direction:



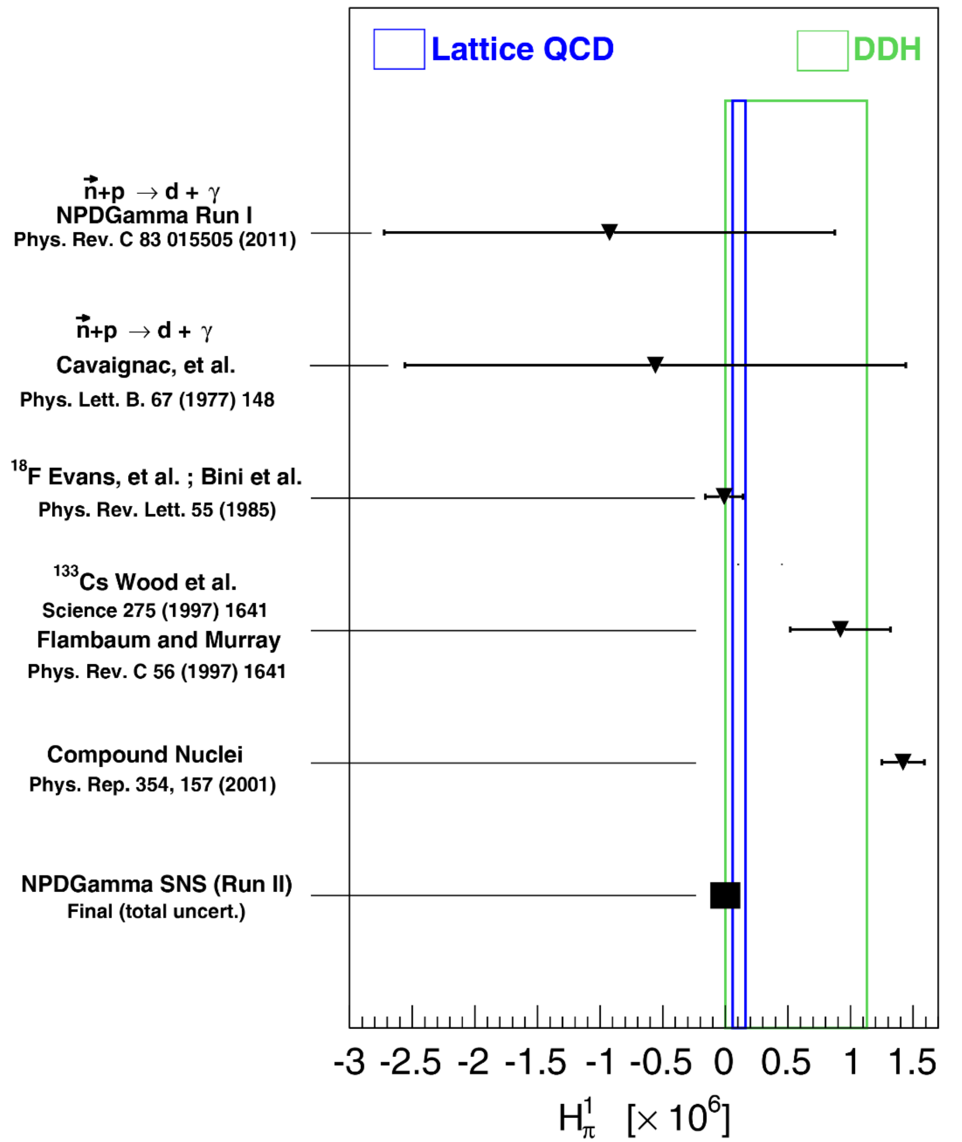


$$A_{raw} = (P_n F_n D_n G) A_\gamma \cos\theta = \frac{1}{2}\left(\frac{\sigma_U^\uparrow - \sigma_D^\uparrow}{\sigma_U^\uparrow + \sigma_D^\uparrow} + \frac{\sigma_U^\downarrow - \sigma_D^\downarrow}{\sigma_U^\downarrow + \sigma_D^\downarrow} \right)$$

DDH: $$A_\gamma = -0.107 H_\pi^{\Delta I=1} \approx -0.107 \times 12 \times g_\pi = -5 \times 10^{-8}$$

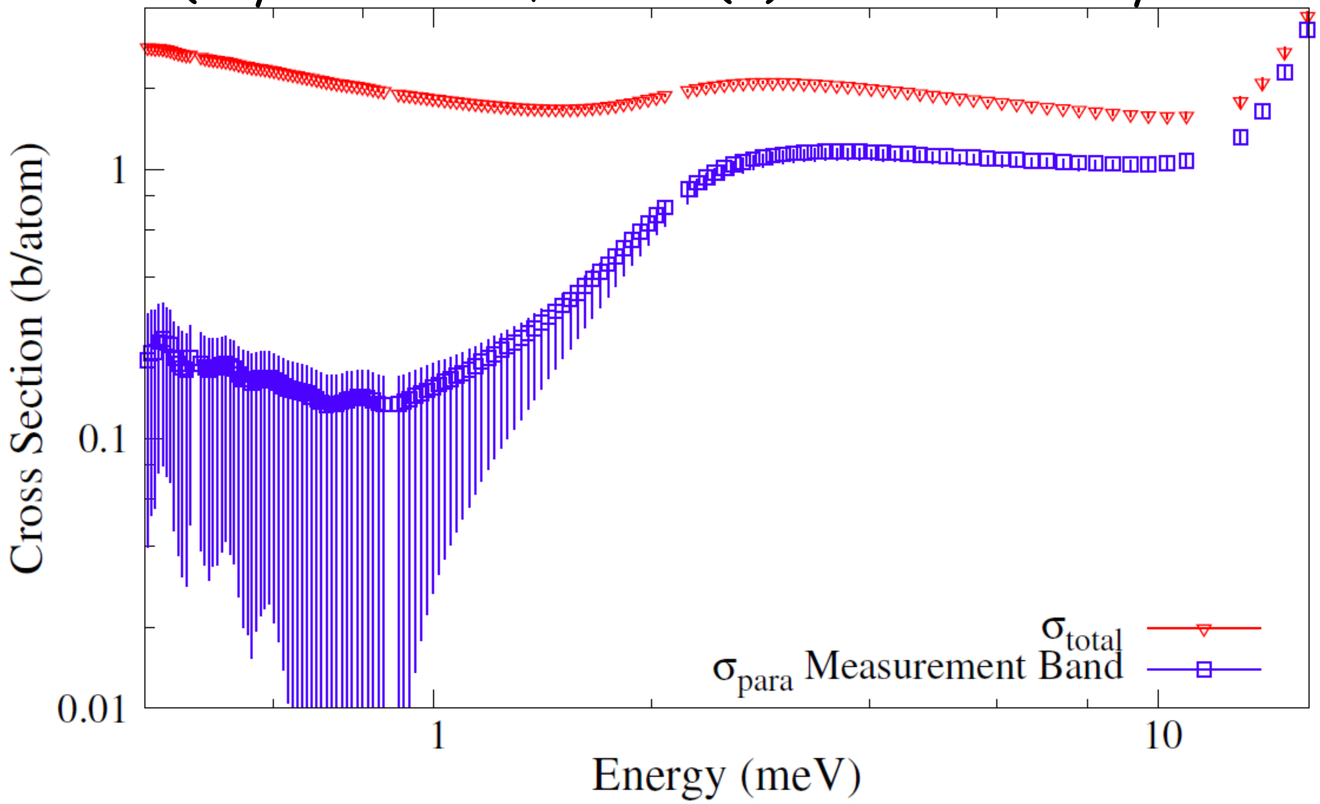
EFT: $$A_\gamma = -0.107 m_N \rho_t = -5 \times 10^{-8}$$

Some Results



Some Results:

(Phys. Rev. B 91, 180301(R) Published 8 May 2015



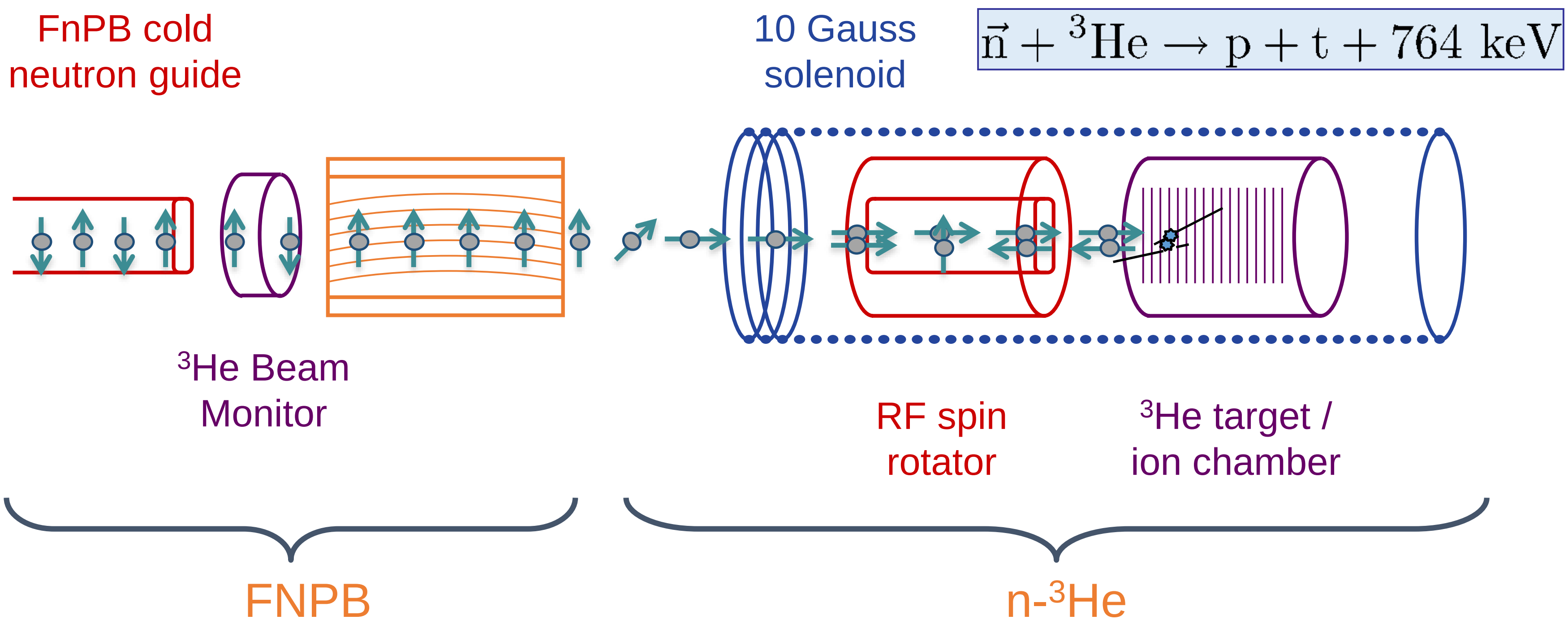
The n3He Collaboration

- Spokespersons
  D. Bowman, M. Gericke, C. Crawford
- Local Project Manager
  S. Penttila
- Project Engineer
  Jack Thomison
- Work Subpackage Leaders

G. Greene	Neutronics
L. Barrón	Solenoid
C. Crawford	Spin rotator
M. Gericke	Target / detector
D. Bowman	Preamplifiers
C. Crawford	Data acquisition
N. Fomin	Online analysis
J. Hamblen	Integration
D. Bowman	Commissioning

Institution	Researcher	Category	2014 Effort
Duke University, Triangle Universities Nuclear Laboratory			
	Pil-Neo Seo	Research Staff	10
Istituto Nazionale di Fisica Nucleare, Sezione di Pisa			
	Michele Viviani	Research Staff	15
Oak Ridge National Laboratory			
	Seppo Penttilä	Research Staff	70
	David Bowman	Research Staff	70
	Paul Mueller	Research Staff	50
	Jack Thomison	Engineer	50
	Vince Cianciolo	Research Staff	10
University of Kentucky			
	Chris Crawford	Faculty	50
	Kabir Latiful	Grad Student	100
Western Kentucky University			
	Ivan Novikov	Faculty	70
University of Manitoba			
	Michael Gericke	Faculty	50
	Mark McCrea	Grad Student	70
	Carlos Olguin	Grad Student	100
Universidad Nacional Autónoma de México			
	Libertad Baron	Faculty	50
	Andrés Ramírez Morales	Grad Student	100
University of New Hampshire			
	John Calarco	Faculty	50
University of South Carolina			
	Vladimir Gudkov	Faculty	5
	Matthias Schindler	Faculty	5
Univeristy of Tennessee			
`	Geoff Greene	Faculty	30
	Nadia Fomin	Faculty	30
	Irakli Garishvili	Postdoc	50
	Chris Hayes	Grad Student	100
	Chris Coppola	Grad Stduent	100
Univeristy of Tennessee at Chattanooga			
`	Josh Hamblen	Faculty	75
	Caleb Wickersham	Undergraduate	100
University of Virginia			
	S. Baessler	Faculty	10

Experimental Setup

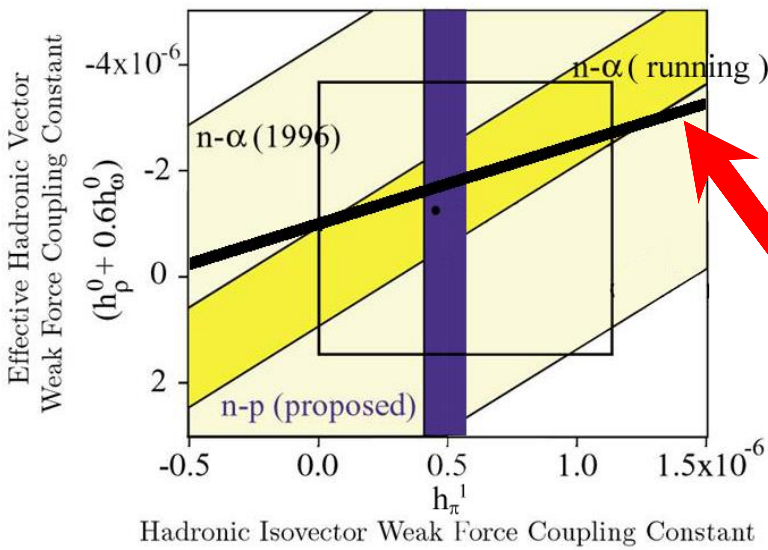


- Measure PV spin asymmetry to 2x10^{-8}
- Longitudinal holding field – suppressing PC nuclear asymmetry:

  (1.7x10^{-6} $\propto s_n \bullet k_n \times k_p$ (Hale) suppressed by two small angles
- RF spin flipper – negligible spin-dependence of neutron velocity
- ^{3}He ion chamber – both target and detector

n^3He Calculations

- Full four-body calculation of strong scattering wave functions
- Evaluation of the weak matrix elements in terms of the DDH potential (Work in progress on calculation of EFT low energy coefficients)



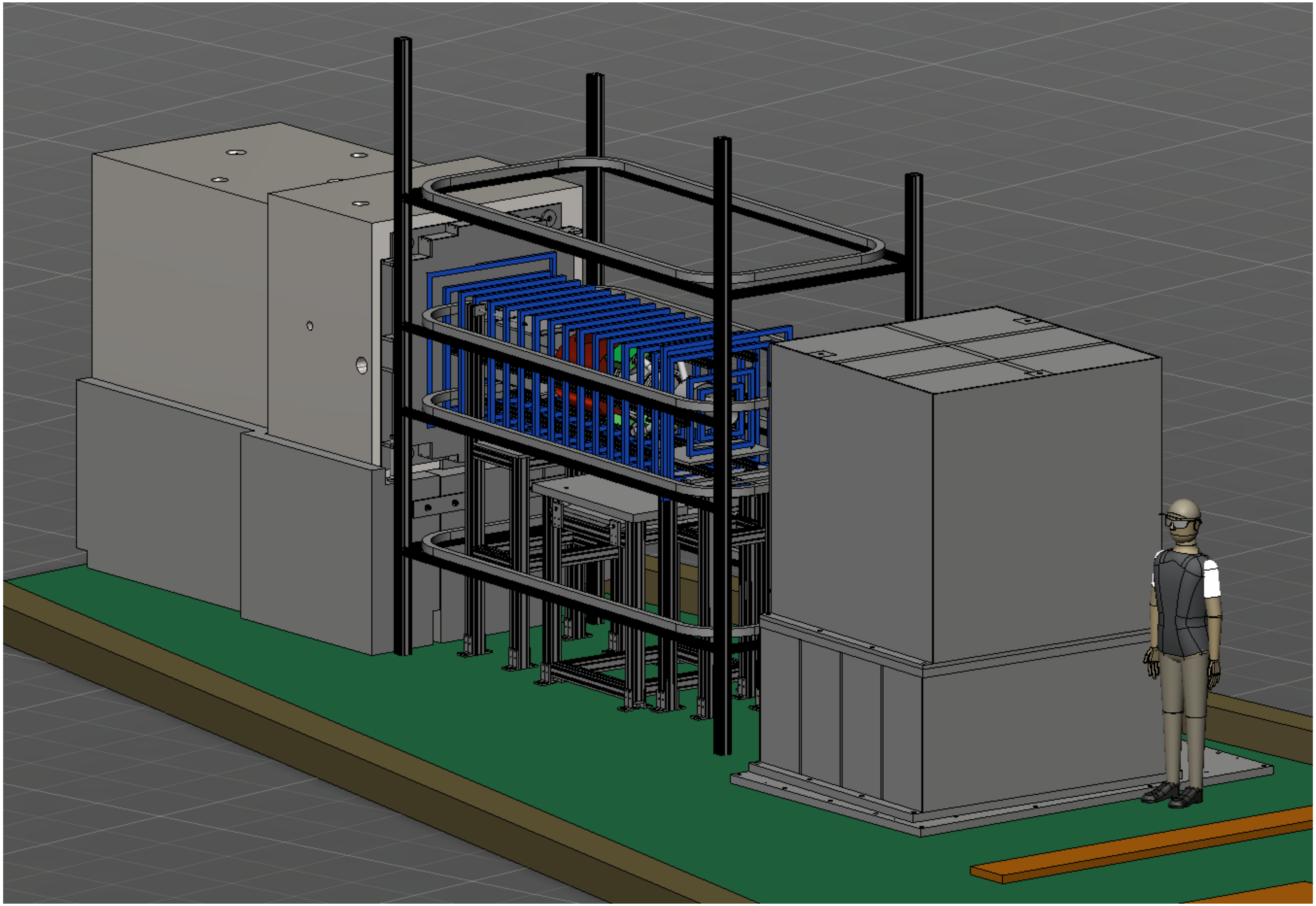
with n^3He (preliminary)

$$A_p^{\vec{n},{}^3He}(th.) \approx (-9.4 \rightarrow 2.5)\times 10^{-8}$$

DDH Weak Coupling	(A^p_Z) $n^3He \rightarrow tp$
a_π^1	-0.189
a_ρ^0	-0.036
a_ρ^1	0.019
a_ρ^2	-0.0006
a_ω^0	-0.0334
a_ω^1	0.0413

M. Viviani, R. Schiavilla, Phys. Rev. C. 82 044001 (2010)
L. Girlanda et al. Phys. Rev. Lett. 105 232502 (2010)

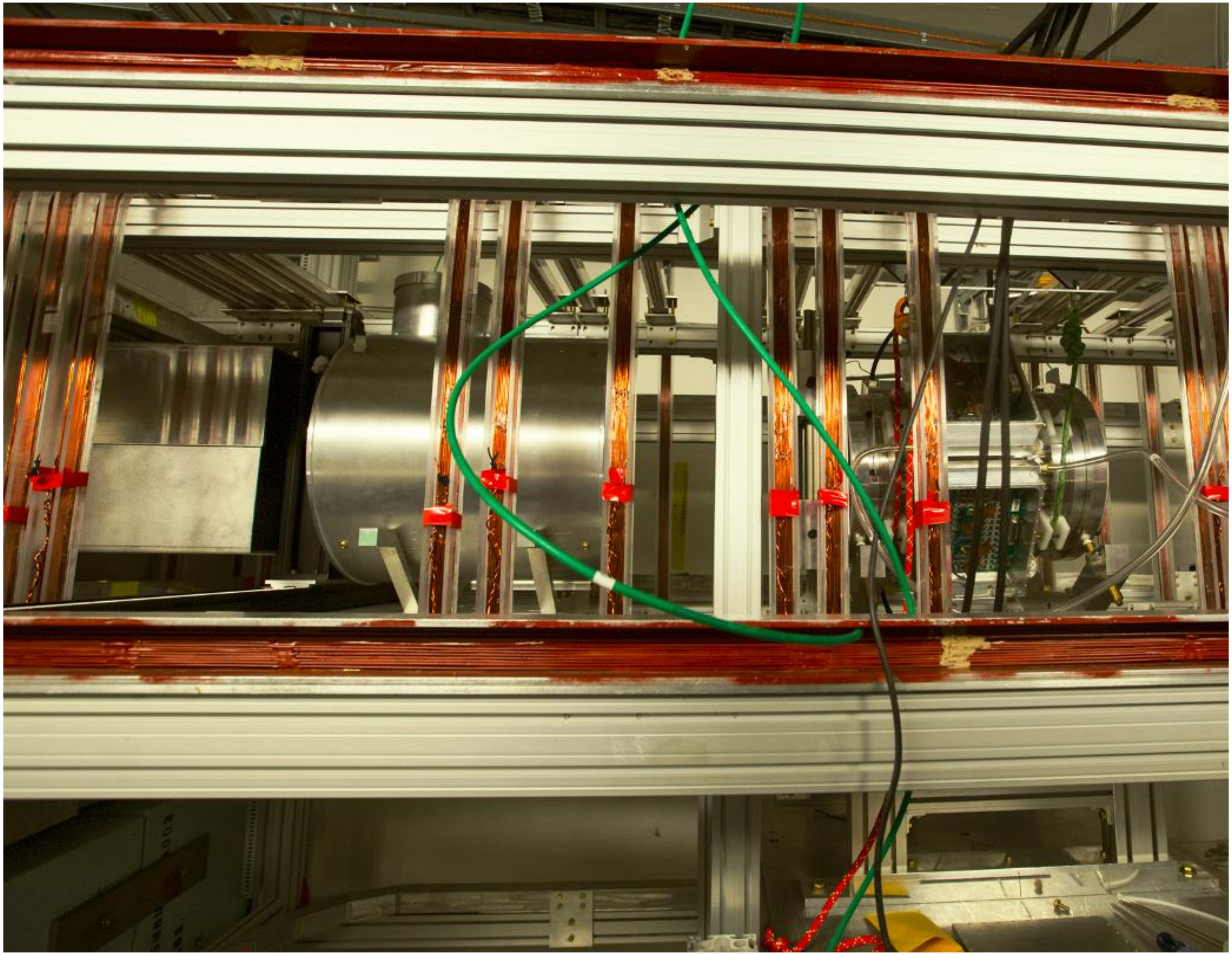
n3He Experimental Setup



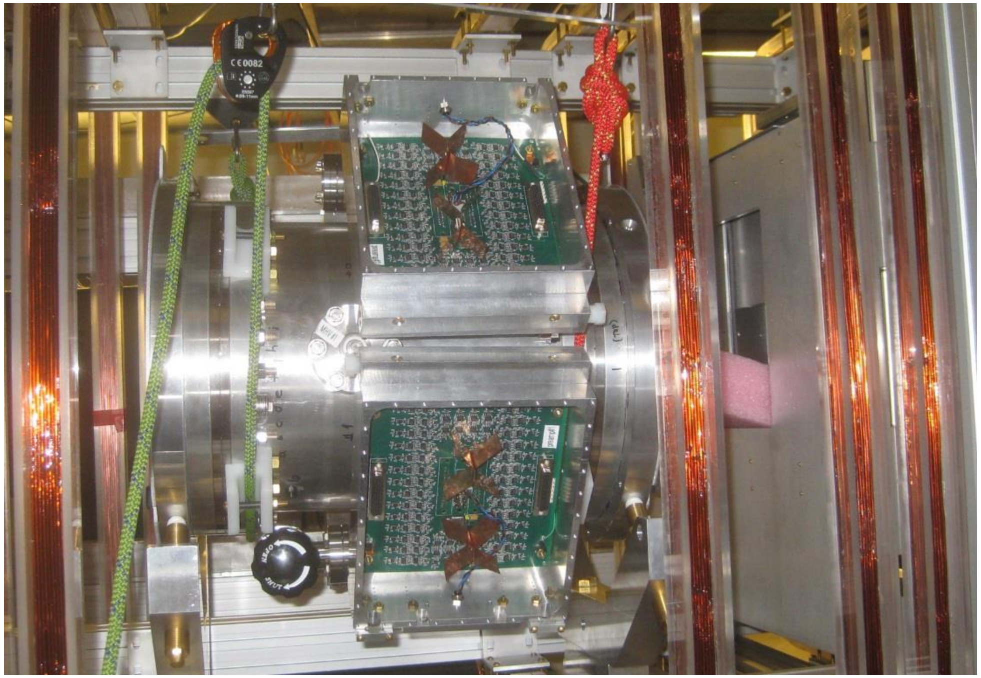
Schedule Overview

• Complete component construction / bench testing	May 2014
• Preassemble in staging area	June 2014
• Facility summer maintenance break	June-27 – Aug-15 2014
• Removal of NPDGamma	June-27 – July -7 2014
• Installation of n-3He on beam line	July-7 - Aug-15 2014
• IRR	August 2014
• Alignment of the experiment with beam	Sep – Oct -2014
• Commissioning;	Oct – Nov - 2014
• Measurement of PC transverse asymmetry;	Dec - 2014
• Facility winter maintenance break	Dec - 2014 - Feb - 2015
• Measurement of PV longitudinal asymmetry;	Feb-2015 – Dec- 2015

Installed Experiment



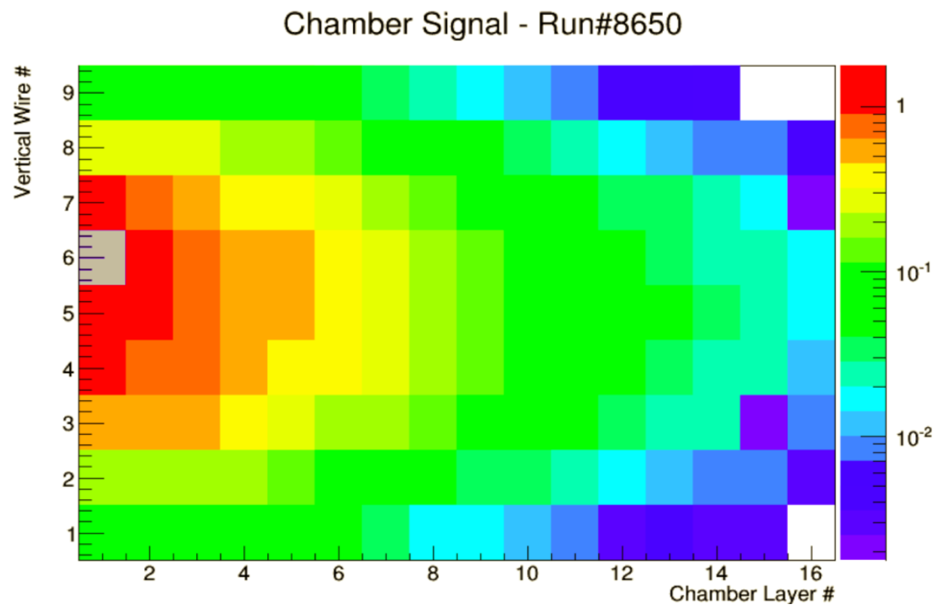
Installed Experiment

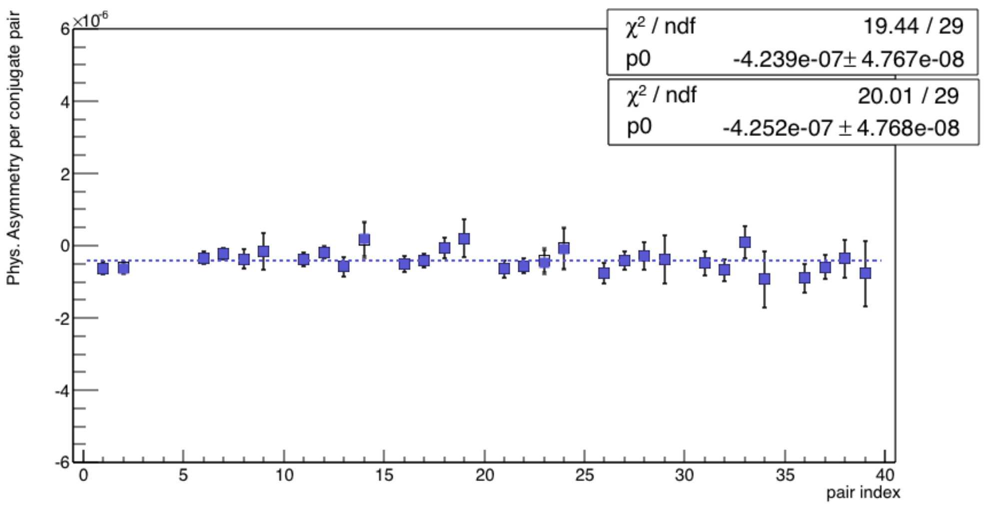


Mark McCrea Ph.D. Thesis Project

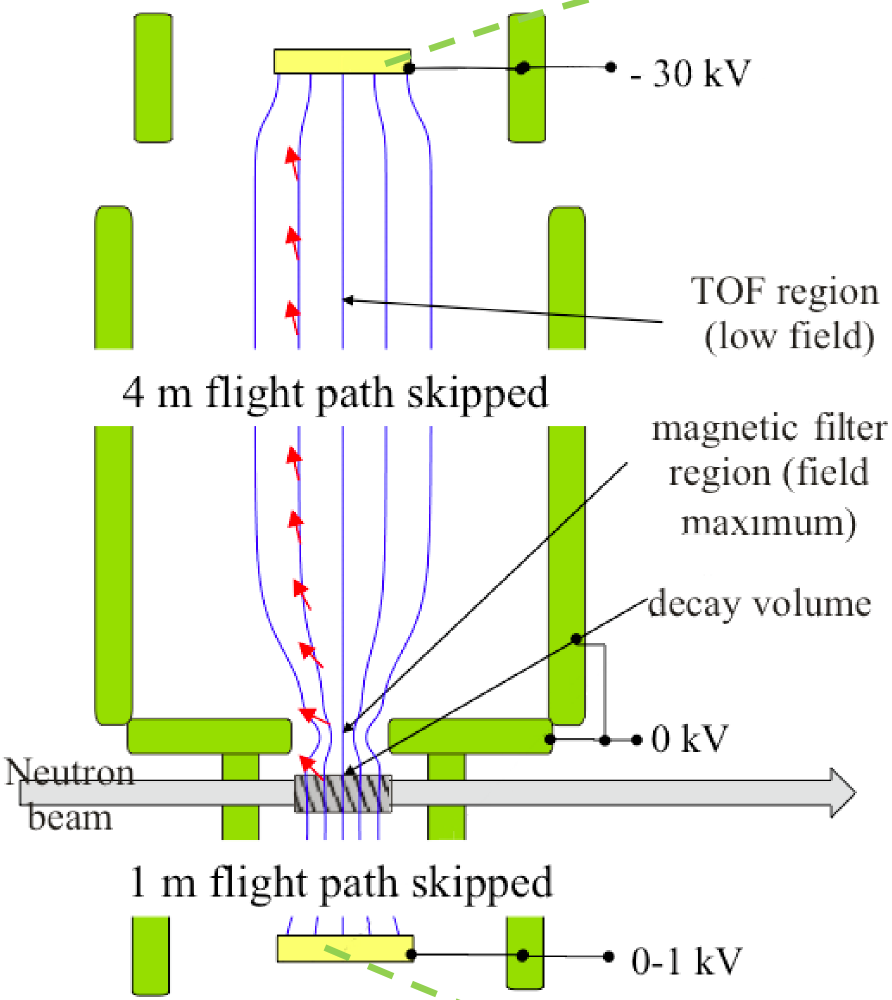
First Data

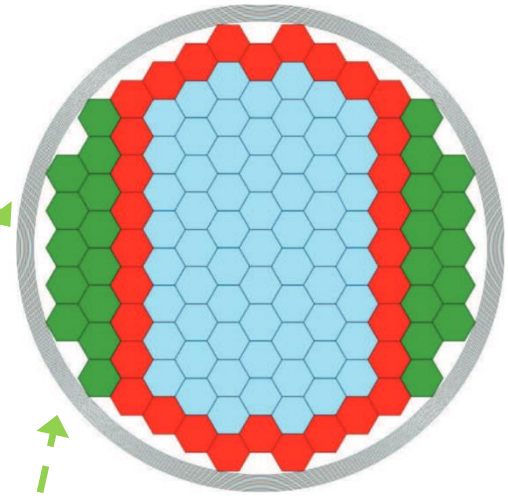
Mark McCrea Ph.D. Thesis Project

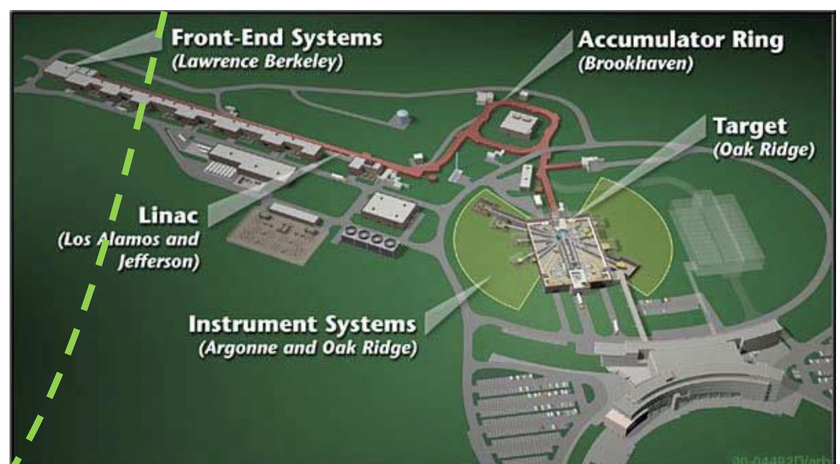




The Nab experiment



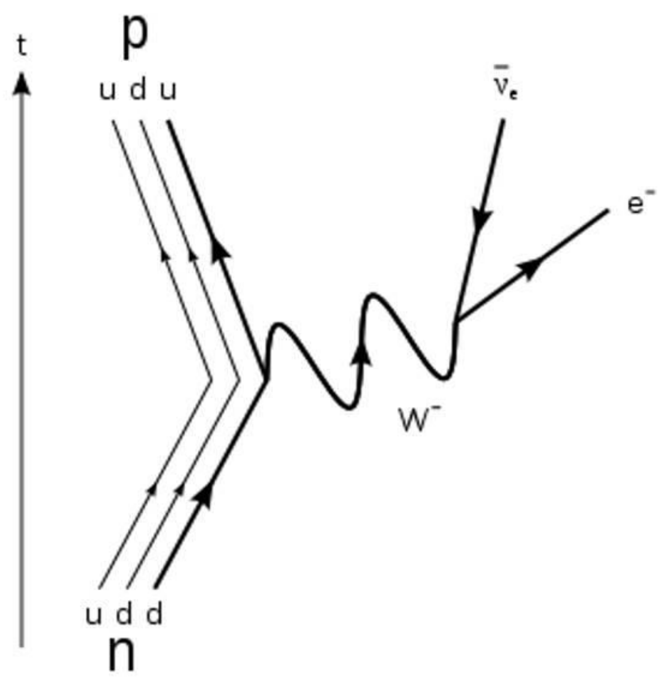




Neutron Beta Decay

Goal: $\Delta a/a \approx 1 \times 10^{-3}$

Goal: $\Delta b \approx 3 \times 10^{-3}$



1. Neutrino physics: Abundance of solar neutrinos
2. Cosmology: abundance of light elements from primordial nucleosynthesis
3. Particle Physics: Unitarity of Cabbibo-Kobayashi-Maskawa (CKM) Matrix, existence of fourth generation of quarks
4. More particle physics: searches for S,T interactions that are motivated by TeV physics
5. Even more particle physics: search for new channels for CP violation

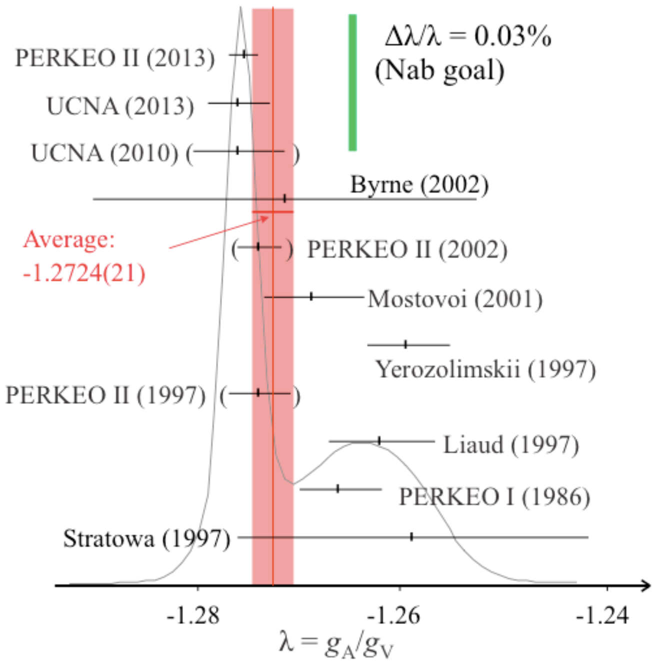
Including all types of interactions (S,P,V,A,T), differential decay rate can be written:

$$\frac{dw}{dE_e d\Omega_e d\Omega_\nu} \propto p_e E_e (E_0 - E_e)^2 \left[1 + a \frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b \frac{m_e}{E_e} + \langle \vec{\sigma}_n \rangle \cdot \left(A \frac{\vec{p}_e}{E_e} + B \frac{\vec{p}_\nu}{E_\nu} + \cdots \right) \right]$$

Physics

1. Determine l = g_A/g_V

From $a = (1-|l|^2)/(1+3|l|^2)$



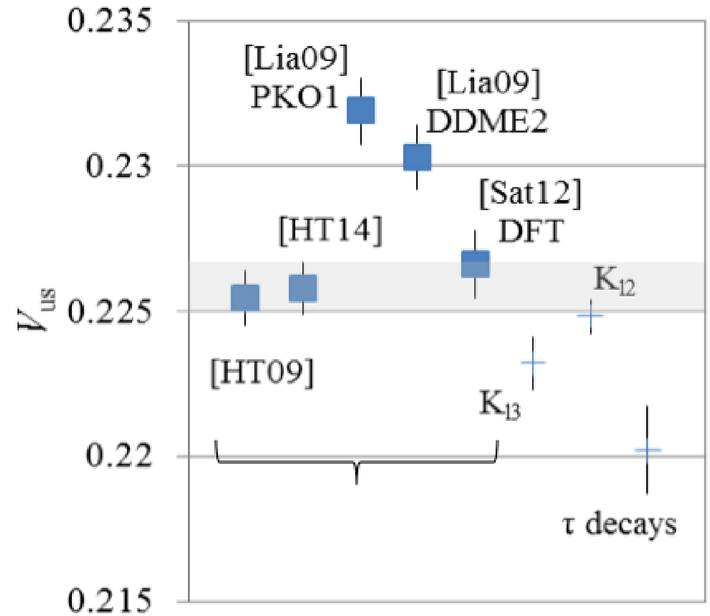
$$\frac{\partial A}{\partial \lambda} = 2\frac{(\lambda-1)(3\lambda+1)}{(1+3\lambda^2)^2} \simeq 0.37$$

$$\frac{\partial a}{\partial \lambda} = \frac{-8\lambda}{(1+3\lambda^2)^2} \simeq 0.30$$

2. Test unitarity of CKM Matrix from

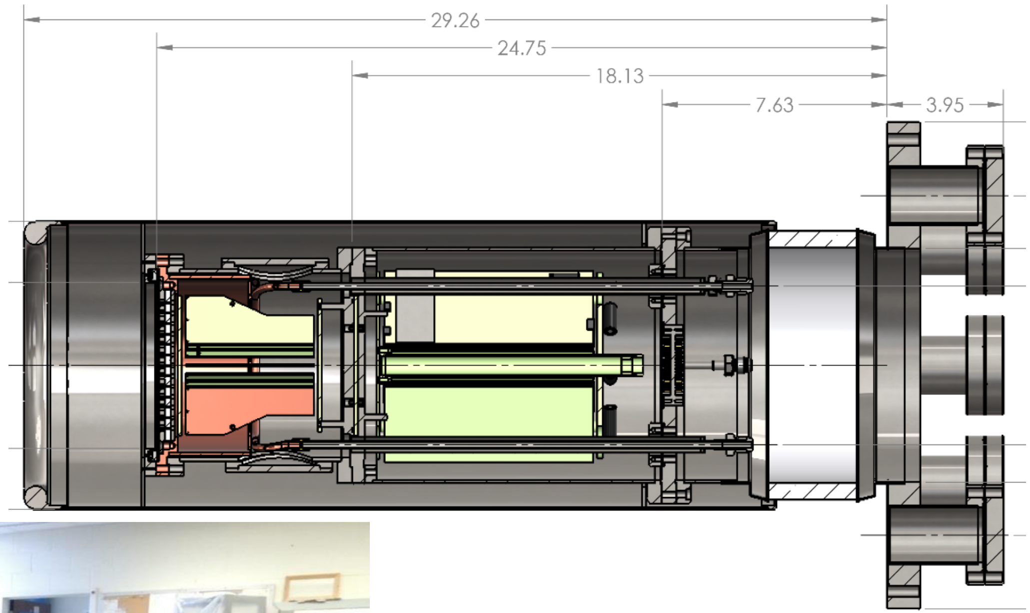
$|V_{ud}|^2 \tau_n (1+3\lambda 2)=4908.7(19)$ s

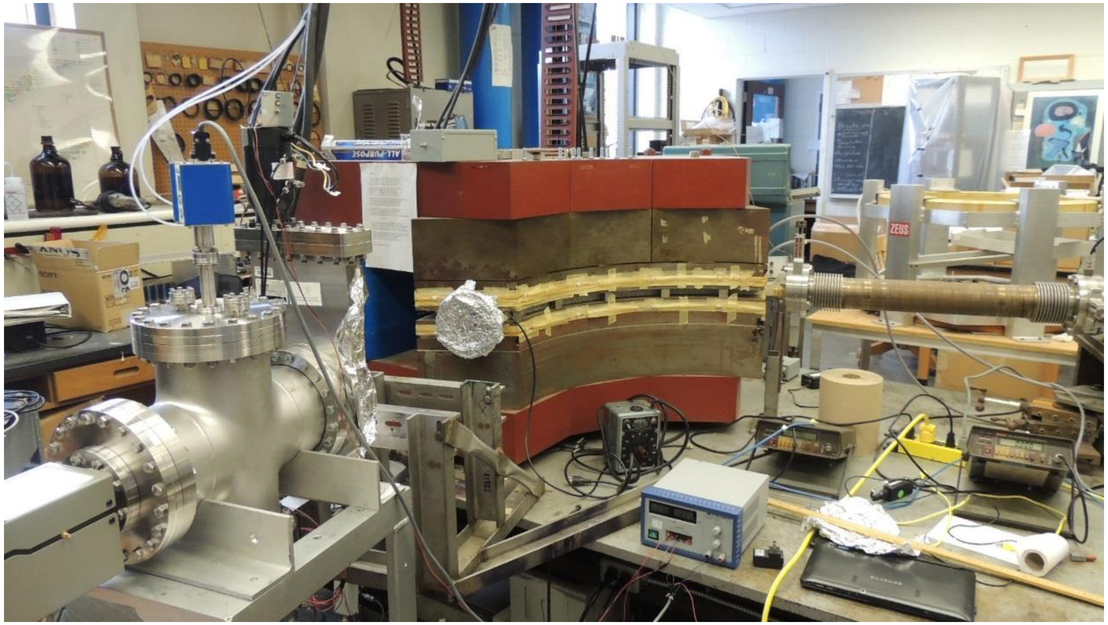
$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$



3. Search for Beyond the Standard Model Physics through S, T interactions

Our Contribution:





Manpower and budget:

Table 1: *Current Canadian Effort and Manpower*

Researcher	Institution	FTE	Effort
M. Gericke	Manitoba	0.3	NPDGamma, n3He, and Nab detectors
M. McCrea (Student)	Manitoba	1.0	NPDGamma and n3He detectors and analysis
N. Macsai (Student)	Manitoba	1.0	Nab detectors and analysis
J. Mammei	Manitoba	0.1	Nab detectors
R. Mammei	Winnipeg	0.1	Nab detectors
J. Martin	Winnipeg	0.1	Nab detectors
C. Olguin (Student)	Manitoba	1.0	n3He detectors and analysis

Table 2: *Estimated Optimum* Nab *Funding Levels.*

Funding Year	Amount	Comments
2017-18	$113k	3 students and $50k in travel
	$ 20k	equipment maintenance
2018-19	$113k	3 students and $50k in travel
	$ 20k	equipment maintenance
2019-20	$82k	2 students and $40k in travel
2020-21	$63k	2 students and $20k in travel
2021-22	$41k	1 students and $20k in travel
2022-26	$0k	