Residual Gas Effect on aCORN

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Acknowledgements

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◦ My advisor Scott Dewey.
◦ My professor Fred Wietfeldt.
◦ Tulane University
◦ The SURF Program and Directors
◦ NIST
◦ DOE and NSF

Outline

1. **aCORN Experiment Overview**

2. Residual Gas Effect Overview

3. Residual Gas Simulation Results

4. Measurement of the Residual Gas Composition

5. How do we arrive at a final value for the size of this systematic effect?
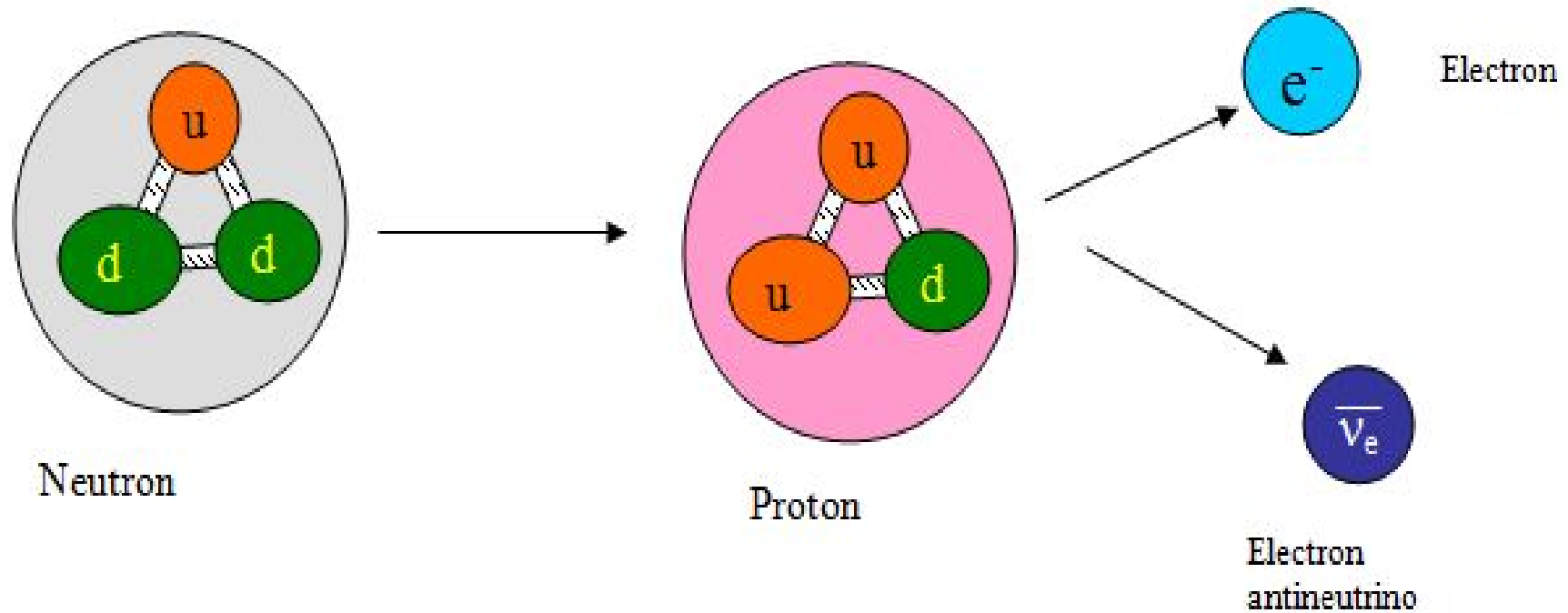
Outline

Neutron Decay

Neutron
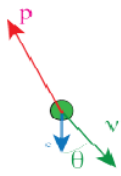
Proton

Electron

e^-

$\overline{\nu_e}$

Electron
antineutrino

What is aCORN?

Little a **COR**relation

in **N**eutron Decay

Neutron Decay Parameters

Phenomenological (½+ → ½+) beta decay formula
(Jackson, Treiman, Wyld, 1957)

$$dW \propto \frac{1}{\tau} F(E_e) \left[1 + a \frac{\vec{p}_e \cdot \vec{p}_\upsilon}{E_e E_\upsilon} + A \frac{\vec{\sigma}_n \cdot \vec{p}_e}{E_e} + B \frac{\vec{\sigma}_n \cdot \vec{p}_\upsilon}{E_\upsilon} + D \frac{\vec{\sigma}_n \cdot (\vec{p}_e \times \vec{p}_\upsilon)}{E_e E_\upsilon} + b \frac{m_e}{E_e} \right]$$

In the standard model we have

$$a \approx \frac{1-\lambda^2}{1+3\lambda^2} \qquad b = 0$$

$$A \approx -2 \frac{\lambda^2 + \text{Re}(\lambda)}{1+3\lambda^2} \qquad B \approx 2 \frac{\lambda^2 - \text{Re}(\lambda)}{1+3\lambda^2}$$

$$\tau \propto \frac{1}{g_V^2(1+\lambda^2)} \qquad D \approx 2 \frac{\text{Im}(\lambda)}{1+3\lambda^2}$$
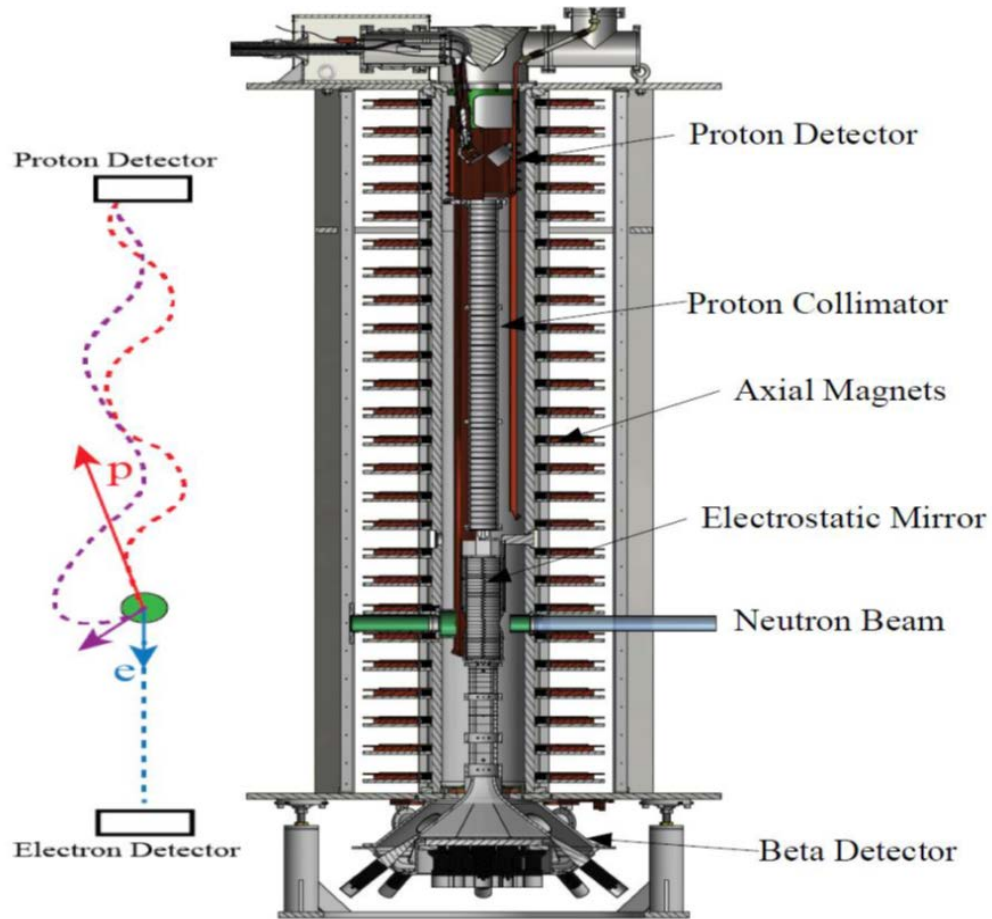
Where $\lambda \equiv \dfrac{g_A}{g_V}$

Standard Model Predictions
- F1 ≡ 1 + A − B - a = 0
- F2 ≡ aB − A − A2 = 0

Present Limits
- F1 = (3 ± 6) x10-3
- F2 = (3 ± 5) x10-3
  (dominated by "a")

a = -0.1030 ± 0.0040

aCORN Schematic

Proton Detector

Proton Detector

Proton Collimator

Axial Magnets

Electrostatic Mirror

Neutron Beam

Beta Detector
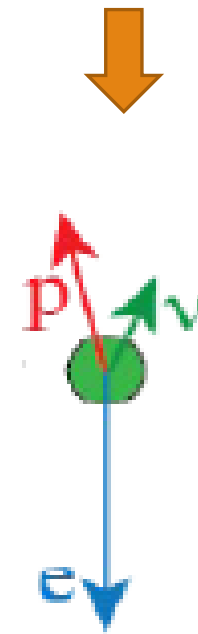
Electron Detector
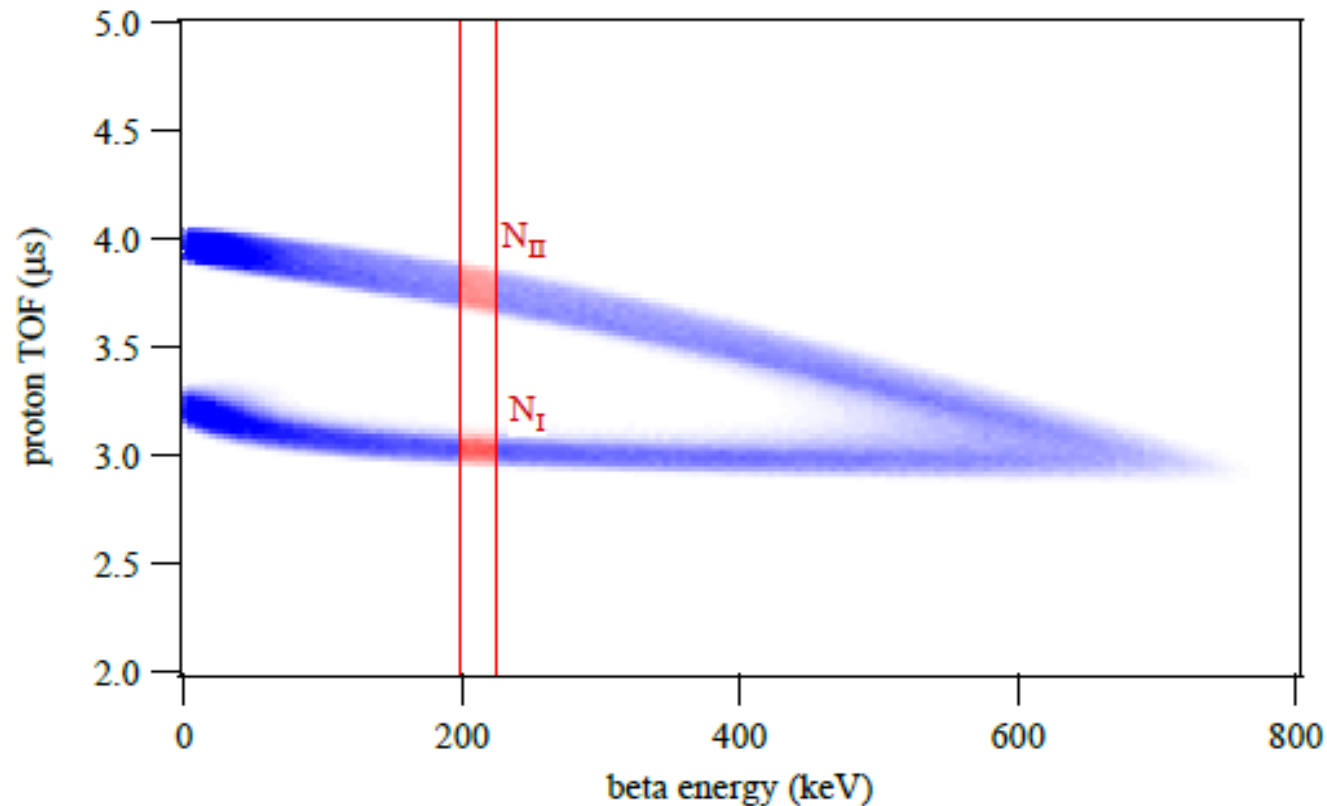
Proton Momentum Space Diagram

Group I (Fast)
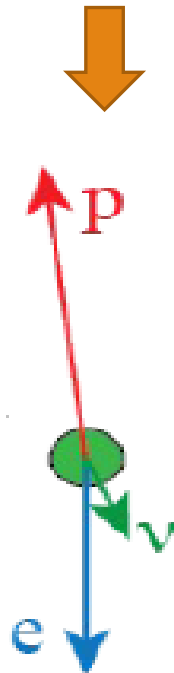
Group II (Slow)

The Wishbone
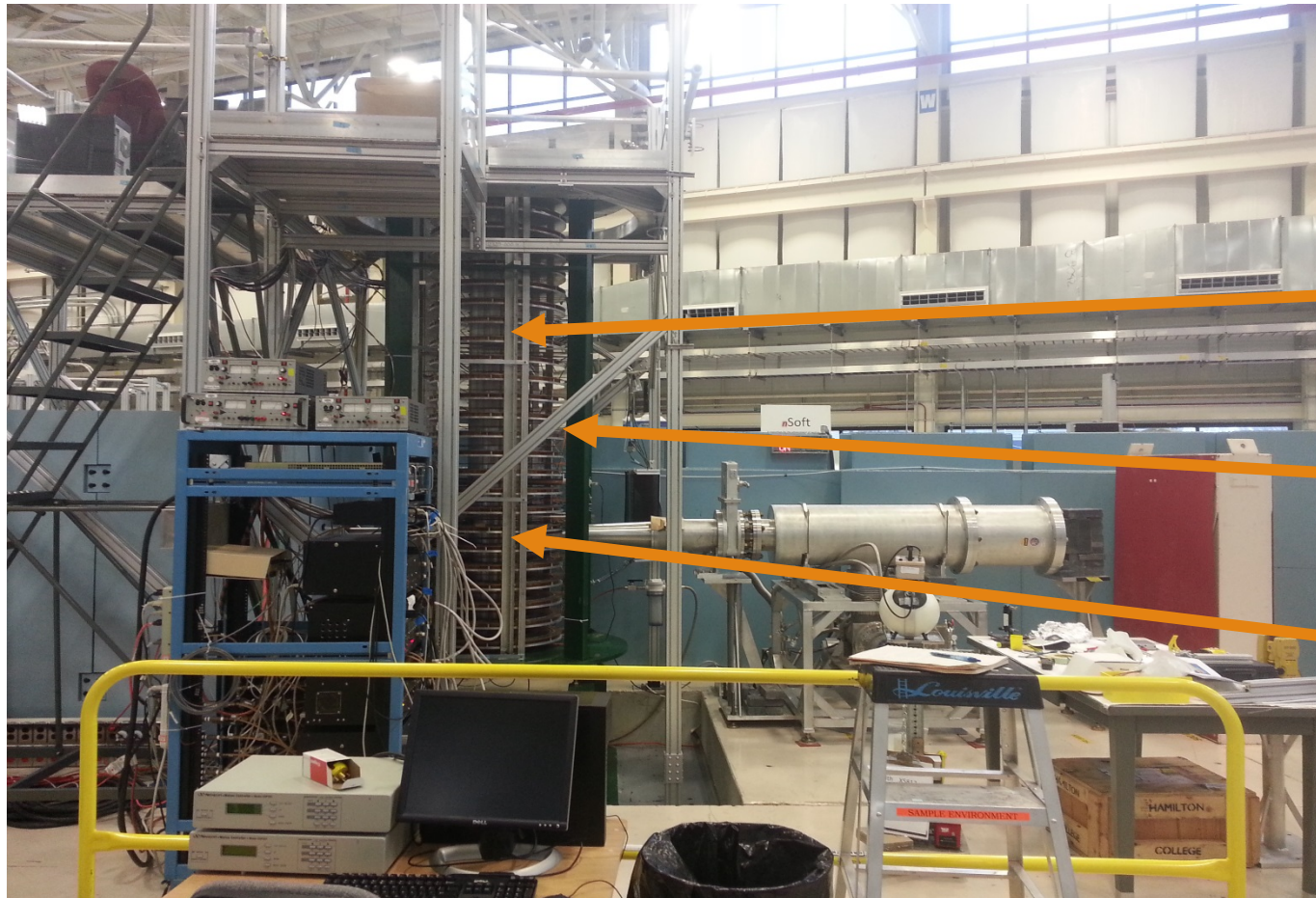

- Group I = Fast, Small TOF
- Group II = Slow, Large TOF

$$a = \frac{1}{v_\beta} K(E_\beta) \left[\frac{N_{Fast} - N_{Slow}}{N_{Fast} + N_{Slow}} \right]$$

The aCORN Apparatus

Proton Collimator Location

Solenoid

Decay Volume Location

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Residual Gas Effect

- The gas remaining in the vacuum apparatus during data collection will have an effect on the asymmetry we are measuring.

- We are attempting to measure the size of this residual gas effect by increasing the pressure in the apparatus and recording the effect this has on the asymmetry. Is the effect linear?

- We are also modelling the effect in order to guarantee that the physics of the effect is well enough understood to trust the experimental data.
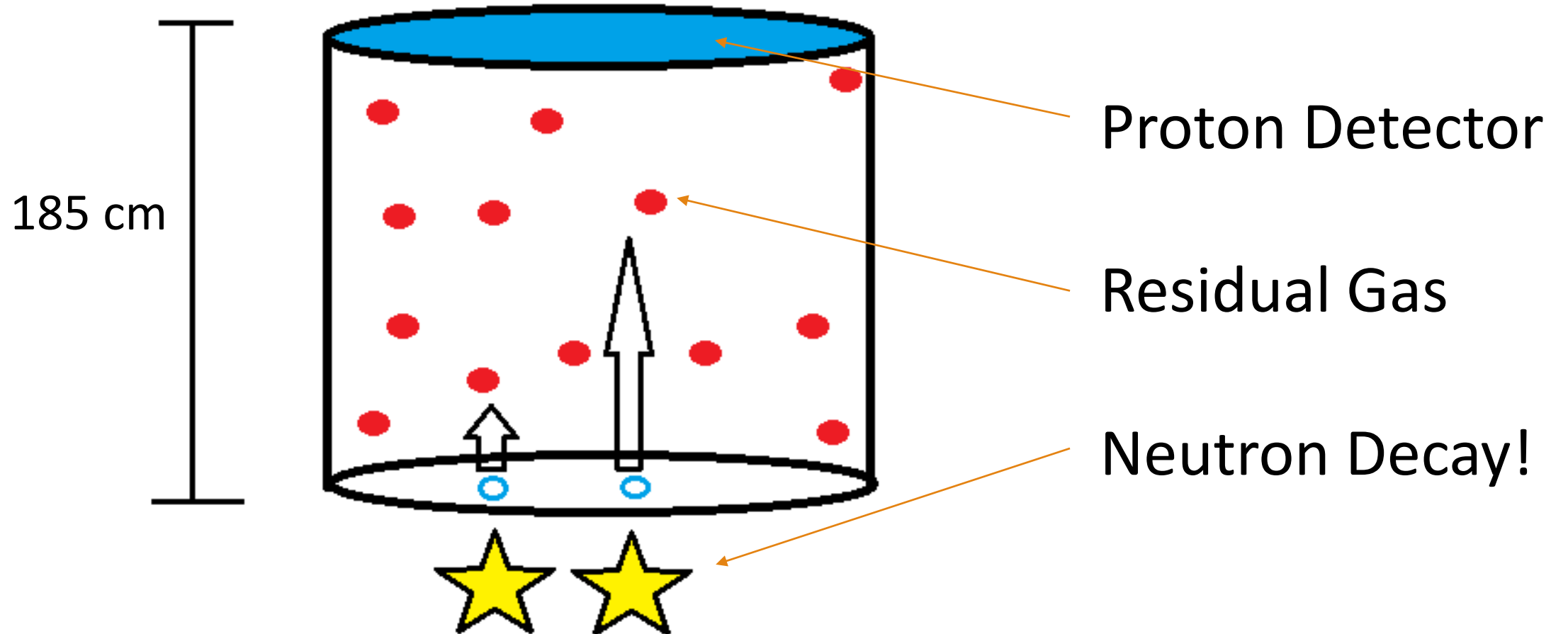
High Pressure = 100 times running pressure
Effect = -.1 (deviation in asymmetry)

Running Pressure
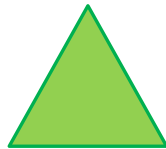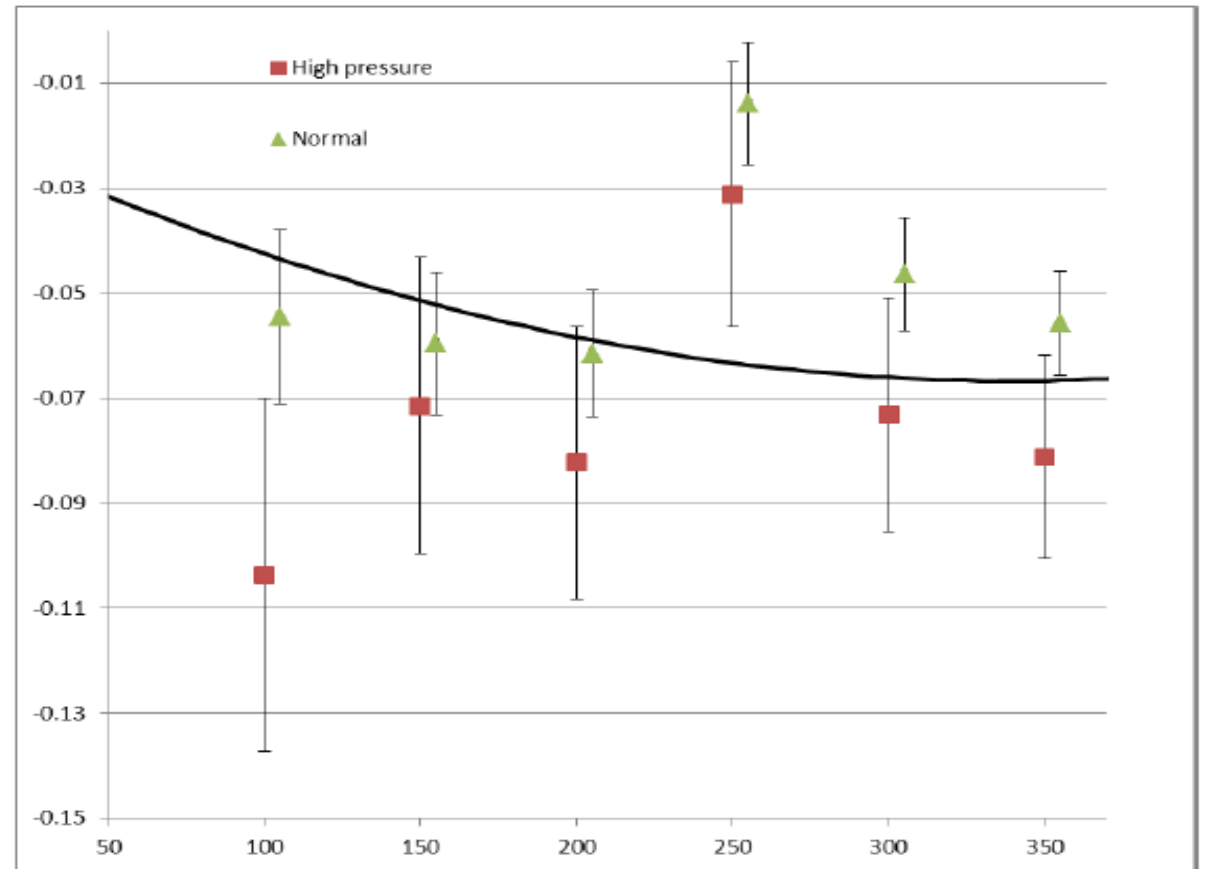Effect = -.1/100 = -.001

Residual Gas Effect Continued

185 cm

Proton Detector

Residual Gas

Neutron Decay!

Residual Gas Experiment

= High pressure
(2.5x10^{-5} torr)

= Normal pressure
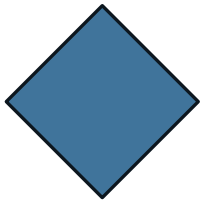(4x10^{-7} torr)
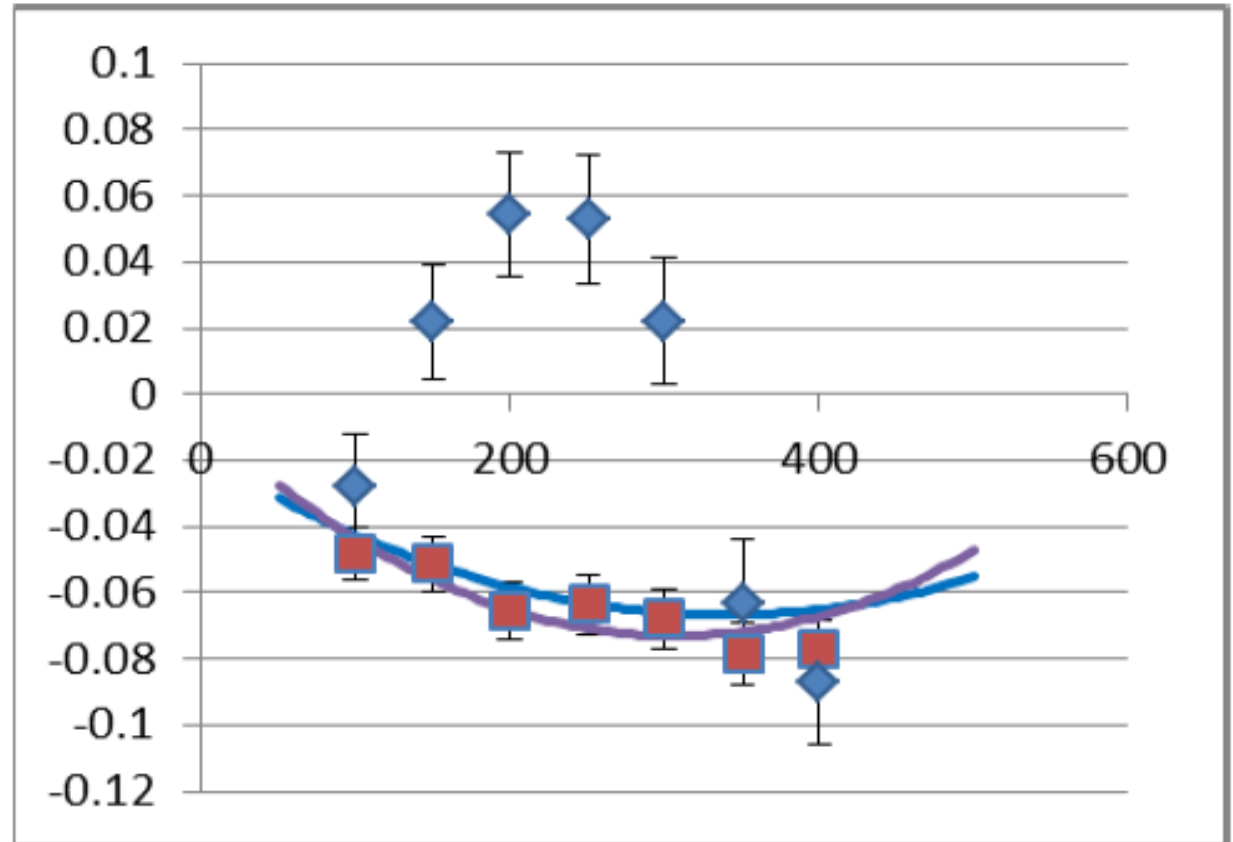
Asymmetry vs. Beta Energy (keV)

Outline

Geant 4 Simulation

◼ = Running pressure (4x10^{-7} torr)

◆ = High pressure (2.5x10^{-5} torr)

Asymmetry vs. Beta Energy (keV)
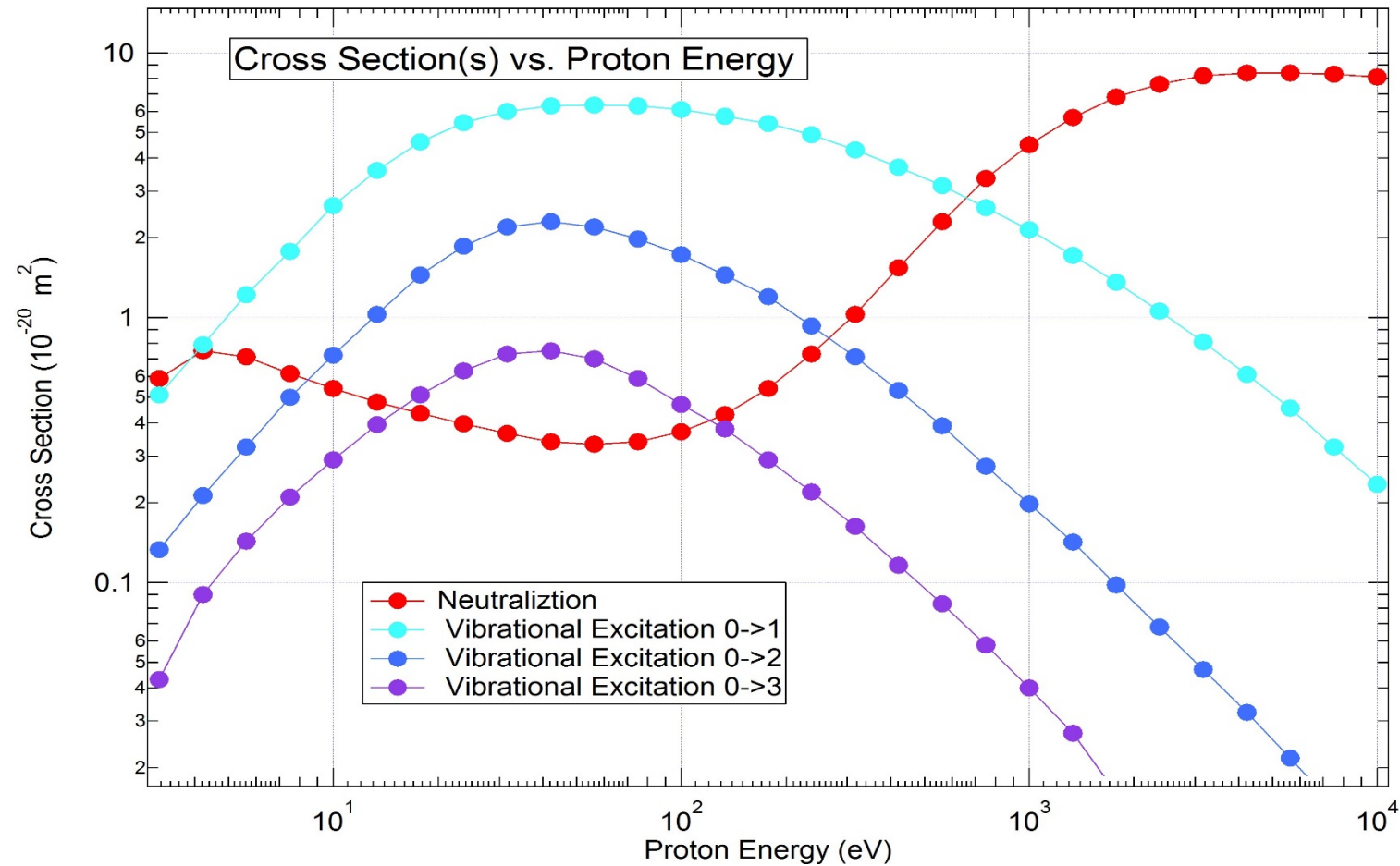
Residual Gas Simulation: Things to Consider

- Neutralization and Scattering

- Residual gas composition: Initially assumed to be H_2

- Pressure and Temperature in proton collimator: **4×10^{-7} torr, 200K**

Cross Sections: Proton in H$_2$ Gas

Cross Section(s) vs. Proton Energy

Legend:
- Neutraliztion
- Vibrational Excitation 0->1
- Vibrational Excitation 0->2
- Vibrational Excitation 0->3

X-axis: Proton Energy (eV)
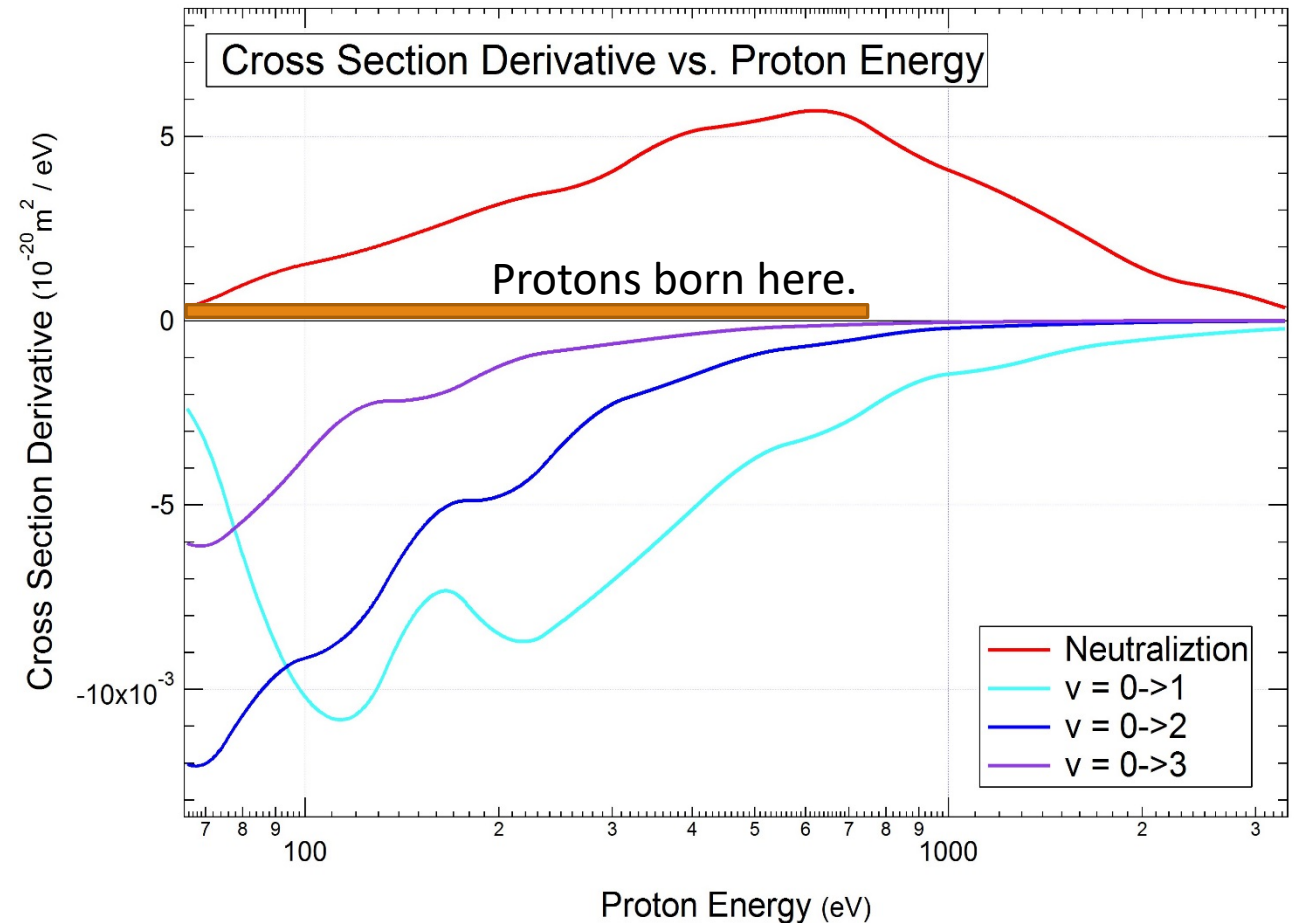Y-axis: Cross Section (10^{-20} m^2)

Cross Section Derivatives

- Recall:

$$\textbf{Asymmetry} = \frac{N_{Fast} - N_{Slow}}{N_{Fast} + N_{Slow}}$$

- Thus:
  - Intuitively, a positive derivative would result in a negative change in asymmetry.
  - And a negative derivative would result in a positive change in asymmetry.
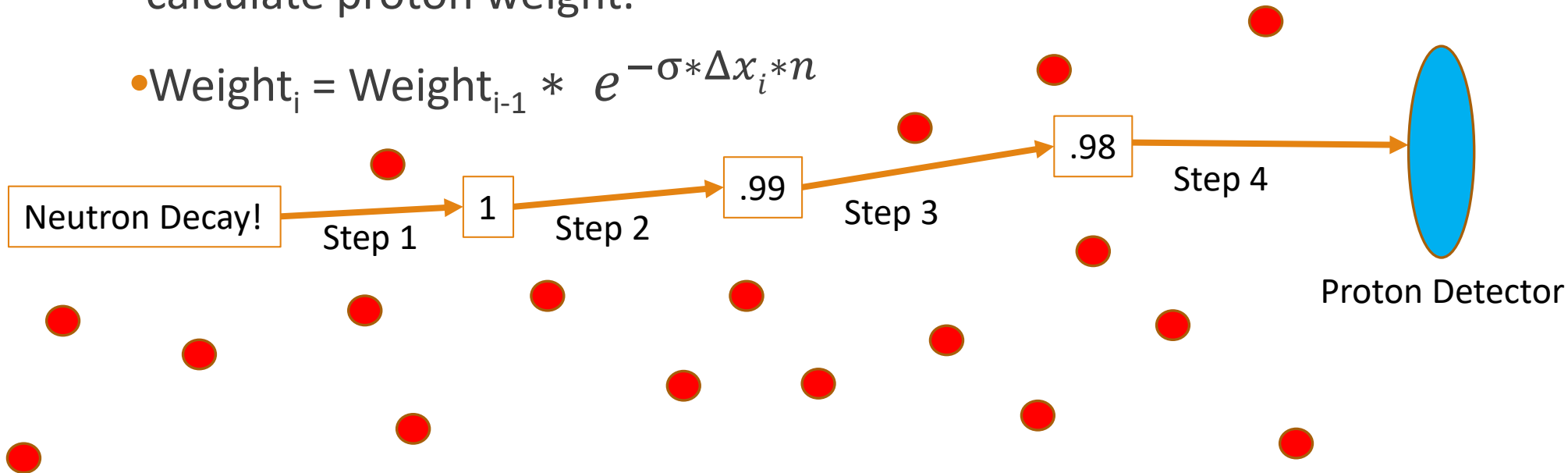
Neutralization

Method:

- Alteration of existing Runge-Kutta Monte Carlo to incorporate the effect of neutralization. Proton Energy and distance traveled per step are used to calculate proton weight.

- Weight$_i$ = Weight$_{i-1}$ * $e^{-\sigma * \Delta x_i * n}$

Scattering

- Energy considerations lead us to believe that the H_2 molecules are in their vibrational ground state.

- The large relative energy of the proton makes many vibrational states accessible for excitation.

Method:

- Alteration of existing Runge-Kutta Monte Carlo to incorporate the effect of scattering. When scattered the proton recoil velocity direction is randomized within a cone.

Monte Carlo Results

- The change in asymmetry (delta asymmetry) caused by the residual gas found in the MC is both the right sign and comparable in size to the preliminary experimental results.
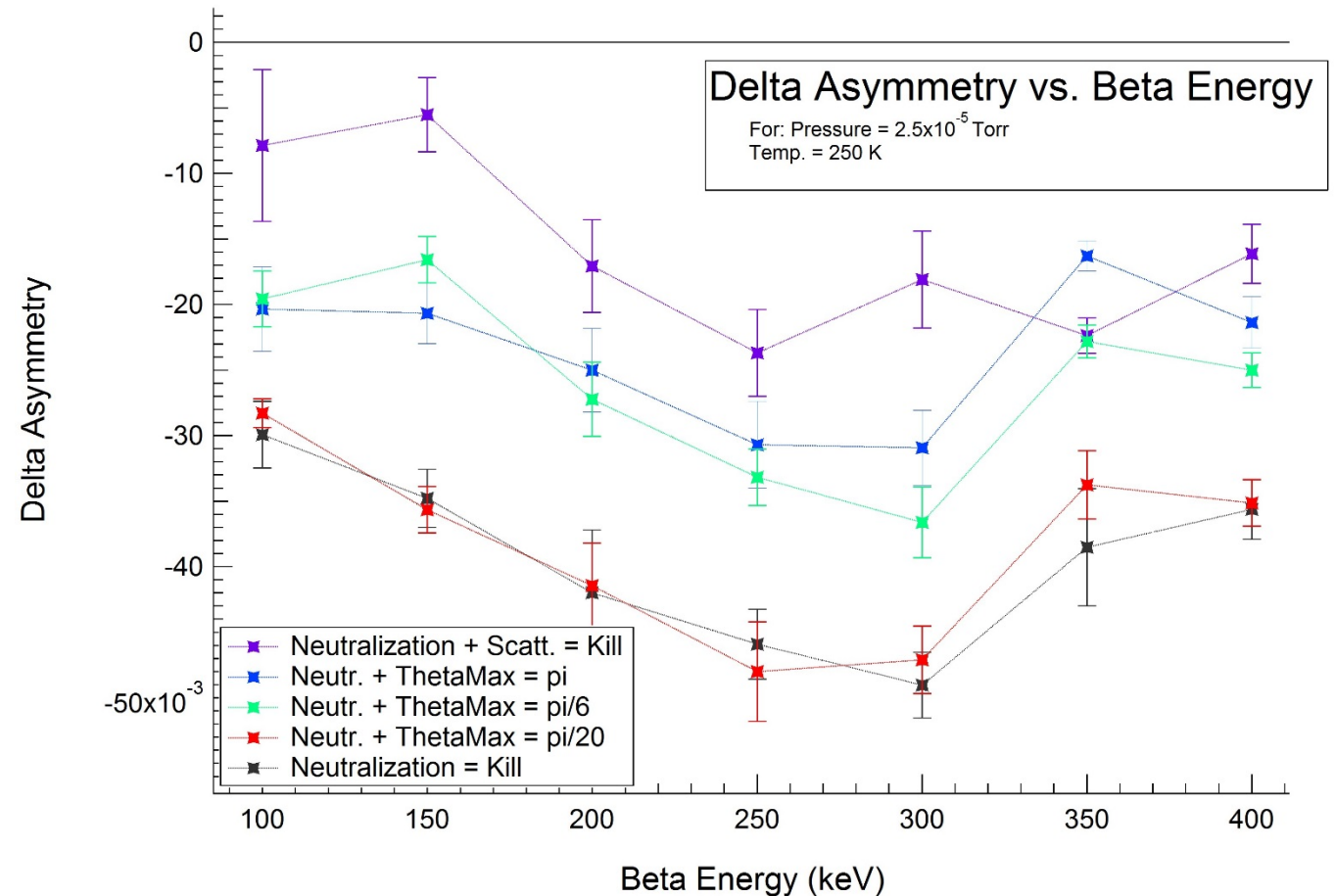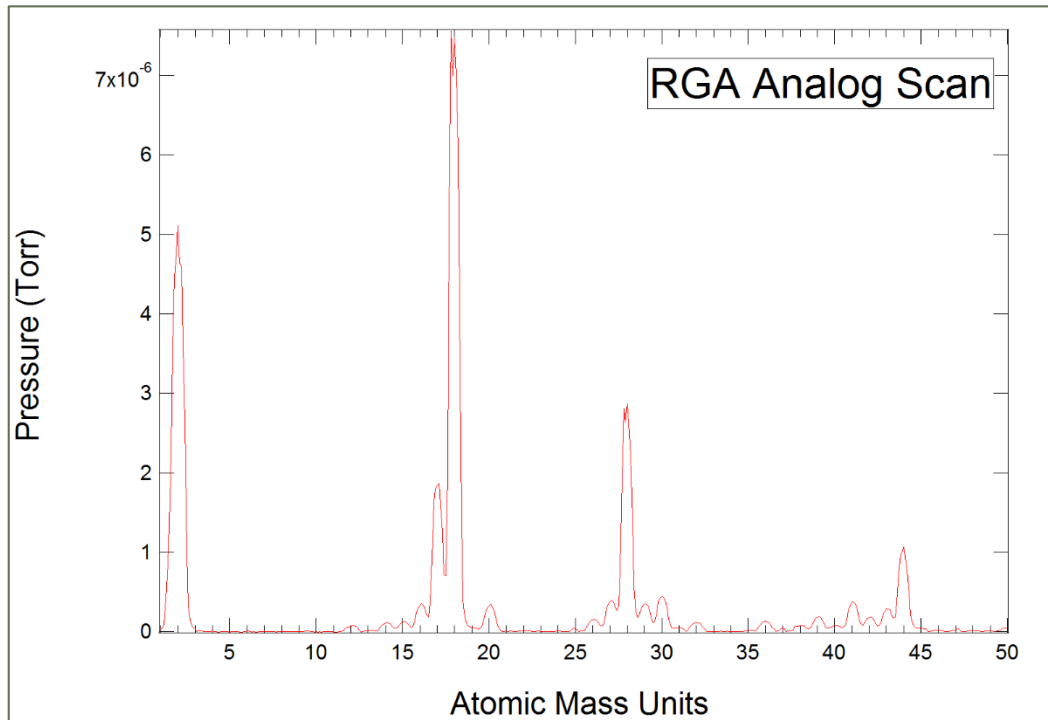

Delta Asymmetry vs. Beta Energy
For: Pressure = 2.5×10^{-5} Torr
Temp. = 250 K

Outline

Residual Gas Analyzer (RGA) Results

Running Pressure (1.04×10^{-6} torr)

High Pressure (5.89×10^{-5} torr)

Highest Gas Load: **H_2 and H_2O**

Highest Gas Load: **N_2 and O_2**

Residual Gas Analyzer (RGA) Results

Running Pressure:
Highest Gas Load: **H_2 and H_2O**

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Highest Gas Load: **N_2 and O_2**
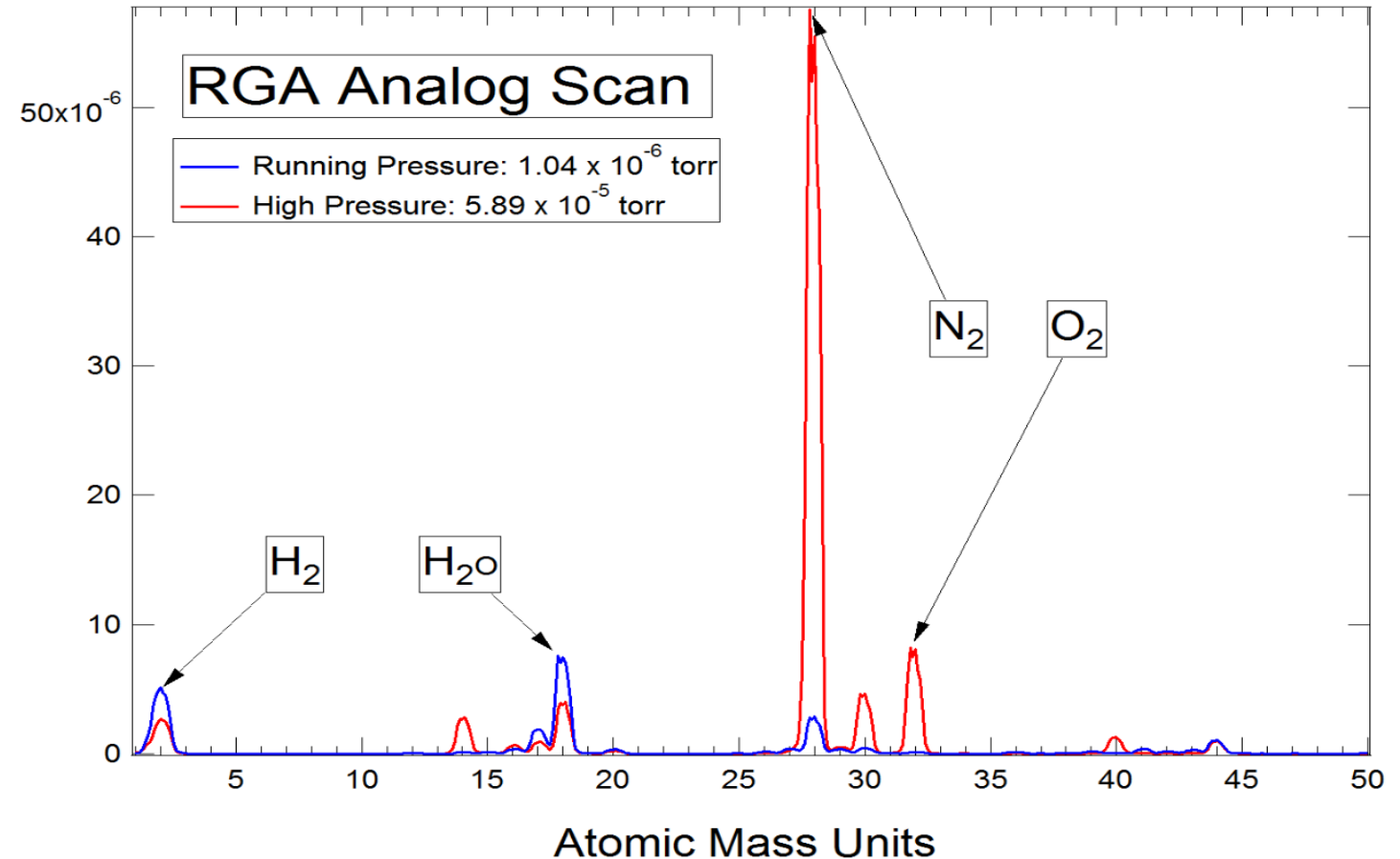
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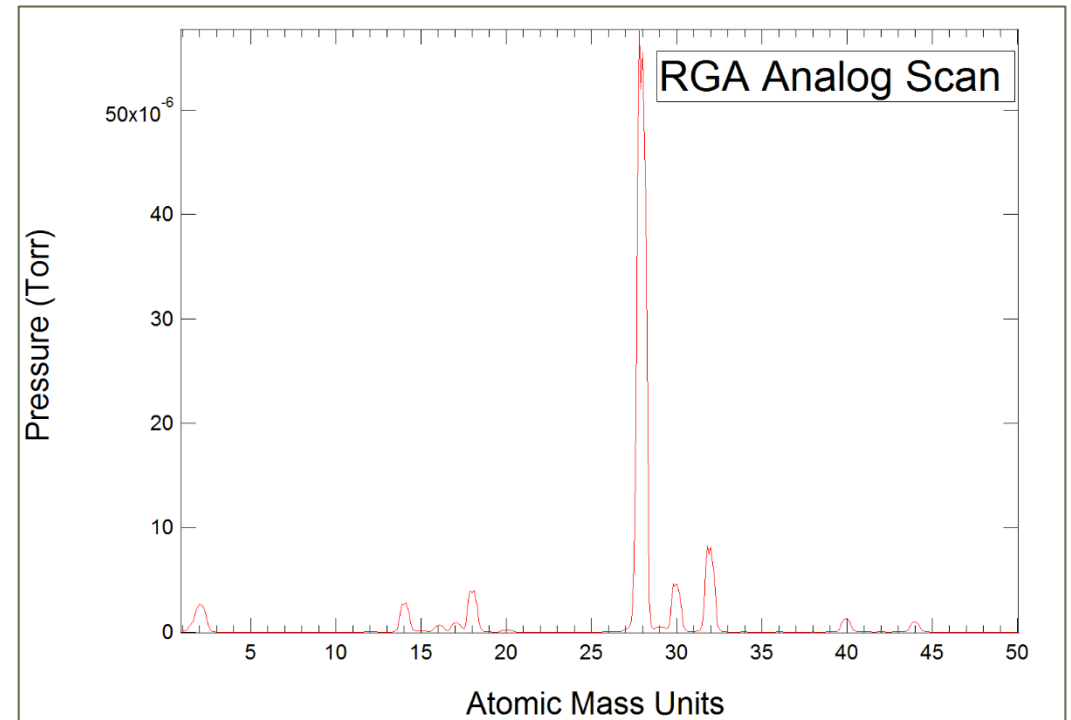5. How do we arrive at a final value for the size of this systematic effect?

How to measure this Effect?

- Our proposed method for measuring the size of the effect will probably not suffice.

- We may need to just scale the pressure by a factor of 4 as opposed to a factor of 40 in order to maintain the same gas composition. But measuring the effect this way will take longer and be more difficult because the pressure effect will be smaller.

- Cross sections for low energy protons in H_2O must be found and put into the Monte-Carlo simulation.
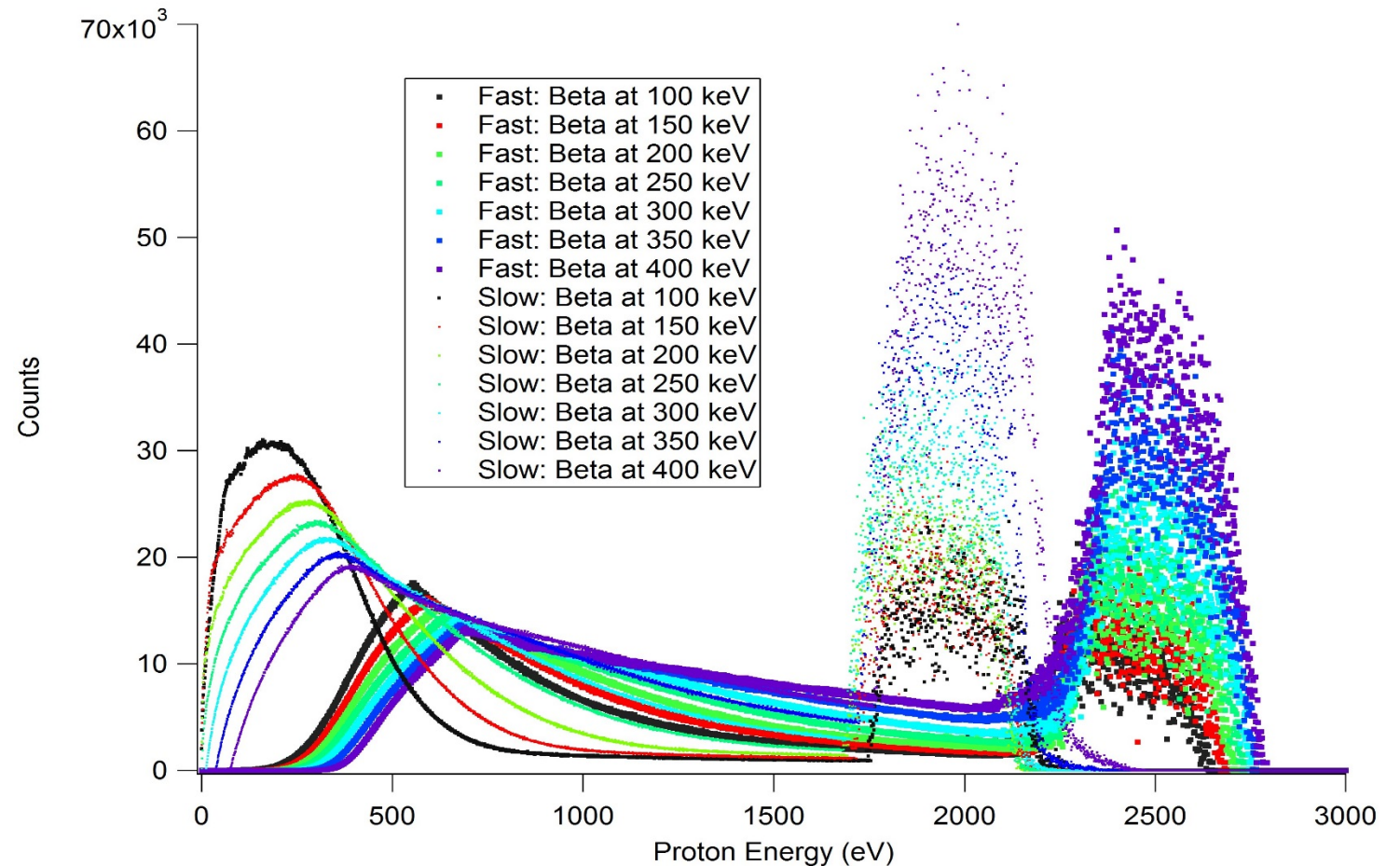
Conclusion

- The residual gas systematic effect is relevant to several major neutron decay experiments (aCORN, Beam Lifetime, Nab) and thus a thorough investigation is necessary, especially when programs like Geant 4 are failing to aptly model the problem.
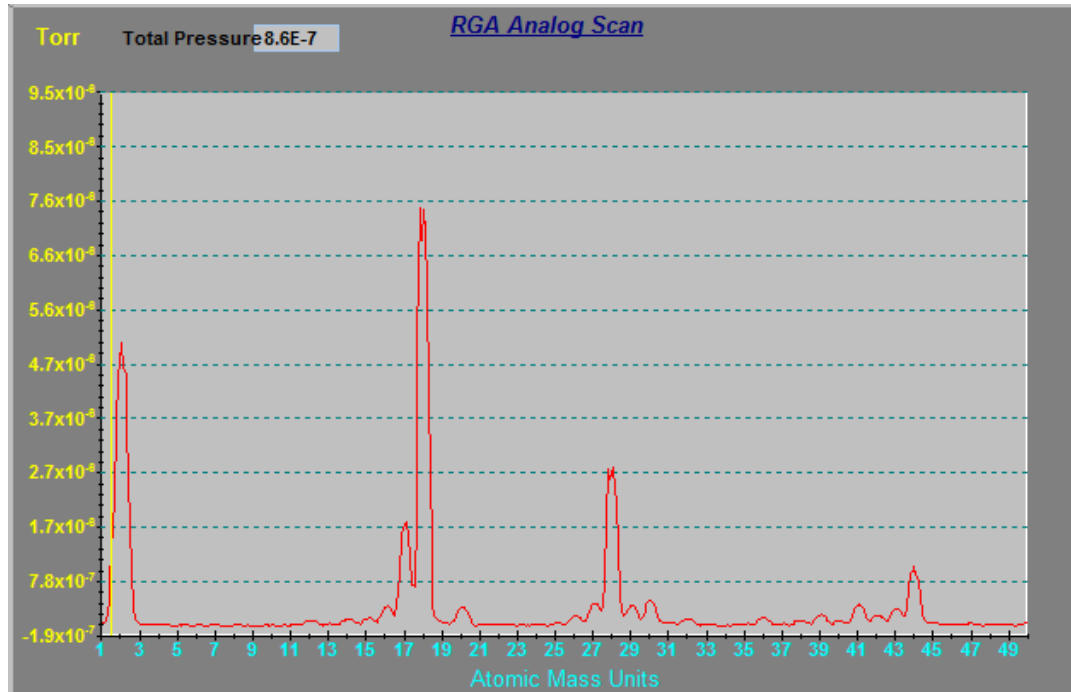
Thank you!

What are the energies of these protons?

- I recorded the energy of the proton for each step in the Monte Carlo for a given proton group (Fast or Slow) and Beta energy.
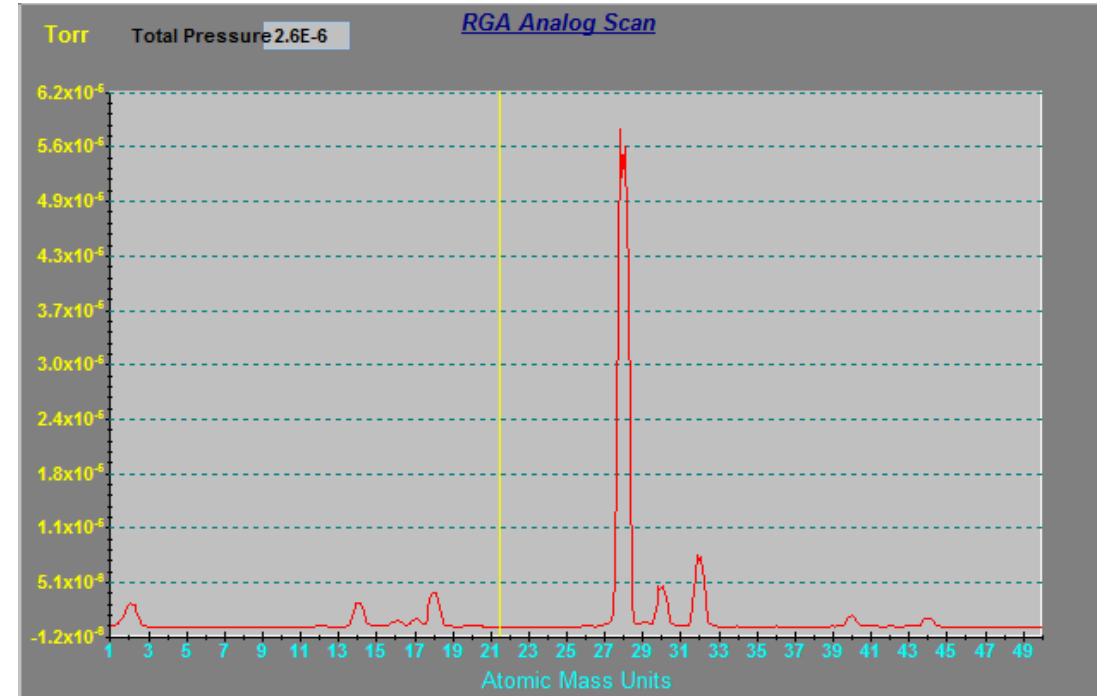
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Highest Gas Load: **N_2 and O_2**

RGA Results Continued

- Our proposed method for measuring the size of the effect will not work as we had thought.

- The regular running pressure, temp, RG composition. And the high pressure temp and RG composition?

Type equation here

- The purpose of the MC and the purpose of the experiment. And how the experimental value is used to actually get a value for the size of the systematic uncertainty.

$$a = \frac{1}{v_\beta} K(E_\beta) \left[\frac{N_{Fast} - N_{Slow}}{N_{Fast} + N_{Slow}}\right]$$

$$a(E_\beta) = \frac{1}{v_\beta} K(E_\beta) \left[\frac{N_I - N_{II}}{N_I + N_{II}}\right]$$