Ultra-Cold Neutron measurement of Proton branching ratio in neutron Beta decay (UCNProBe)

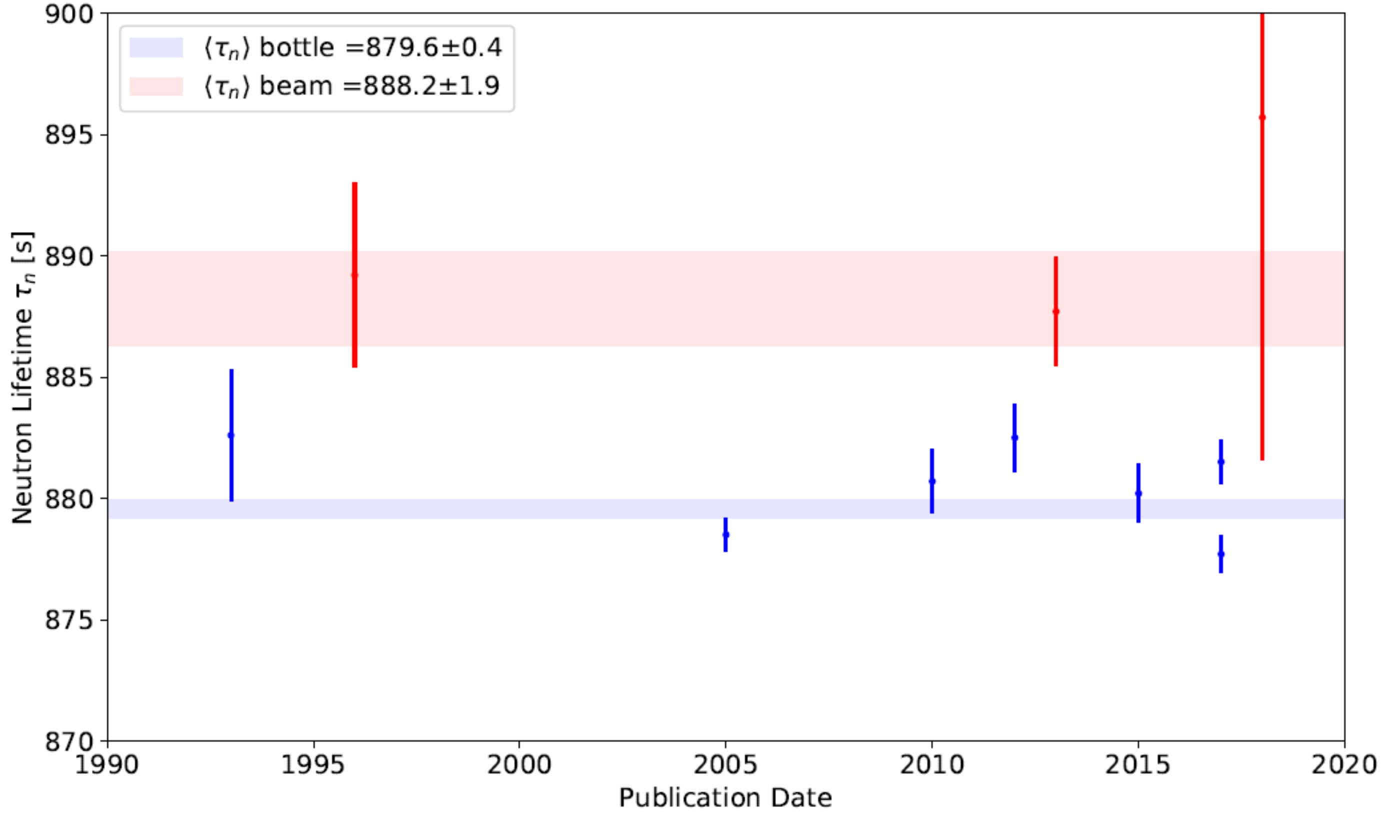
Zhaowen Tang
Los Alamos National Lab

Particle Physics with Neutrons at the ESS
Nordita, 2018

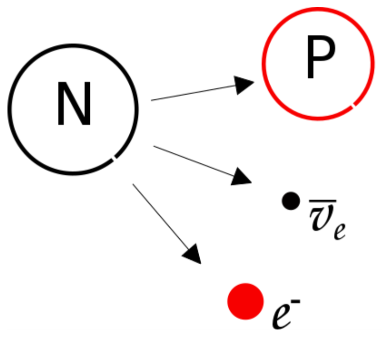
Outline

- Neutron lifetime discrepancy
- Experimental Concept
- Experimental challenges
  - Background reduction
  - Residual ^3He gas
  - Simulation of efficiencies

Neutron Lifetime Discrepancy



- 8.6 or ~4.5 σ discrepancy
- Two explanations
  - unknown systematic error
  - new neutron decay mode with small branching ratio (mirror neutrons, DM, etc)
- New beam like experiment with different systematic effects



+ ?

$$\frac{1}{\tau_n} = \frac{1}{\tau_\beta} + \frac{1}{\tau_?}$$

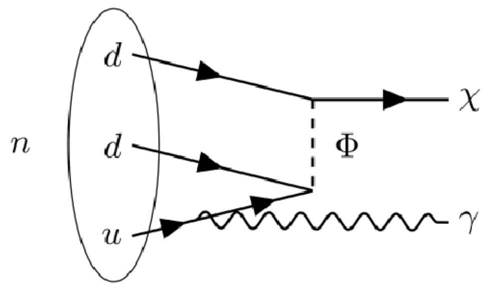
Dark Matter Interpretation of the Neutron Decay Anomaly

Bartosz Fornal and Benjamín Grinstein
Department of Physics, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093, USA
(Dated: January 16, 2018)

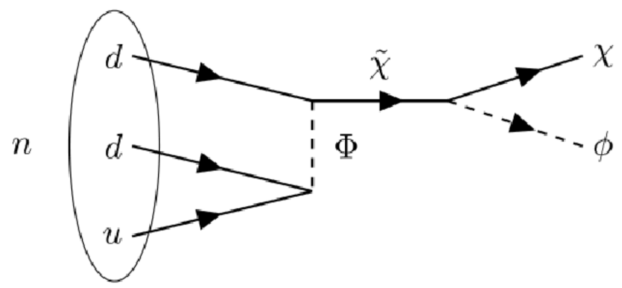
There is a long-standing discrepancy between the neutron lifetime measured in beam and bottle experiments. We propose to explain this anomaly by a dark decay channel for the neutron, involving a dark sector particle in the final state. If this particle is stable, it can be the dark matter. Its mass is close to the neutron mass, suggesting a connection between dark and baryonic matter. In the most interesting scenario a monochromatic photon with energy in the range 0.782 MeV – 1.664 MeV and branching fraction 1% is expected in the final state. We construct representative particle physics models consistent with all experimental constraints.

3 Possible modes of decay:

1. Neutron → dark matter + photon (0.782 MeV < E_γ < 1.664 MeV) Phys. Rev. Lett, 121.022505
2. Neutron → dark matter + $e^+ e^-$ ($2m_e \leq E_{e+e-}$ < 1.664 MeV) Phys. Rev. C 97, 052501 (2018)
3. Neutron → two dark particles (937.900 MeV < DM < 939.565 MeV)



Mode 1 & 2

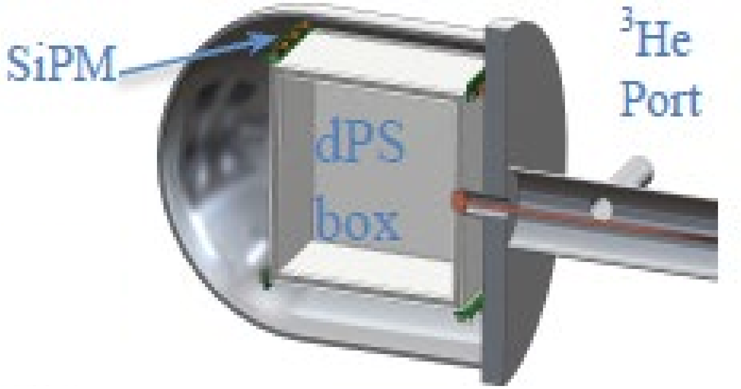


Mode 3

Experimental Concept

Measure τ_β using UCNs

- if $\tau_\beta = \tau_n$(from Bottle), then unaccounted systematic error in beam method
- $\tau_\beta > \tau_n$, then possible new physics



Requires absolute measurements of two quantities

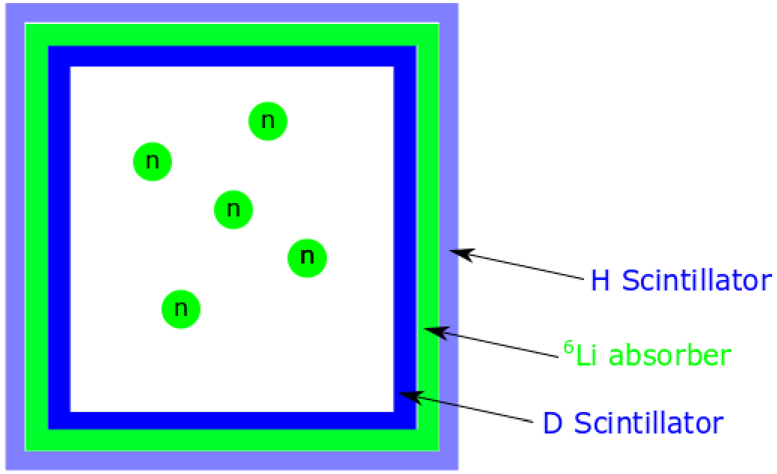
- Number of neutrons in the trap
- Number of neutrons that decayed (measurement of charged particles)

Charged particle detection

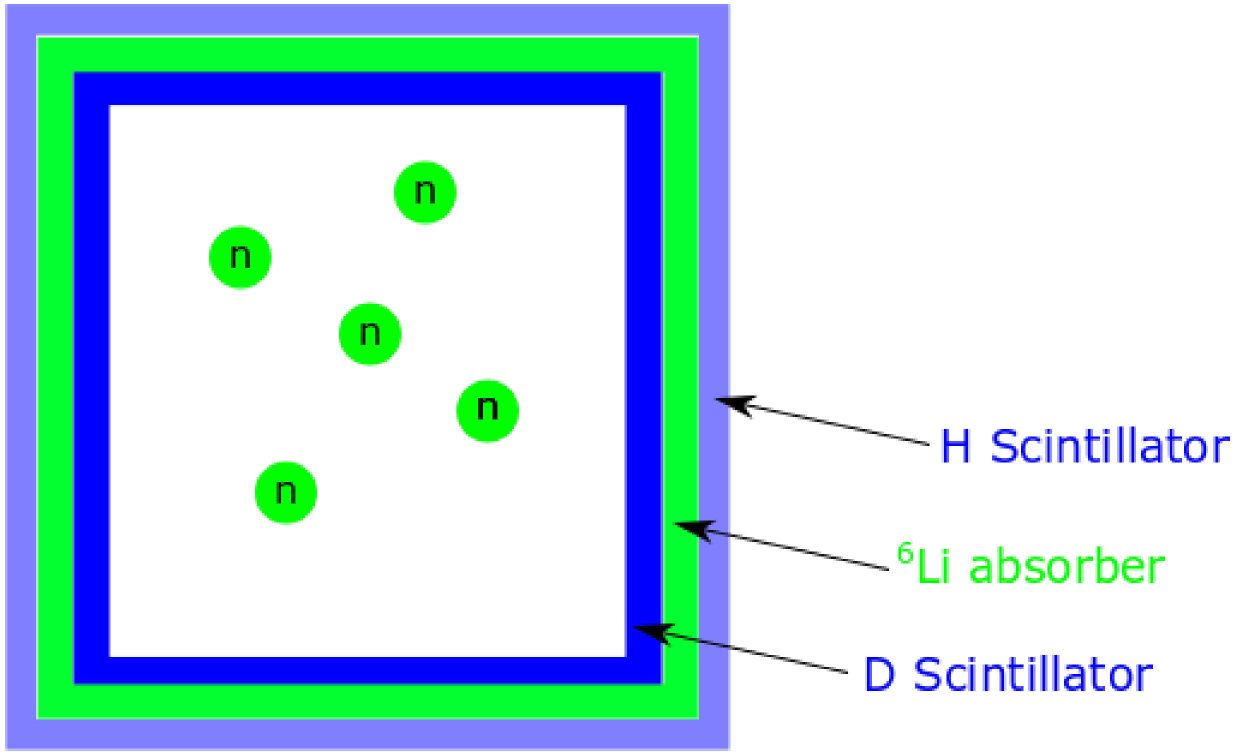
- Electron (Using deuterated polystyrene (dPS) as a UCN trap and detector)
- dPS scintillator (Eljen 299-2D) potential measured at 168 neV

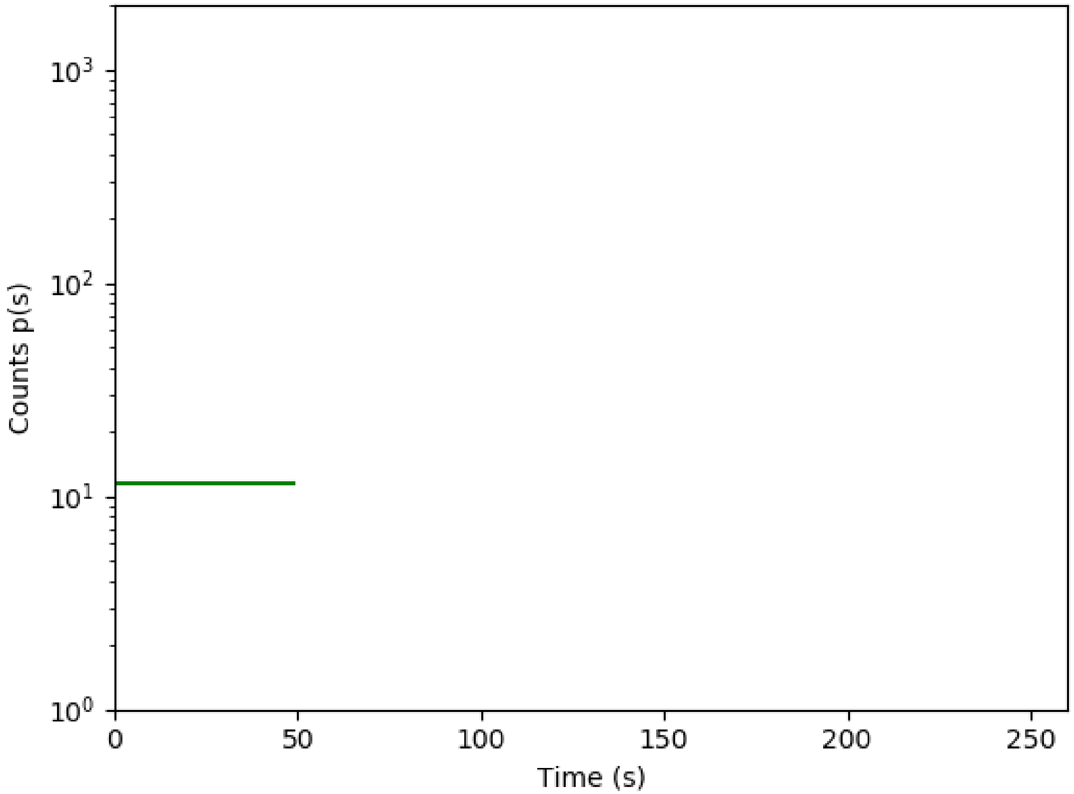
Neutron detection

- UCN capture on ^{3}He gas

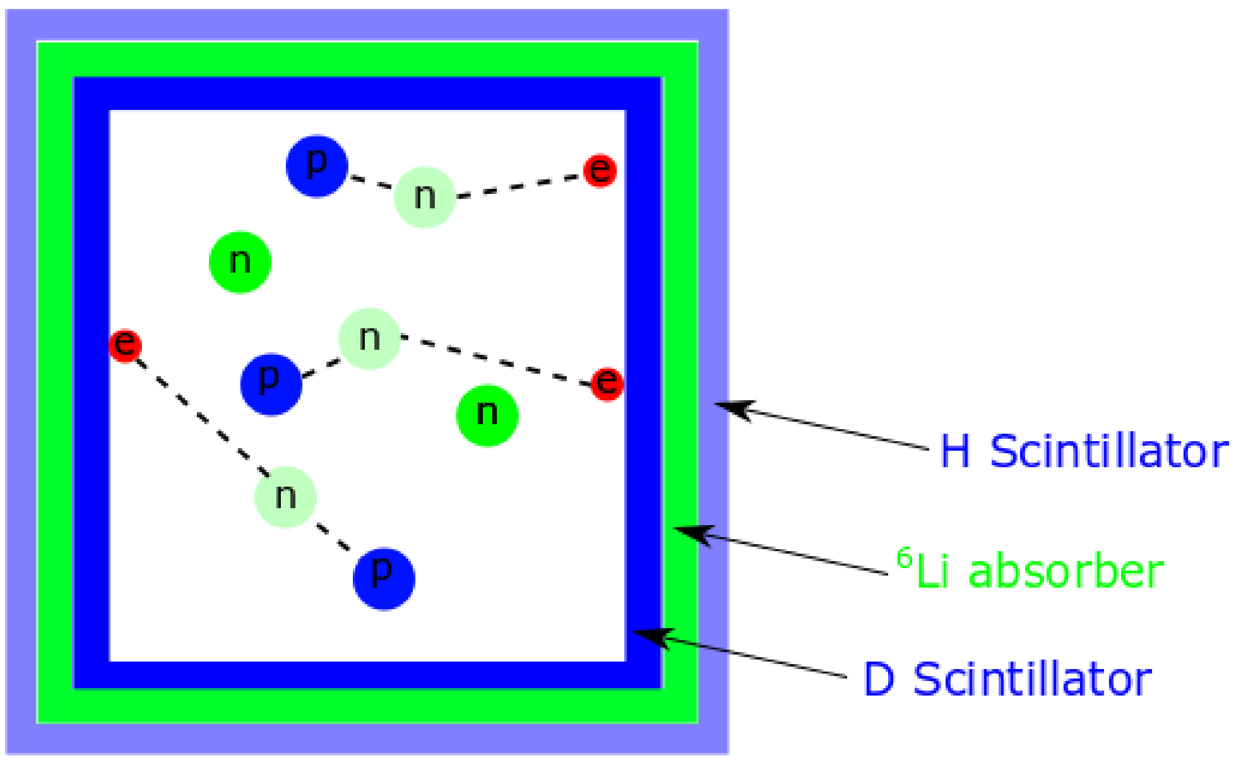


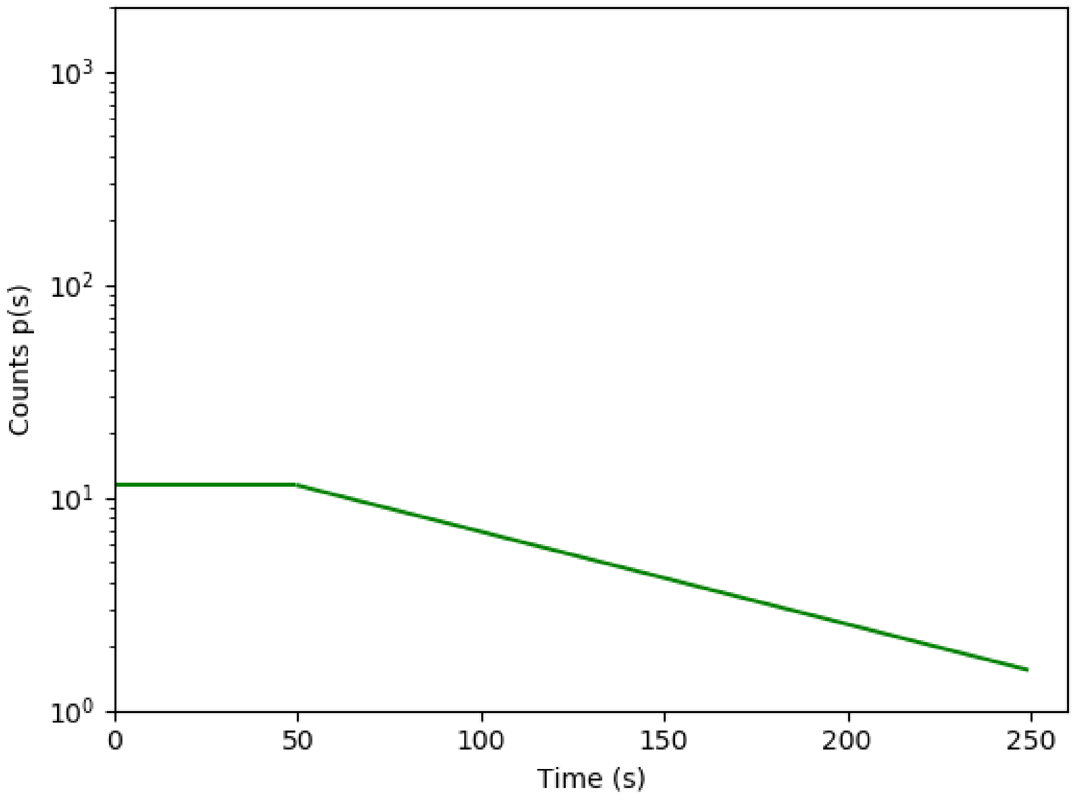
Method for measurement



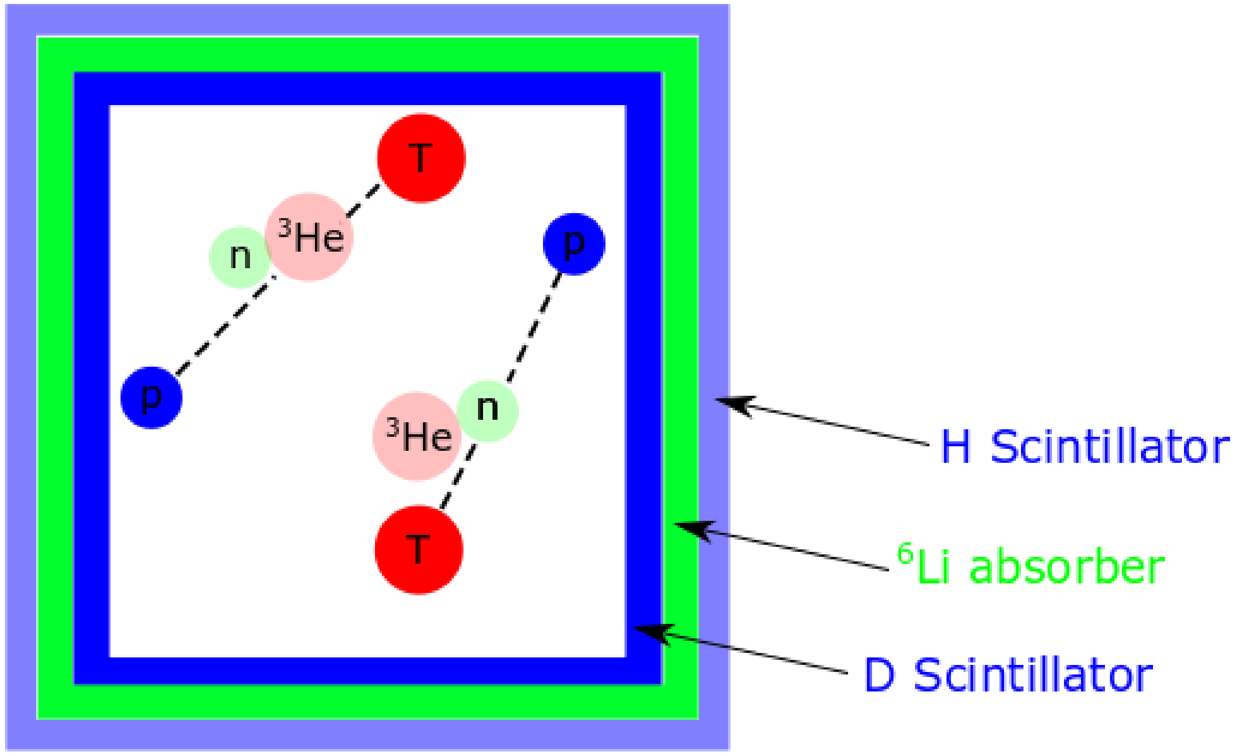


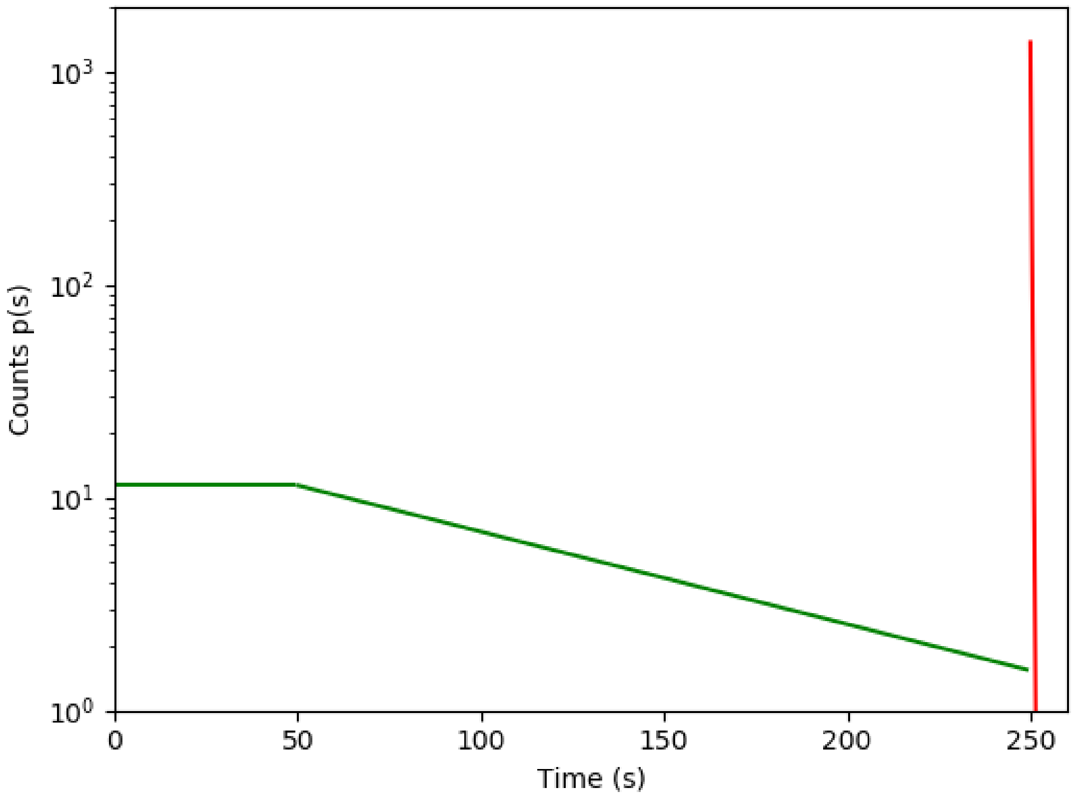
Method for measurement





Method for measurement



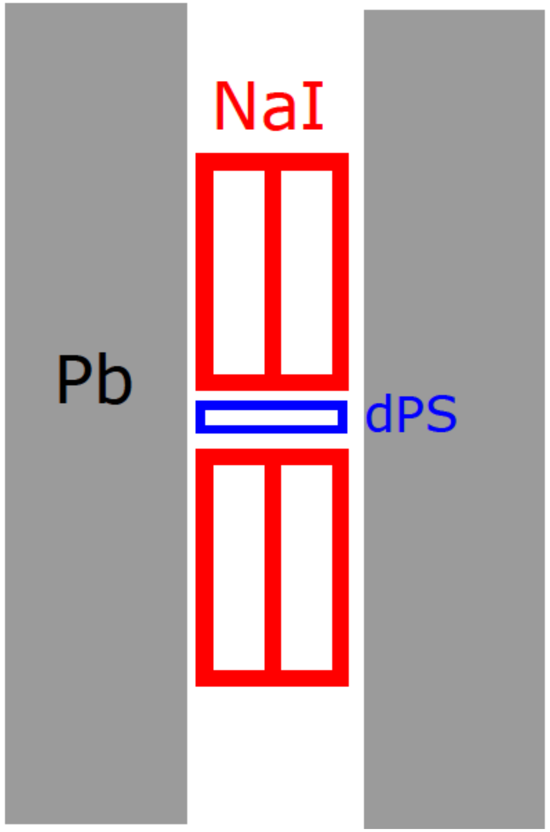


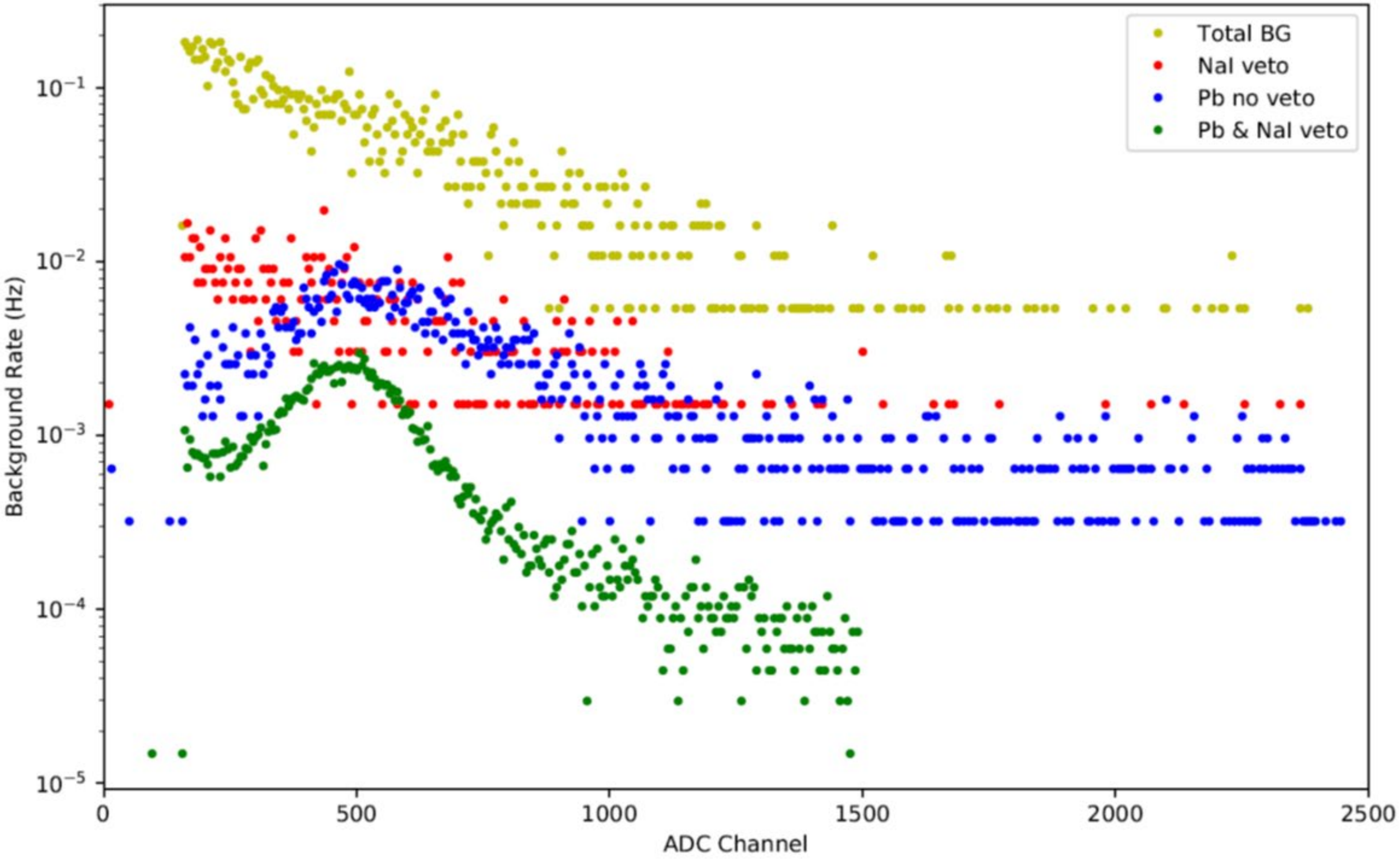
Challenges for the experiment

- Background in scintillator
  - Room background
  - Spallation related background
  - UCN related background
- Residual ^{3}He in the scintillator
  - Residual ^{3}He gas in the measurement cell
  - ^{3}He diffusion into the wall of the scintillator
- Efficiency calibration for electron and proton (from n^{3}He capture) detection
  - Scintillator dead layer
  - Light collection on low energy part of the beta spectrum
  - Proton detection efficiency due to ^{3}He gas

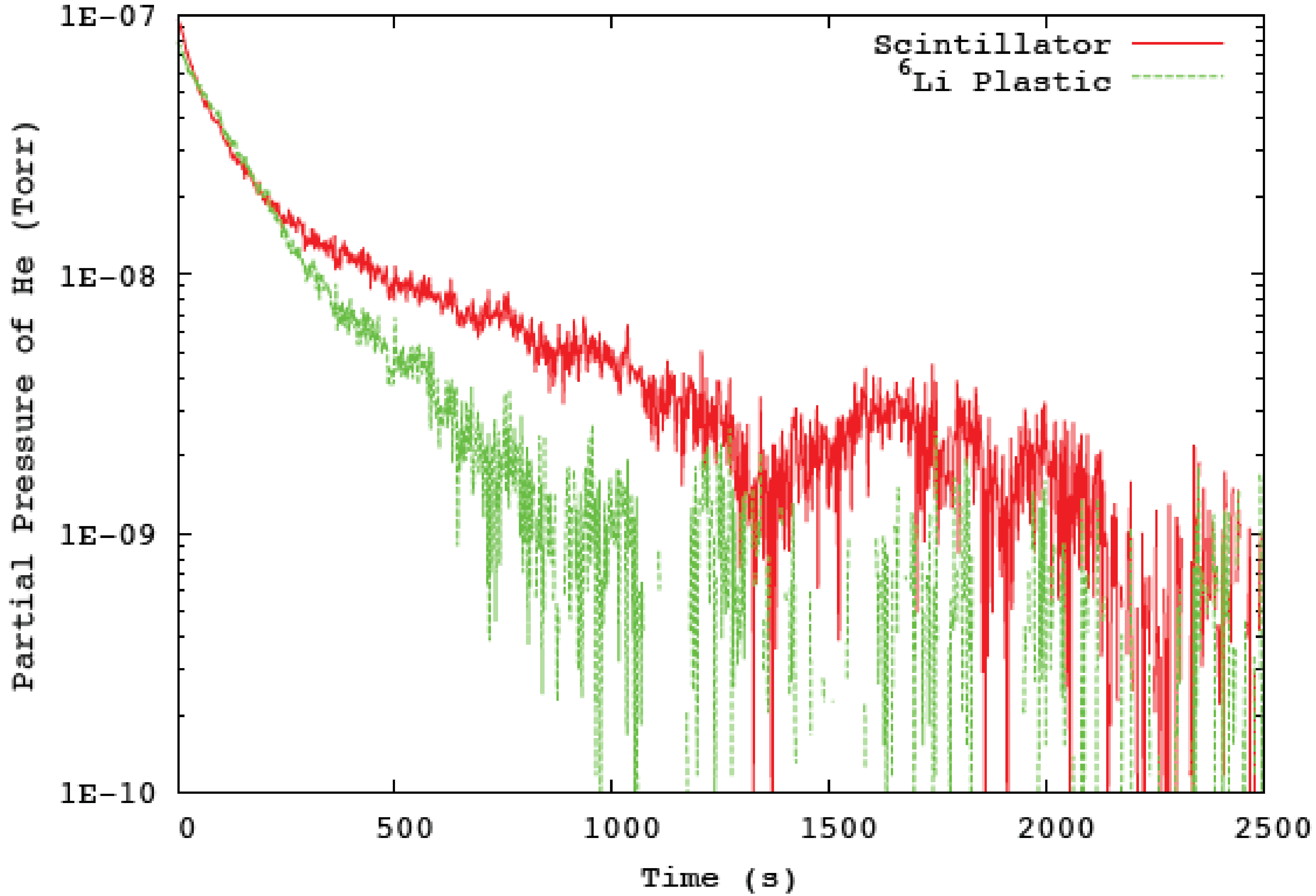
Background reduction

Active/Passive shielding scheme will significantly reduce background





^{3}He pumping Test

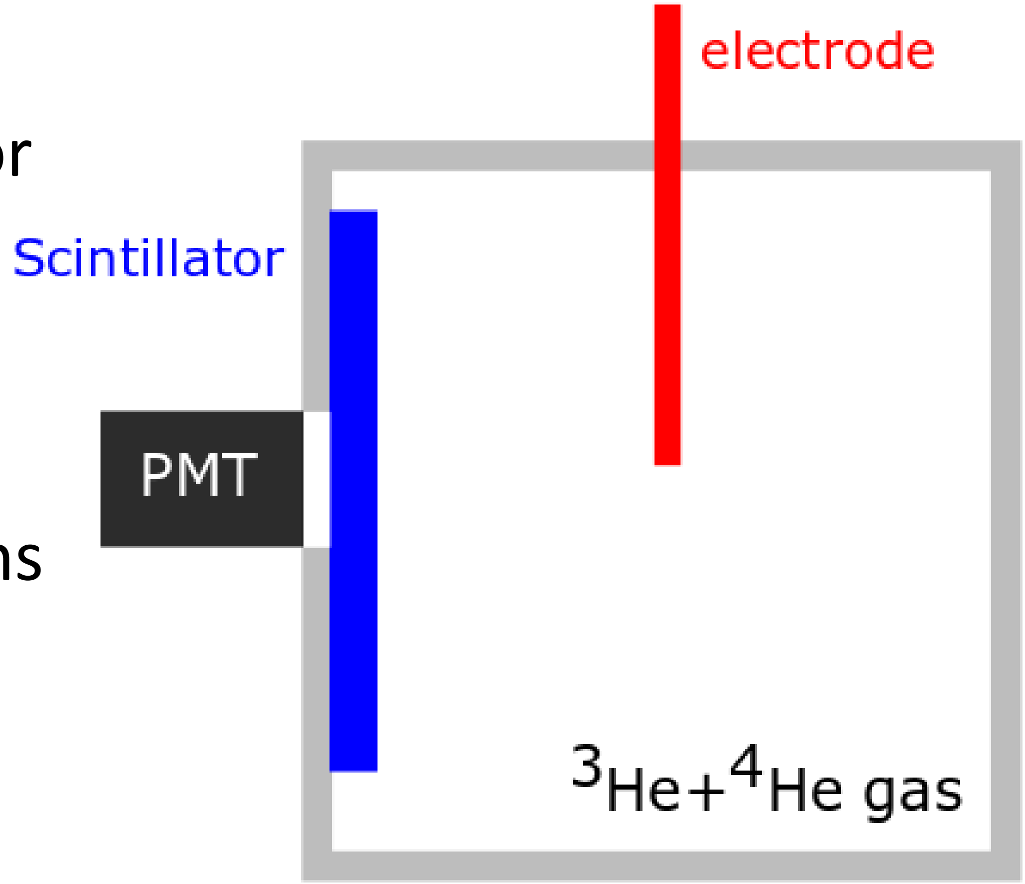


5x10^{-8} Torr of ^{3}He $\Rightarrow$ 1 s effect on lifetime

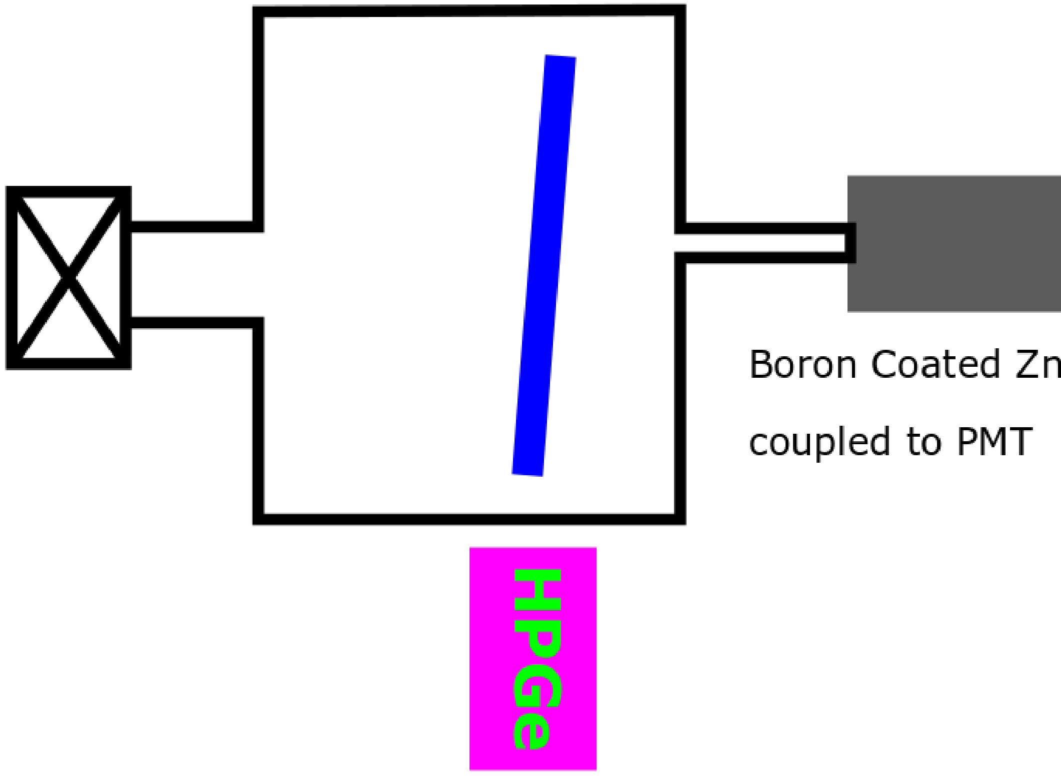
^{3}He on surface of scintillator (ongoing)

Dedicated experiment to study ^{3}He on scintillator

1. Add in ^{3}He gas and pump it out
2. Add in just ^{4}He gas and look for UCN capture
   - Coincidence signal
3. Background studies in different configurations

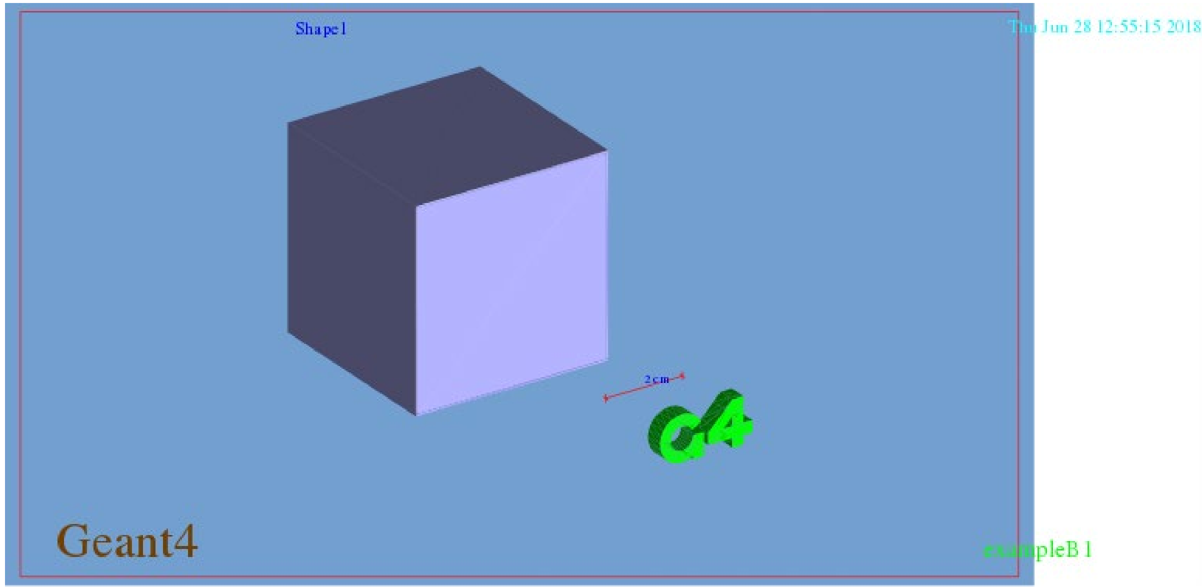


D2 scintillator study (Loss per bounce, on going)

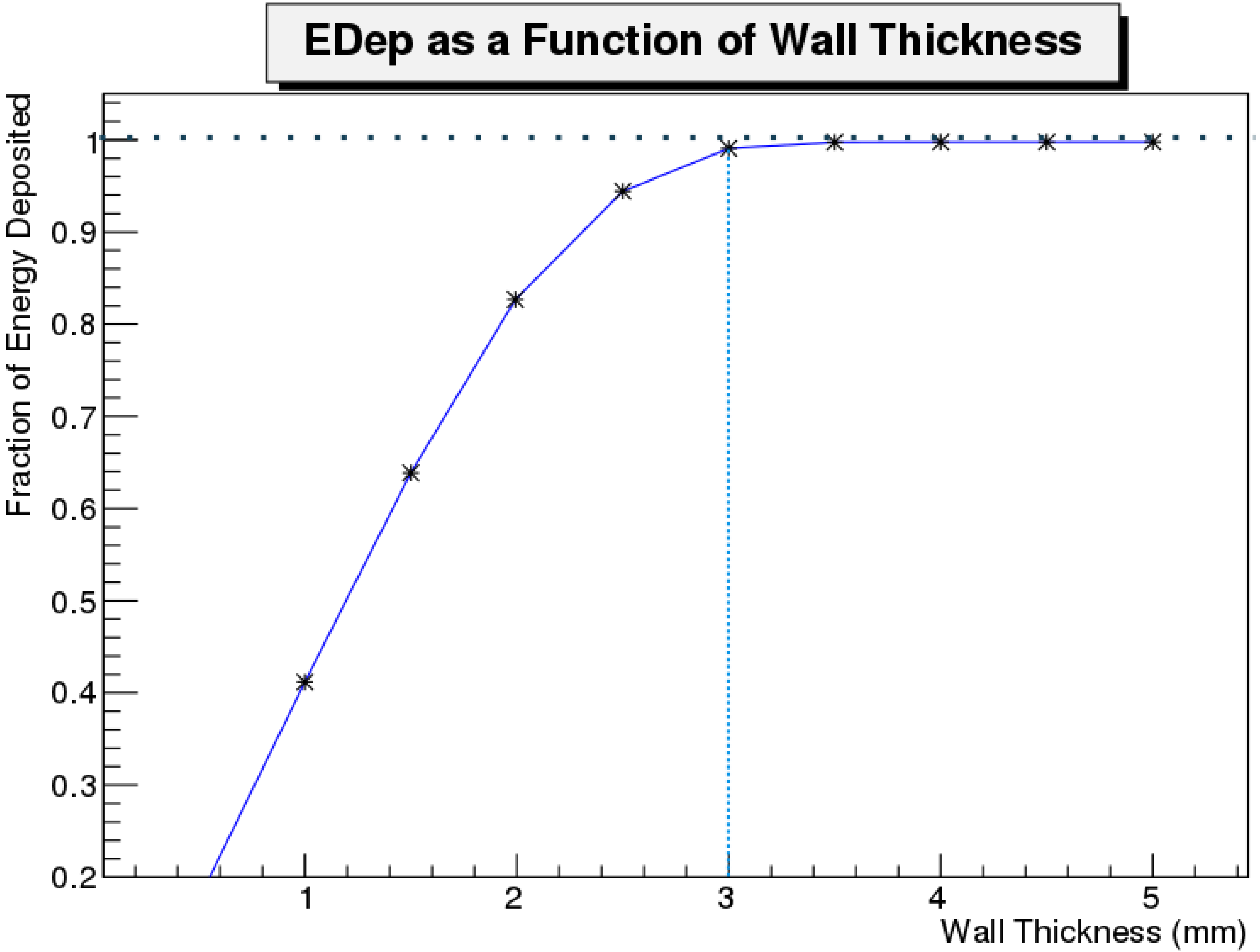


Simulation: Overview

- Thickness of the scintillator
- Electron counting efficiency
  - Dead layer
  - Low energy deposition events
- Neutron counting efficiency
  - Detection of 573 keV Proton

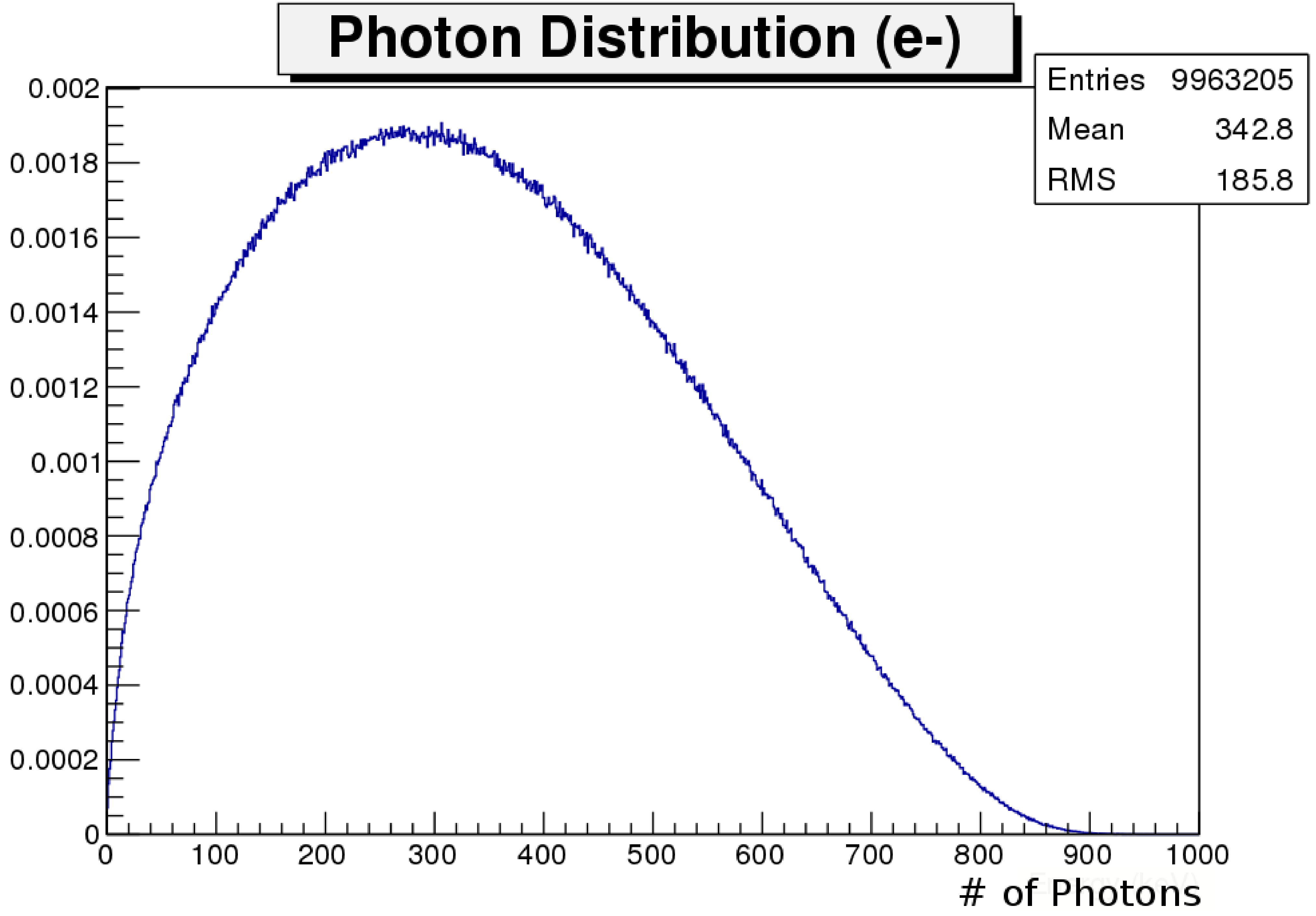


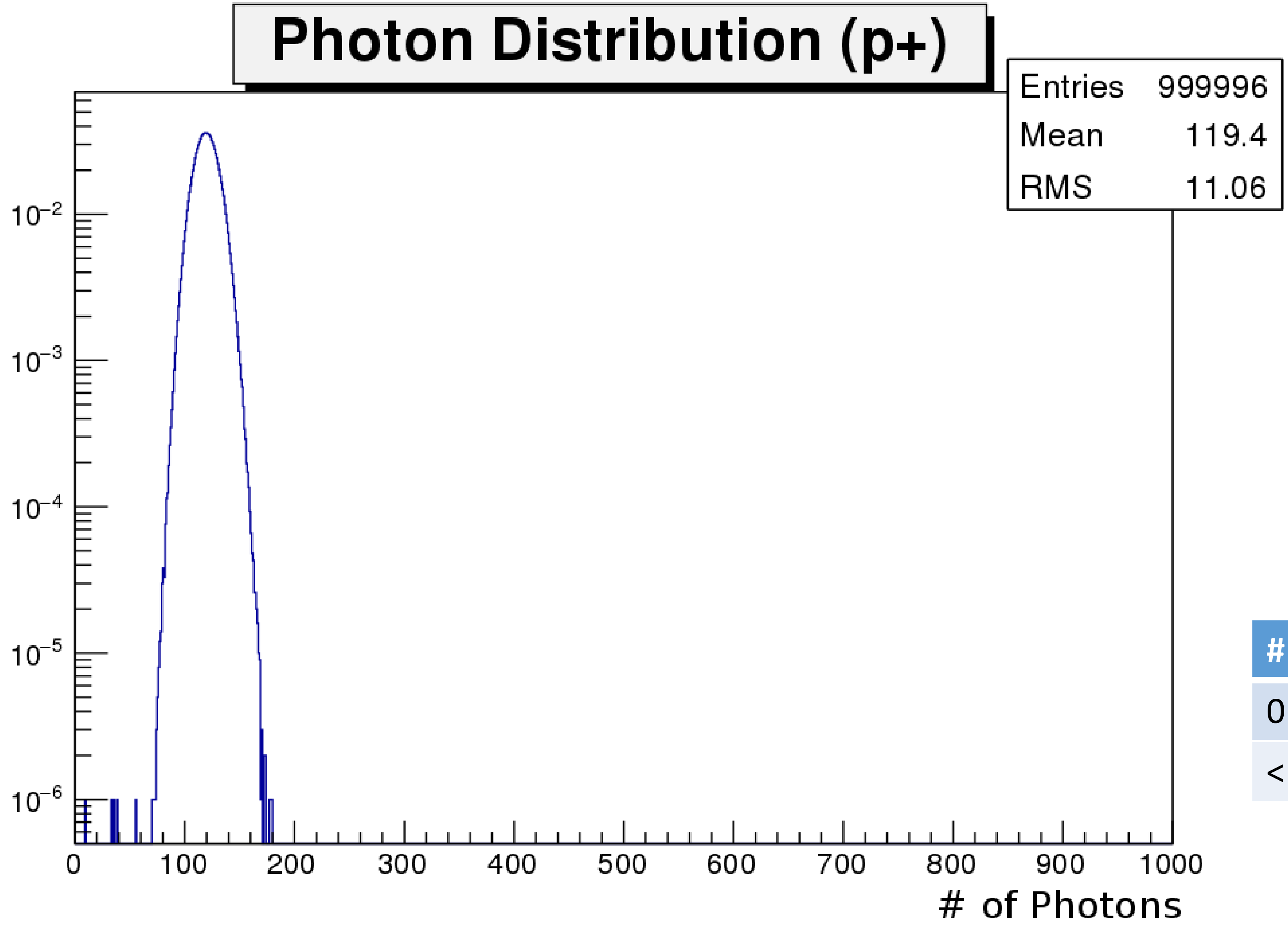
Wall thickness for scintillator



Simulation for detection efficiencies

- Dead layer thickness (1 um)
- Electron to photon conversion (8000 photons/MeV)
- Photon transport losses
  - 2/3 due to edge coupling of SiPM to scintillator
  - 40% quantum efficiency for the SiPM.
- Protons have an additional quenching factor of 20%.
- < 5 photons is considered undetectable


Photon Distribution (e-)
Entries 9963205
Mean 342.8
RMS 185.8
0.002
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
0
100
200
300
400
500
600
700
800
900
1000
# of Photons



# photons	Electrons	Protons
0	0.368%	0.0004%
< 5	0.083%	0

Timeline

Goal: Acquired funding for next 3 years to demonstrate the feasibility of 0.1% lifetime measurement

- Year 1: feasibility study with dPS scintillator and start dPS box procurement process.
- Year 2: construction of the experiment (scintillator boxes, vacuum chamber, dPS, SiPM, and DAQ)
- Year 3: offline tests of complete assembly with beta-gamma and alpha gamma sources, then UCN test.

Conclusion

Sources of Errors	Estimated size of effect	Method to measure/reduce
Dead time (decay)	5×10^{-6}	<50 ns response
Dead time (Neutron)	5×10^{-4}	<50 ns response
Electron detection efficiency	Need to measure	β-γ sources
Neutron detection efficiency	Need to measure	α-γ sources
Dead layer correction	4×10^{-3}	Characterize dead layer
Neutron room background	Need to measure	^{6}Li shield, dPS scintillator
Backgrounds (cosmic, spallation…)	Need to measure	Active rejection (NaI, double scintillaor)
Residual ^{3}He	3×10^{-4}	Need to sample gas frequently

Acknowledgements

Z. Tang, C. Morris, S. Clayton, C. Cude-Woods, D. Fellers, K. Hickerson, J. Lambert, T. Ito, M. Makela, C. O'Shaughnessy, A. Saunders, R.W. Pattie, A. R. Young, B. Zeck, E. Watkins

Supports from:

DOE SULI program
APS CEU program
LANL LDRD program