Observation of the Radiative Decay Mode of the Free Neutron

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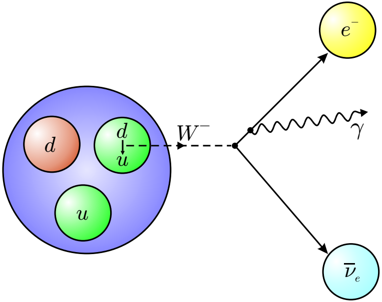
Outline

Radiative Decay of the Neutron



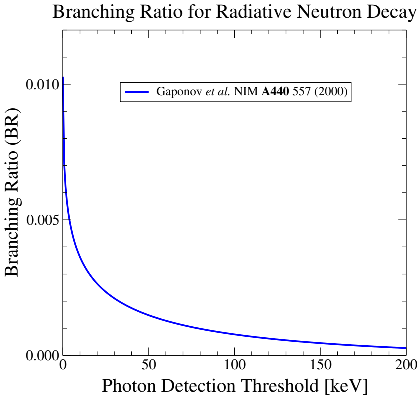
Motivation

- Rare branch recently measured, to 10%
- Aiming for a 1% measurement of photon spectrum
- Radiative corrections and new physics

Experimental Challenges

- Long τ_n (885.7 $\pm$ 0.8 s)
- Small branching ratio
- Large γ backgrounds

Radiative Decay of the Neutron



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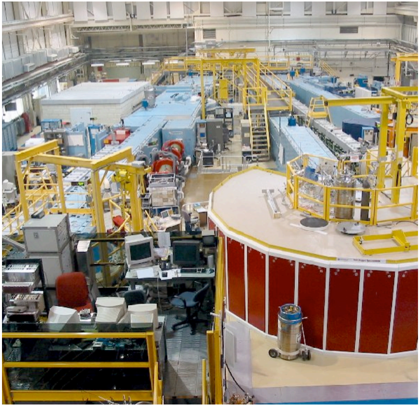

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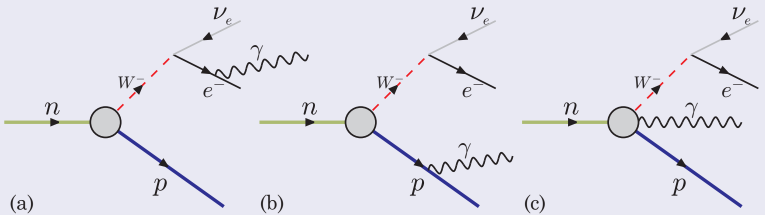
Theoretical Formulation

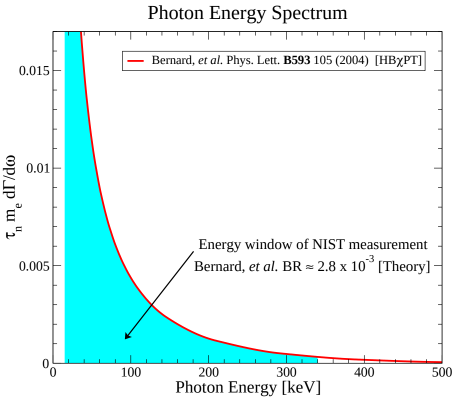
Feynman Diagrams



- Diagrams a.) and b.) QED calculable; c.) requires HBχPT EFT
- Proton bremsstrahlung suppressed $\mathcal{O}(1/m_p)$
- Electron bremsstrahlung dominates

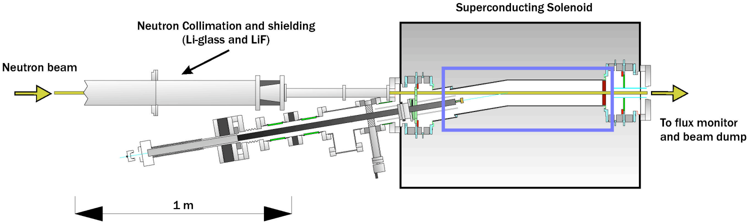
Calculation Predictions

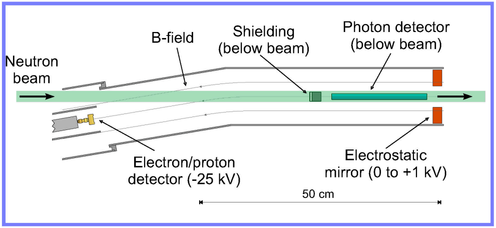
- Photon energy acceptance 15 - 340 keV
- BR = 2.85 x 10^{-3} [theory]
- Characteristic $1/k$ IR divergence of bremsstrahlung

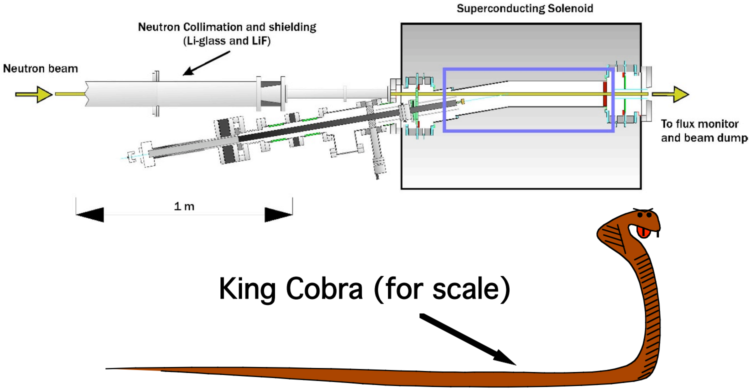


Outline

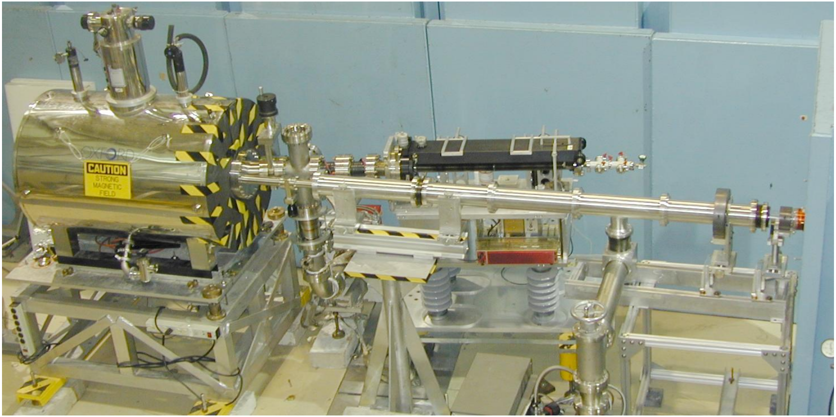
Experimental Apparatus






Superconducting Solenoid
Neutron Collimation and shielding
(Li-glass and LiF)
Neutron beam
To flux monitor
and beam dump
1 m
King Cobra (for scale)

Experimental Apparatus (continued)

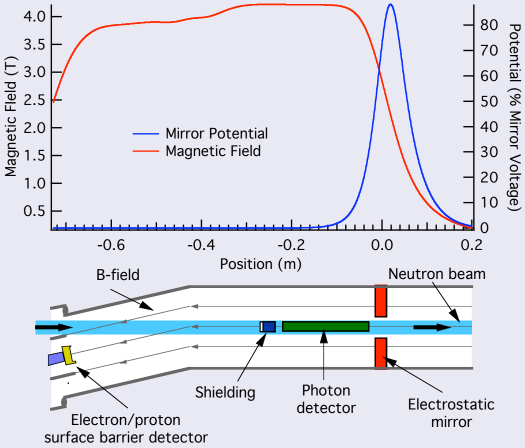


Built from existing NIST neutron lifetime apparatus and emiT beamline (collimation and shielding)

Charged Particle Detection

- e^- and p constrained to cyclotron orbits
- Protons need -25 kV acceleration into SBD
- Electrostatic mirror reflects “wrong-way” protons ($E_p \leq 750$ eV)
- Mirror a free parameter of experiment

Setup Schematic



Photon Detector

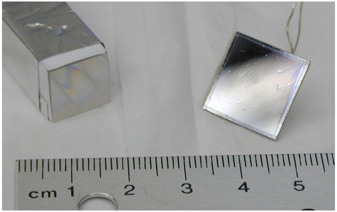
Preamplifier signal from a bismuth germanate (BGO) scintillating crystal coupled to avalanche photodiode (APD)

Operating Conditions

- Cryogenic temperatures
- High B-field

BGO

- Light yield ↑ as T ↓
- Large size (20 cm long)
- 15 keV - 340 keV primarily photopeak



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- Noise ↓ as T ↓

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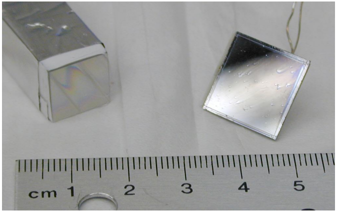

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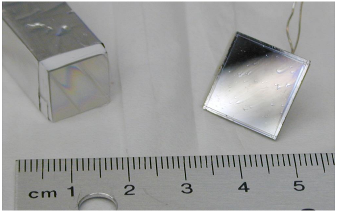

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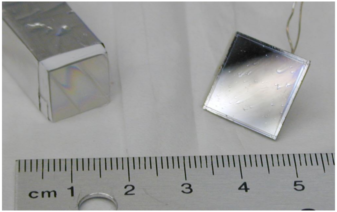

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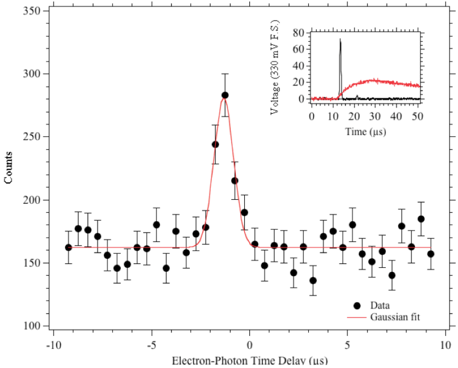
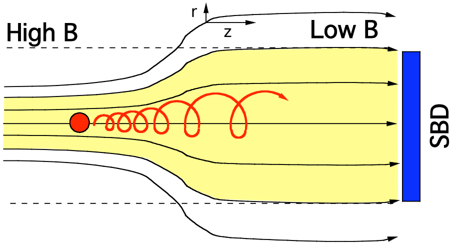
Outline

Selecting Events

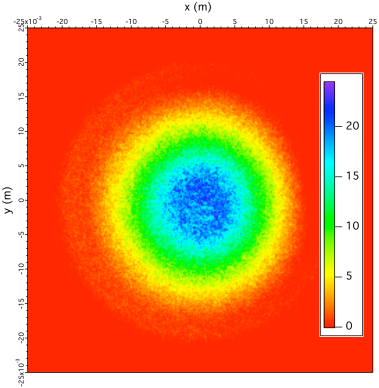
- e^- and γ correlated in time for radiative decay events
- Uncorrelated background "flat" in time
- Correlated background small
- $R_{ep\gamma}$ is normalized to R_{ep} for each mirror voltage



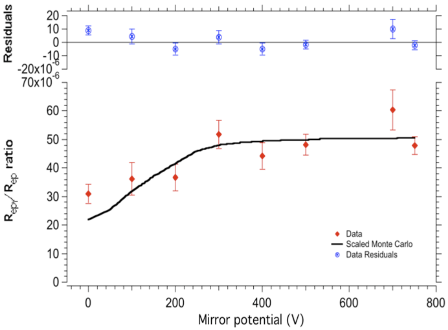
Monte Carlo Modeling



- Effective fiducial volume complicated
- Detailed tracking and modeling performed
- 4$^{\text{th}}$ Runge-Kutta and adiabatic transport



Effect of Mirror Potential



Typical Rates

Mirror (V)	Live (day)	R_{ep} (s^{-1})	$R_{ep\gamma}/R_{ep}$
0	36	5	3×10^{-5}
750	12	20	5×10^{-5}

Solid angle acceptance $\sim 10^{-2}$

- Data fit to Monte Carlo shape. $\mathrm{BR} = 3.13 \pm 0.34 \times 10^{-3}$ for 15-340 keV photons.
- HBχPT calculation 2.85×10^{-3} [Bernard et al., Phys. Lett. B **593**, 105 (2004)]
- J.S. Nico et al. Nature **444** 1059 (2006).

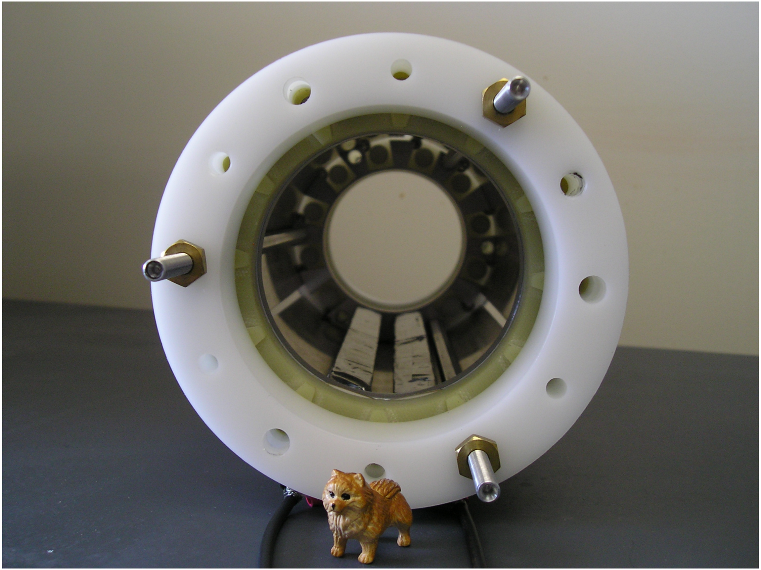
Outline

12-Element Detector

Nearly complete!

- 12 BGO crystals coupled to 12 APDs
- 12 independent HV and signals
- Cryostat tests with external sources (e.g. ^{241}Am)
- Other improvements to reduce systematics

12-Element Detector (continued)



Summary

- NIST lifetime apparatus was reused
- Novel photon detector; BGO scintillating crystal coupled to APD operates in the bore of a superconducting magnet
- Triple coincidence of e^-, p, and γ suppresses backgrounds
- Extensive Monte Carlo to model detector response
- Branching ratio in agreement with theory
- 12-Element detector under construction with other improvements to do a 1% precision measurement