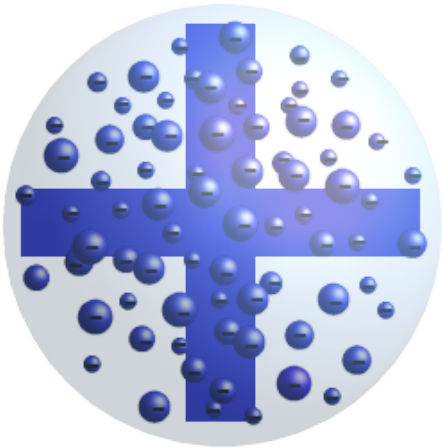
Rutherford Scattering Detection through Gold Foil

Henry Shackleton

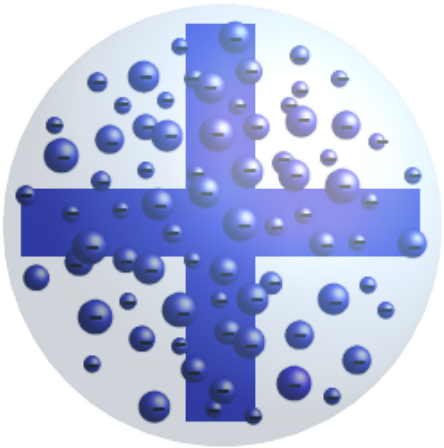
April 27, 2017

Plum Pudding and Rutherford Models Predict Different Scattering Behavior



Plum Pudding Model

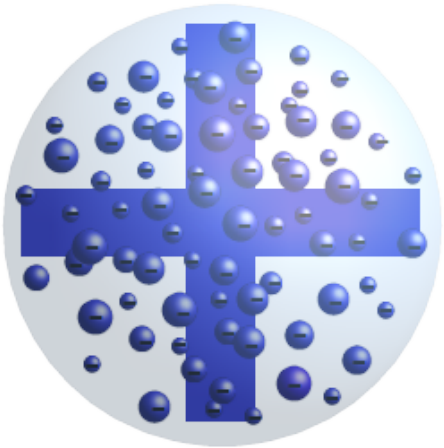
Plum Pudding and Rutherford Models Predict Different Scattering Behavior



Plum Pudding Model

- Small electrons in a "soup" of positive charge

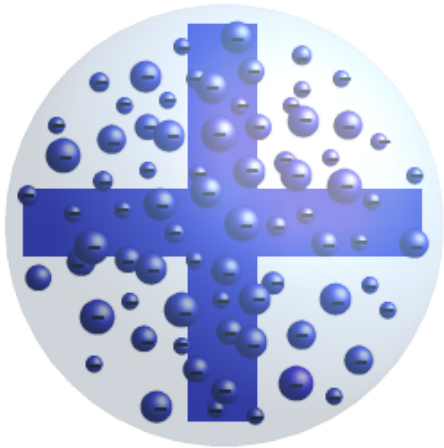
Plum Pudding and Rutherford Models Predict Different Scattering Behavior



Plum Pudding Model

- Small electrons in a "soup" of positive charge
- Produces small-angle scattering that dies off exponentially

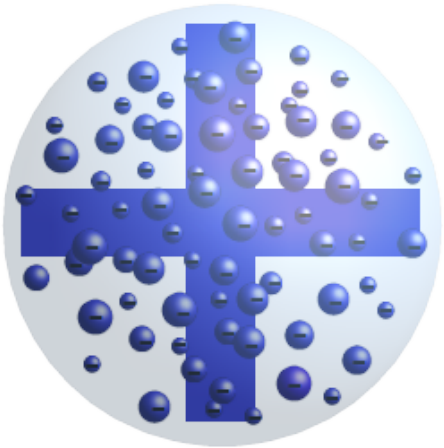
Plum Pudding and Rutherford Models Predict Different Scattering Behavior



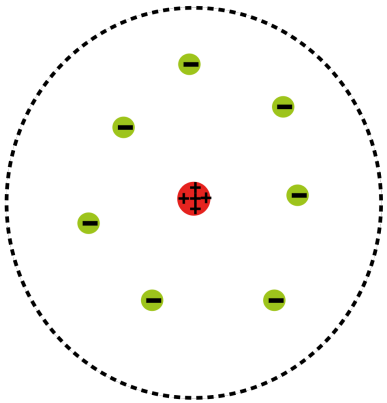
Plum Pudding Model

- Small electrons in a "soup" of positive charge
- Produces small-angle scattering that dies off exponentially
- $F(\theta) \propto e^{-\theta^2/\theta_m^2}$

Plum Pudding and Rutherford Models Predict Different Scattering Behavior



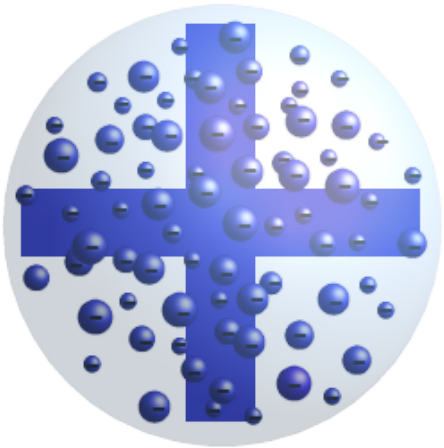
Plum Pudding Model



Rutherford Model

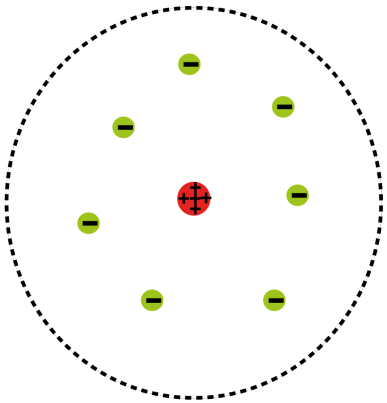
- Small electrons in a "soup" of positive charge
- Produces small-angle scattering that dies off exponentially
- $F(\theta) \propto e^{-\theta^2/\theta_m^2}$

Plum Pudding and Rutherford Models Predict Different Scattering Behavior



Plum Pudding Model

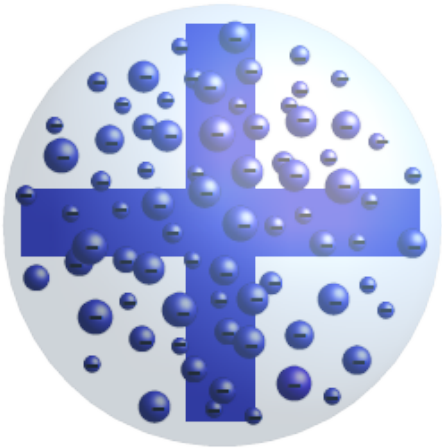
- Small electrons in a "soup" of positive charge
- Produces small-angle scattering that dies off exponentially
- $F(\theta) \propto e^{-\theta^2/\theta_m^2}$



Rutherford Model

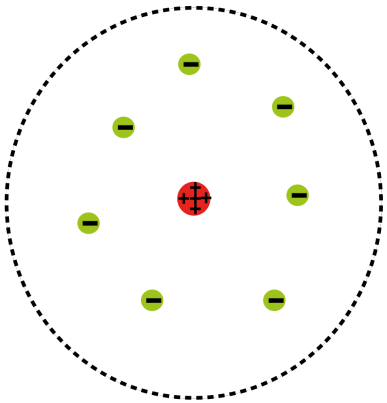
- Electrons surround a concentrated positive charge

Plum Pudding and Rutherford Models Predict Different Scattering Behavior



Plum Pudding Model

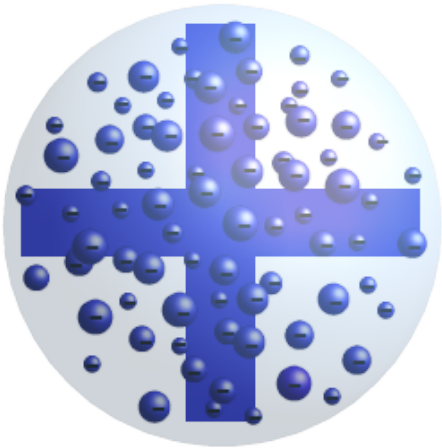
- Small electrons in a "soup" of positive charge
- Produces small-angle scattering that dies off exponentially
- $F(\theta) \propto e^{-\theta^2/\theta_m^2}$



Rutherford Model

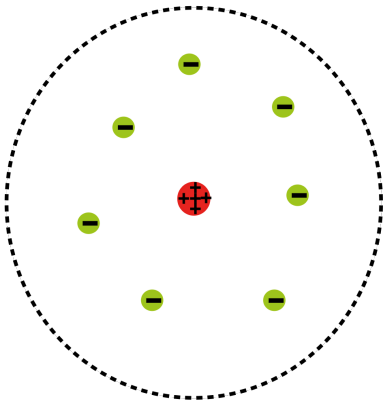
- Electrons surround a concentrated positive charge
- Allows for large scattering angles

Plum Pudding and Rutherford Models Predict Different Scattering Behavior



Plum Pudding Model

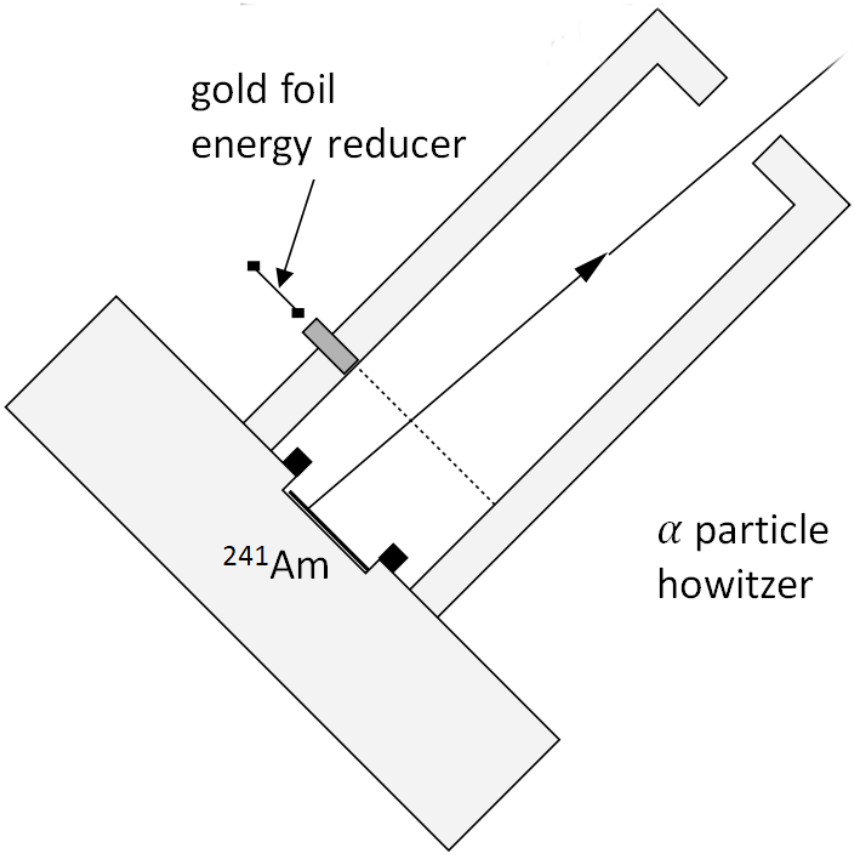
- Small electrons in a "soup" of positive charge
- Produces small-angle scattering that dies off exponentially
- $F(\theta) \propto e^{-\theta^2/\theta_m^2}$



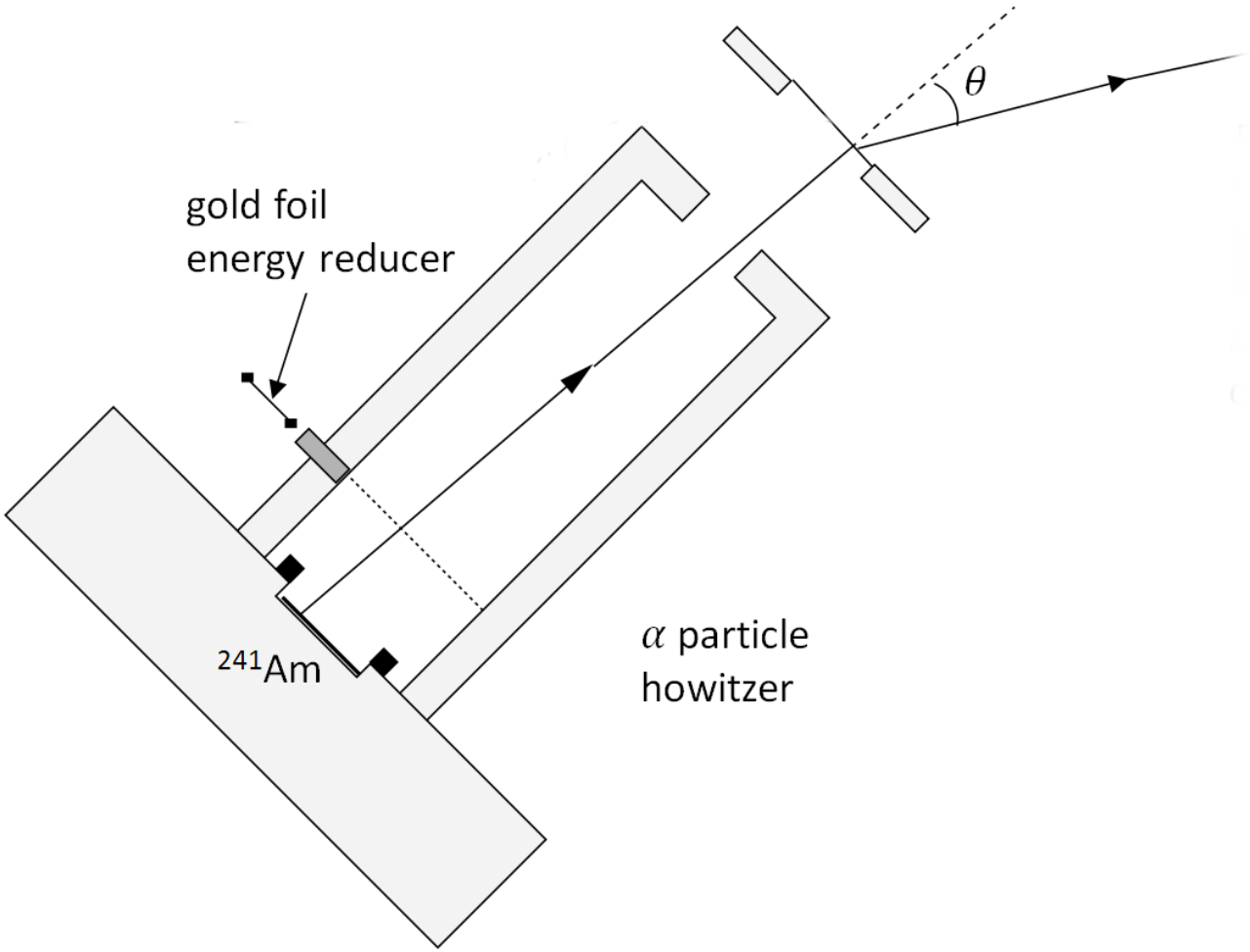
Rutherford Model

- Electrons surround a concentrated positive charge
- Allows for large scattering angles
- $F(\theta) \propto \frac{1}{\sin^4(\theta/2)}$

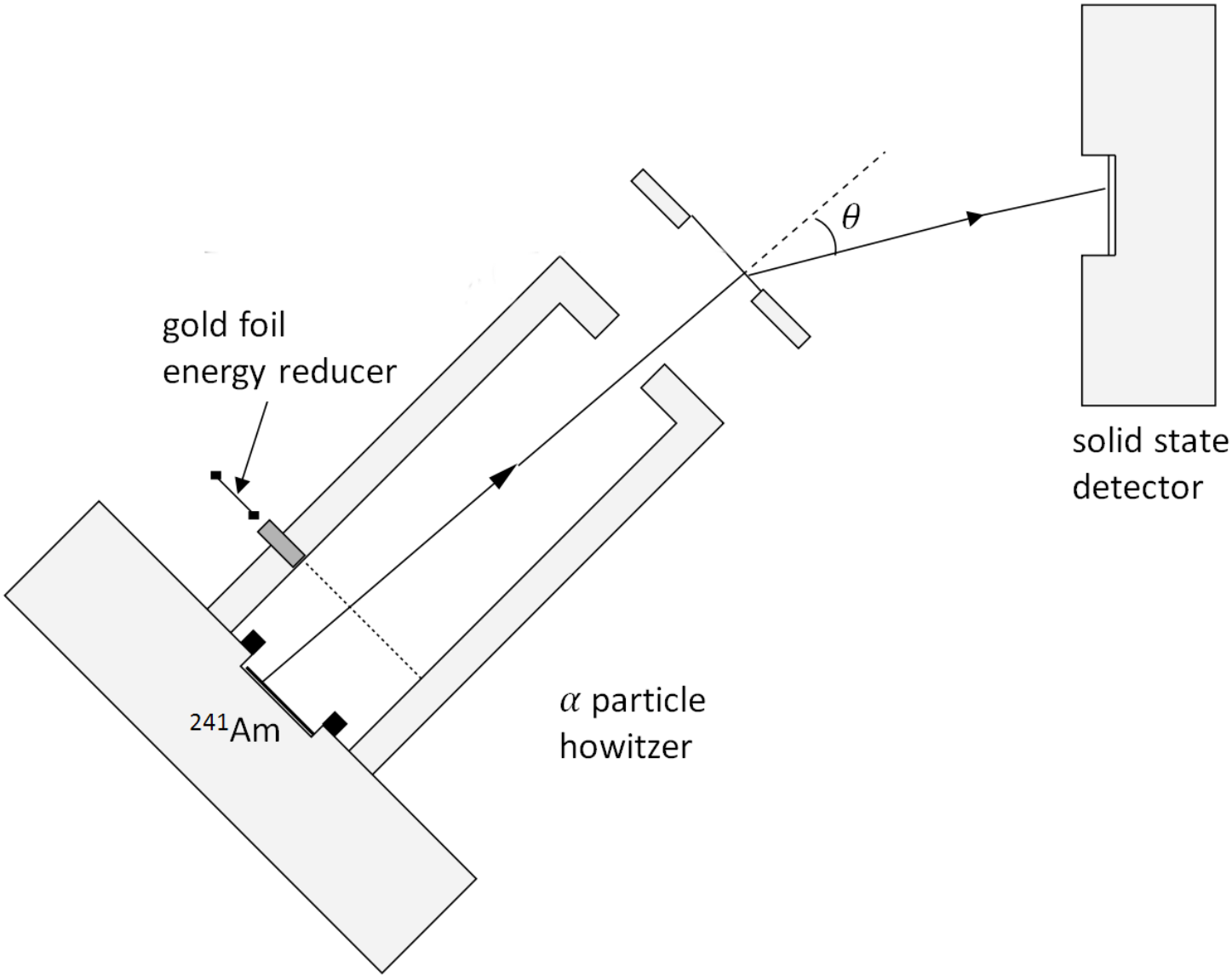
Apparatus allows for scattering detection at various angles



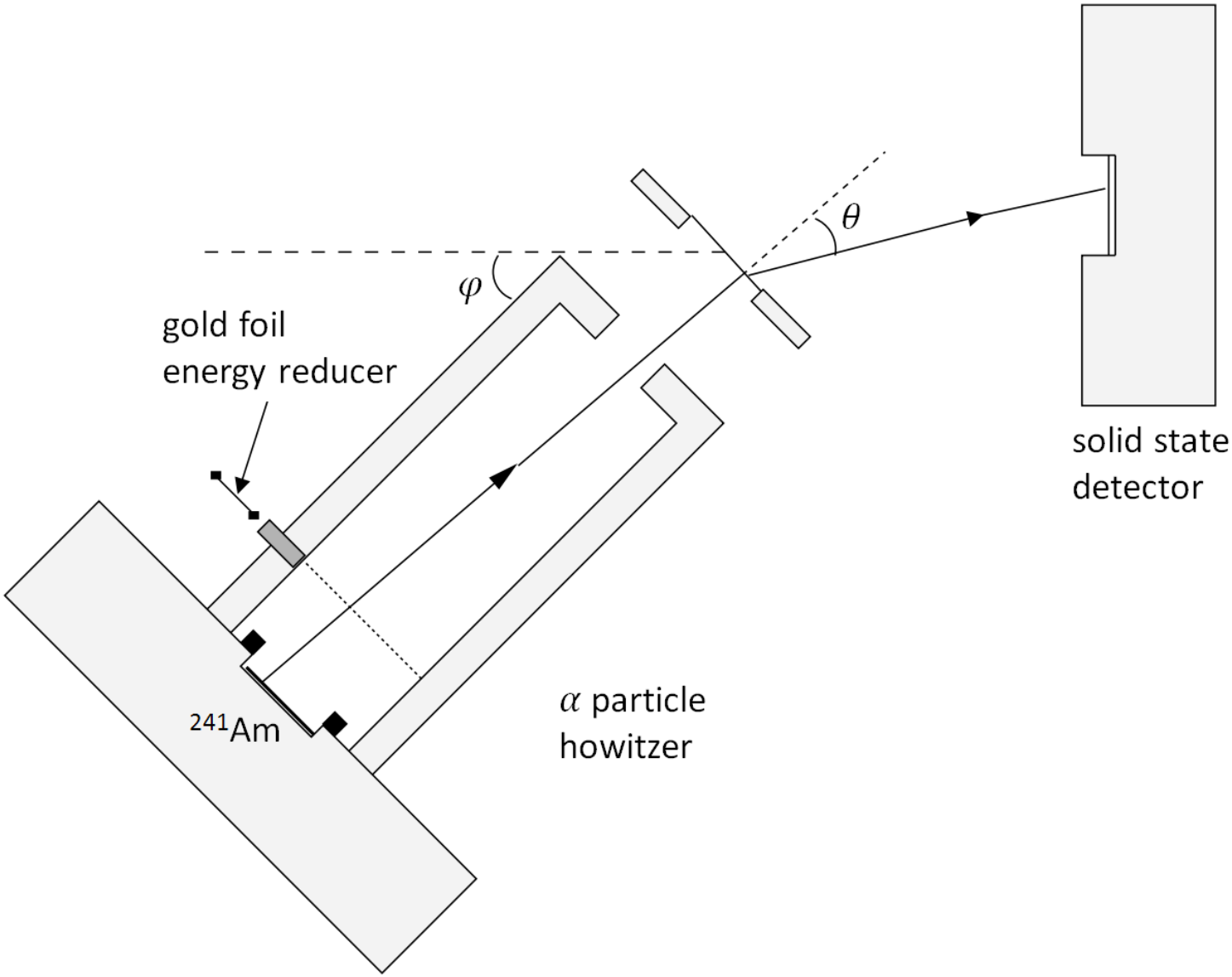
Apparatus allows for scattering detection at various angles



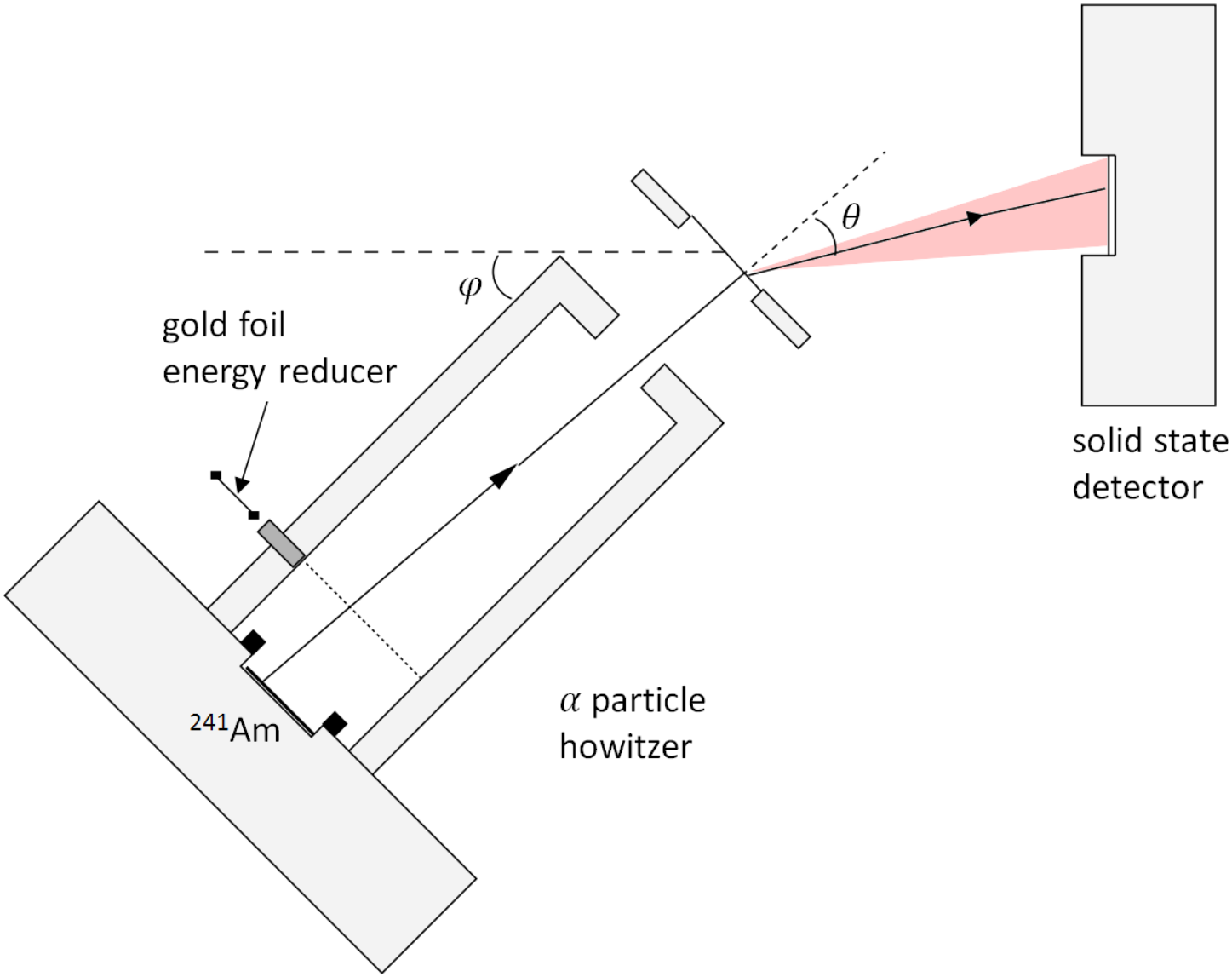
Apparatus allows for scattering detection at various angles



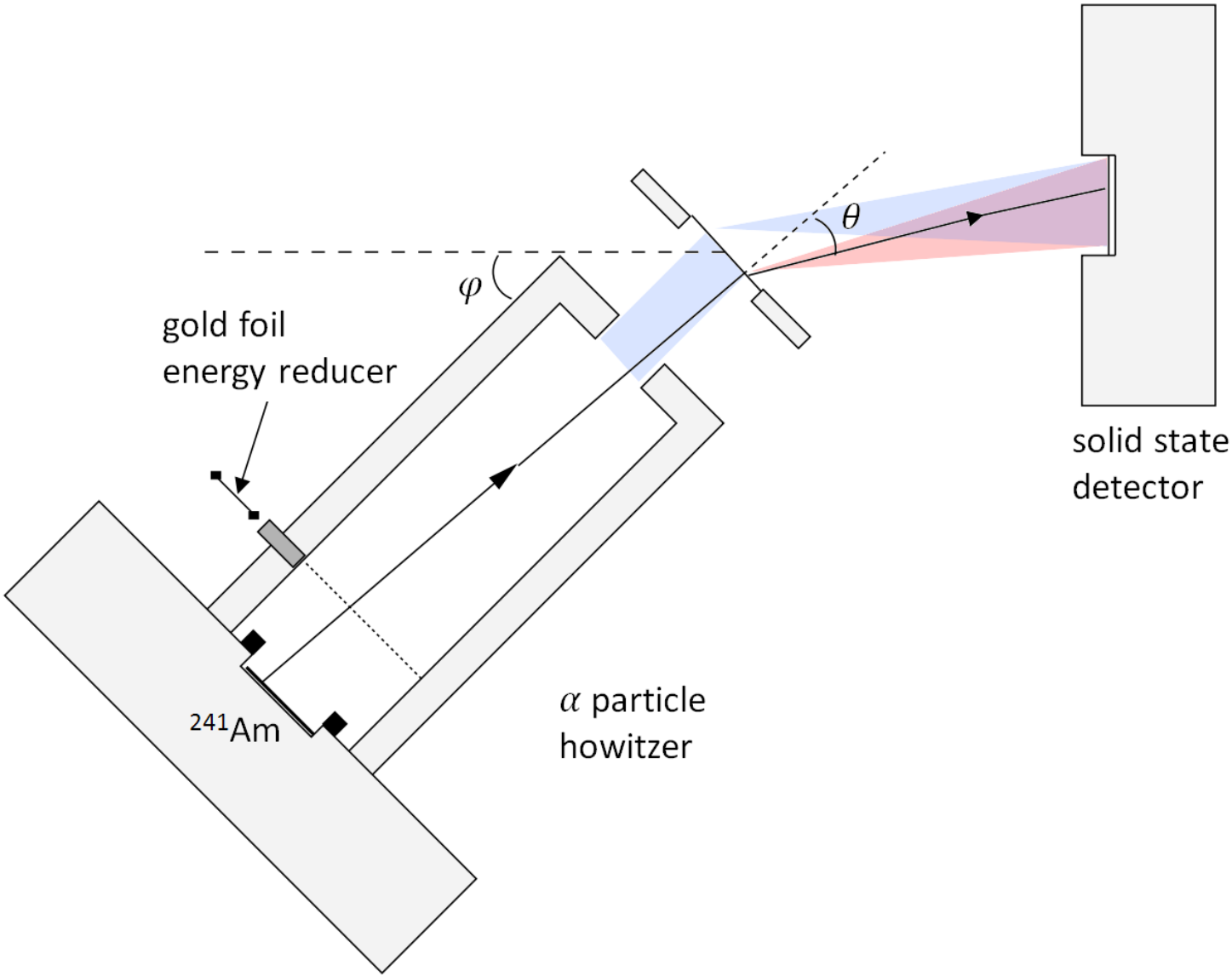
Apparatus allows for scattering detection at various angles



Apparatus allows for scattering detection at various angles



Apparatus allows for scattering detection at various angles



Geometry of Detector Leads to Deviations from Scattering Predictions

- With the howitzer at an angle ϕ, what is the probability of detecting a particle scattered between θ and $\theta + \mathrm{d}\theta$?

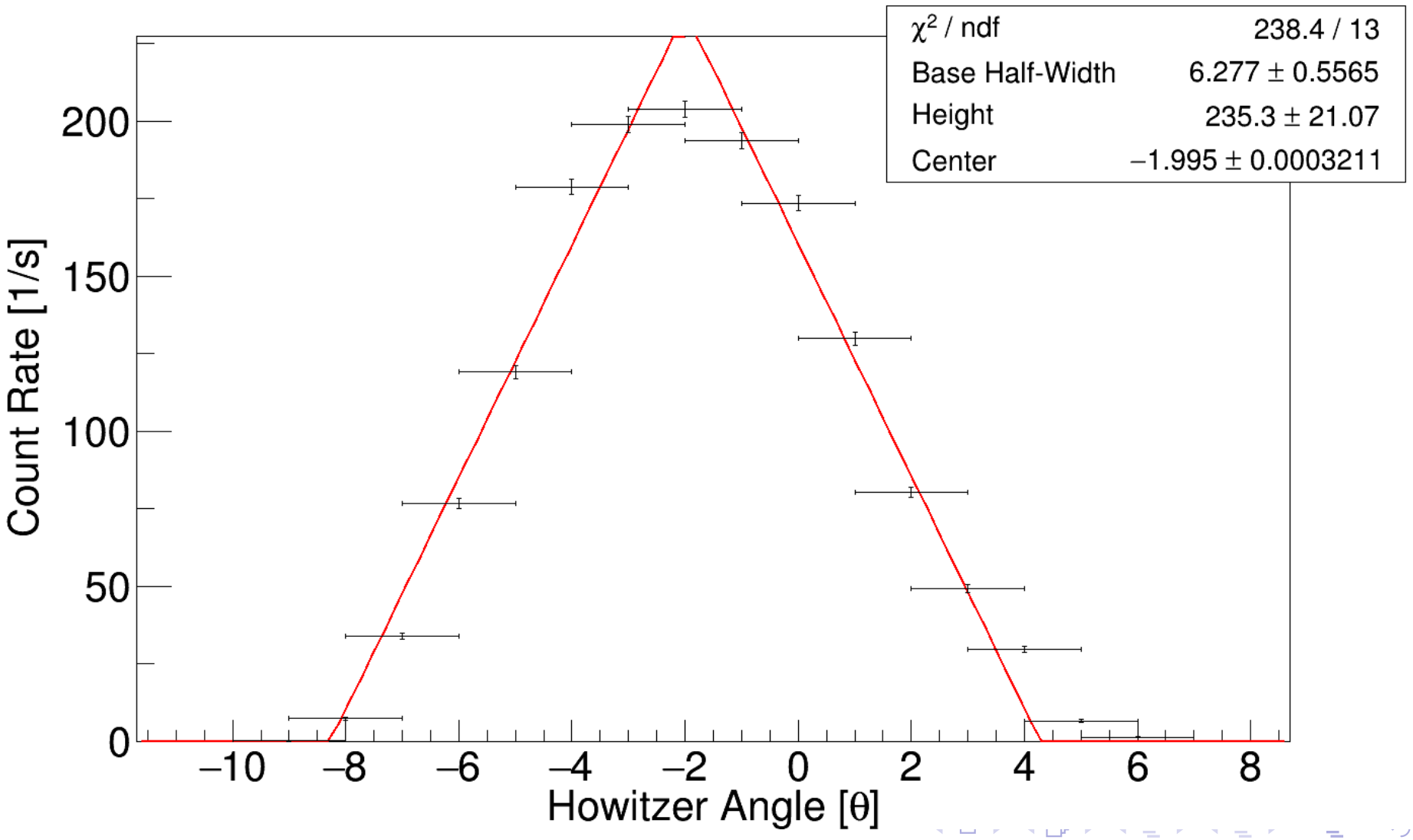
Geometry of Detector Leads to Deviations from Scattering Predictions

- With the howitzer at an angle ϕ, what is the probability of detecting a particle scattered between θ and $\theta + \mathrm{d}\theta$?
- Ideally, $P(\theta) = \delta(\theta - \phi)$.

Geometry of Detector Leads to Deviations from Scattering Predictions

- With the howitzer at an angle ϕ, what is the probability of detecting a particle scattered between θ and $\theta + \mathrm{d}\theta$?
- Ideally, $P(\theta) = \delta(\theta - \phi)$.
- Realistically, we expect roughly a triangle-shaped distribution.

Beam Profile Indicates Both Angular Spread and Systematic Angular Offset



Convolving Beam Profile Corrects for Beam/Detector Width

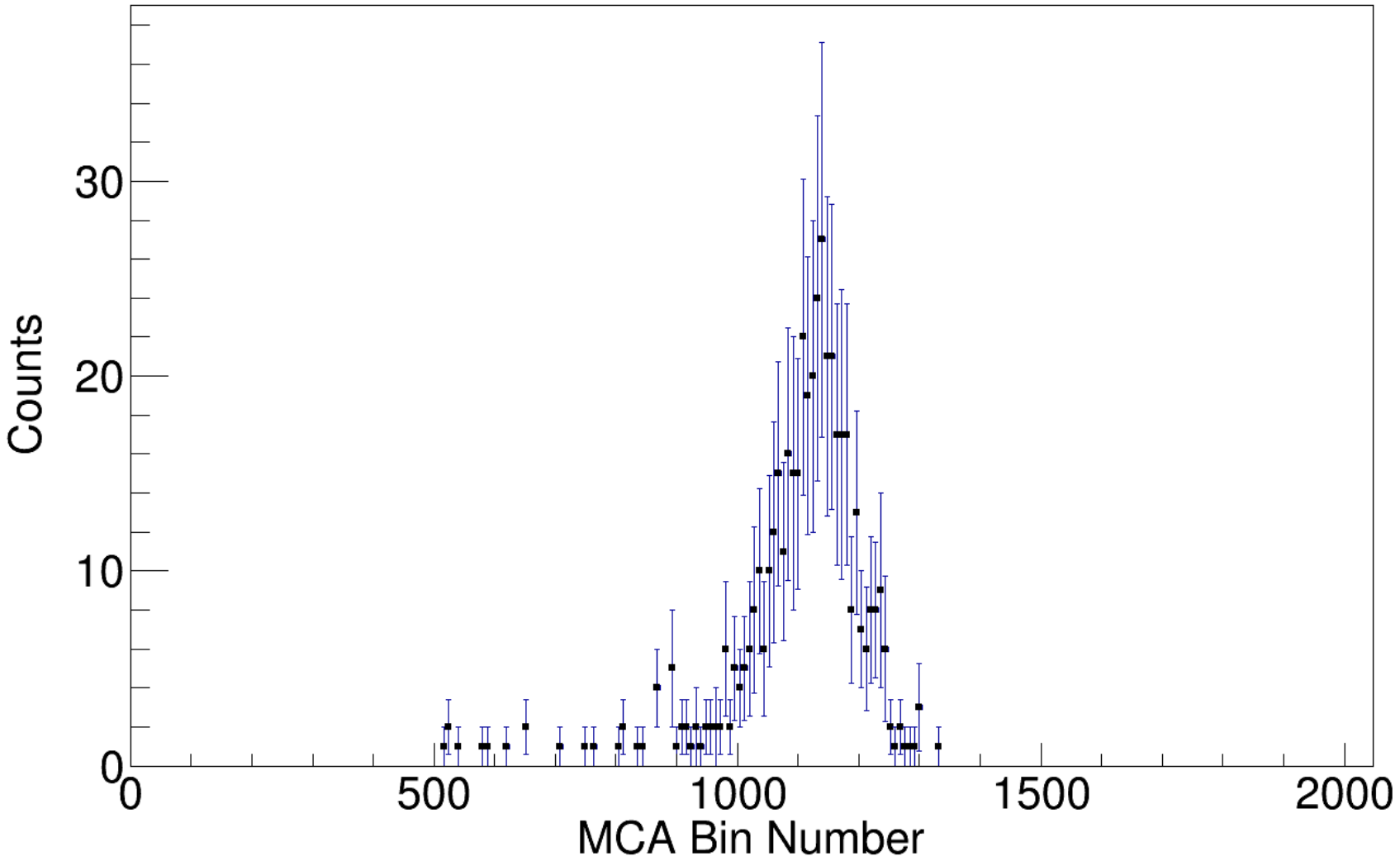
Rutherford

$$C_r(\phi) = C_{r,0} \int_0^{\pi} g(\phi, \theta) \sin^{-4}(\theta/2)\, \mathrm{d}\theta$$

Thomson

$$C_t(\phi) = C_{t,0} \int_0^{\pi} g(\phi, \theta) e^{-\frac{\theta^2}{\theta_m^2}}\, \mathrm{d}\theta$$

MCA Readout Centered Around Energy Range



Uncertainty in Angles and Counting Rates Contribute to Overall Uncertainty

Noise

Uncertainty in Angles and Counting Rates Contribute to Overall Uncertainty

Noise

- Took measurements with the howitzer pointed away from the source to measure noise

Uncertainty in Angles and Counting Rates Contribute to Overall Uncertainty

Noise

- Took measurements with the howitzer pointed away from the source to measure noise
- Minimal noise detected, all at energies much less than our range of interest

Uncertainty in Angles and Counting Rates Contribute to Overall Uncertainty

Noise

- Took measurements with the howitzer pointed away from the source to measure noise
- Minimal noise detected, all at energies much less than our range of interest

Energy Distribution

Uncertainty in Angles and Counting Rates Contribute to Overall Uncertainty

Noise

- Took measurements with the howitzer pointed away from the source to measure noise
- Minimal noise detected, all at energies much less than our range of interest

Energy Distribution

- Landau distribution of energy loss allows us to consider all points as valid data

Uncertainty in Angles and Counting Rates Contribute to Overall Uncertainty

Noise

- Took measurements with the howitzer pointed away from the source to measure noise
- Minimal noise detected, all at energies much less than our range of interest

Energy Distribution

- Landau distribution of energy loss allows us to consider all points as valid data
- Count rate still affected by counting uncertainty

Uncertainty in Angles and Counting Rates Contribute to Overall Uncertainty

Noise

- Took measurements with the howitzer pointed away from the source to measure noise
- Minimal noise detected, all at energies much less than our range of interest

Energy Distribution

- Landau distribution of energy loss allows us to consider all points as valid data
- Count rate still affected by counting uncertainty

Angular Uncertainty

Uncertainty in Angles and Counting Rates Contribute to Overall Uncertainty

Noise

- Took measurements with the howitzer pointed away from the source to measure noise
- Minimal noise detected, all at energies much less than our range of interest

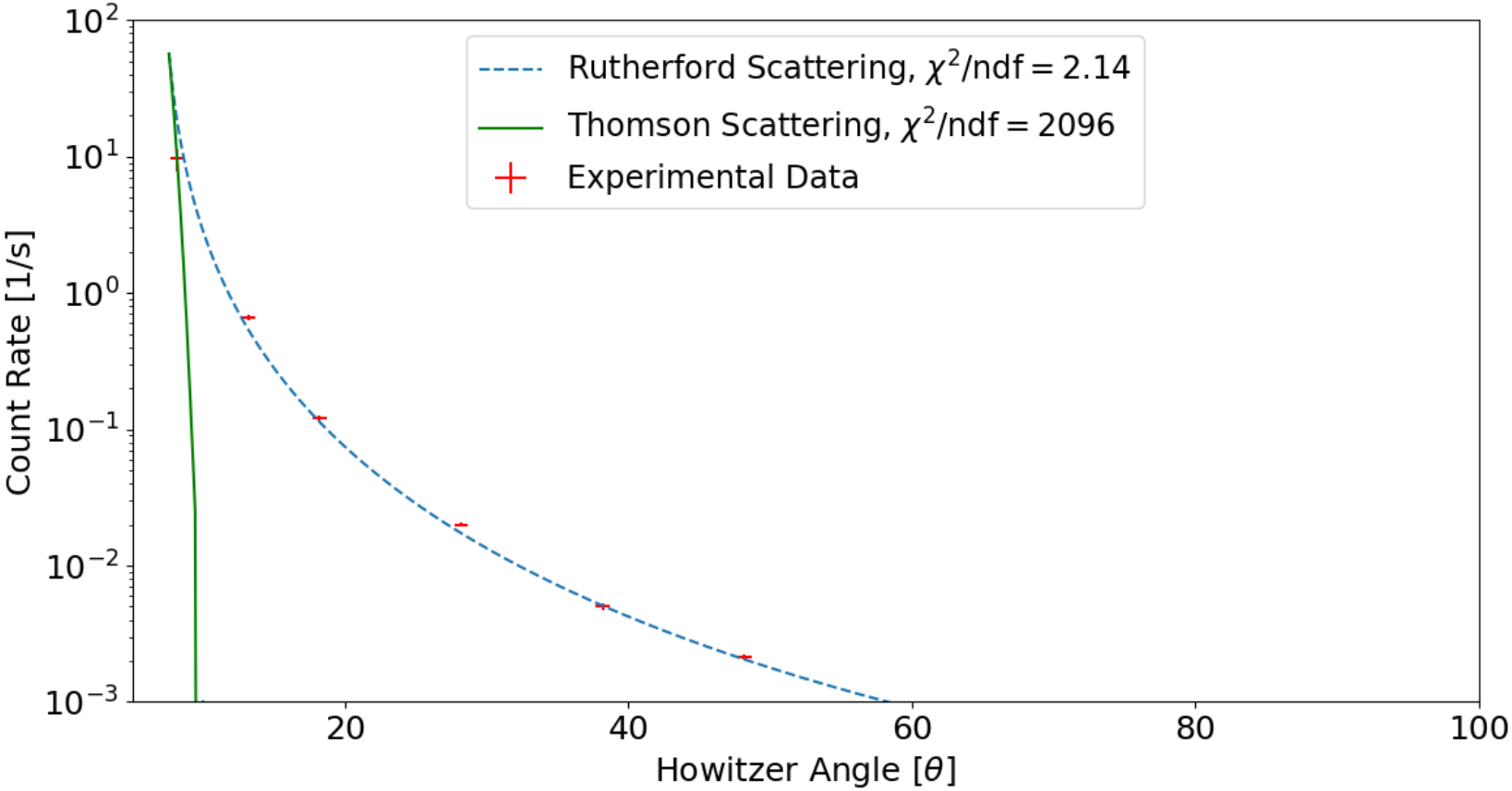
Energy Distribution

- Landau distribution of energy loss allows us to consider all points as valid data
- Count rate still affected by counting uncertainty

Angular Uncertainty

- Protractor read by eye contributes ± 1 degree uncertainty to angular measurements

Rutherford Scattering Effectively Predicts High-Angle Scattering



Uncertainty in Convolution Contributes Small Uncertainty in χ^2/ndf

Model	χ^2/ndf
Rutherford	2.14 ± 0.11
Thomson	2096 ± 24

Rutherford Model Predicts High-Angle Scattering

Rutherford Model Predicts High-Angle Scattering

- Thomson's plum pudding model is unable to predict scattering trends at high angles.

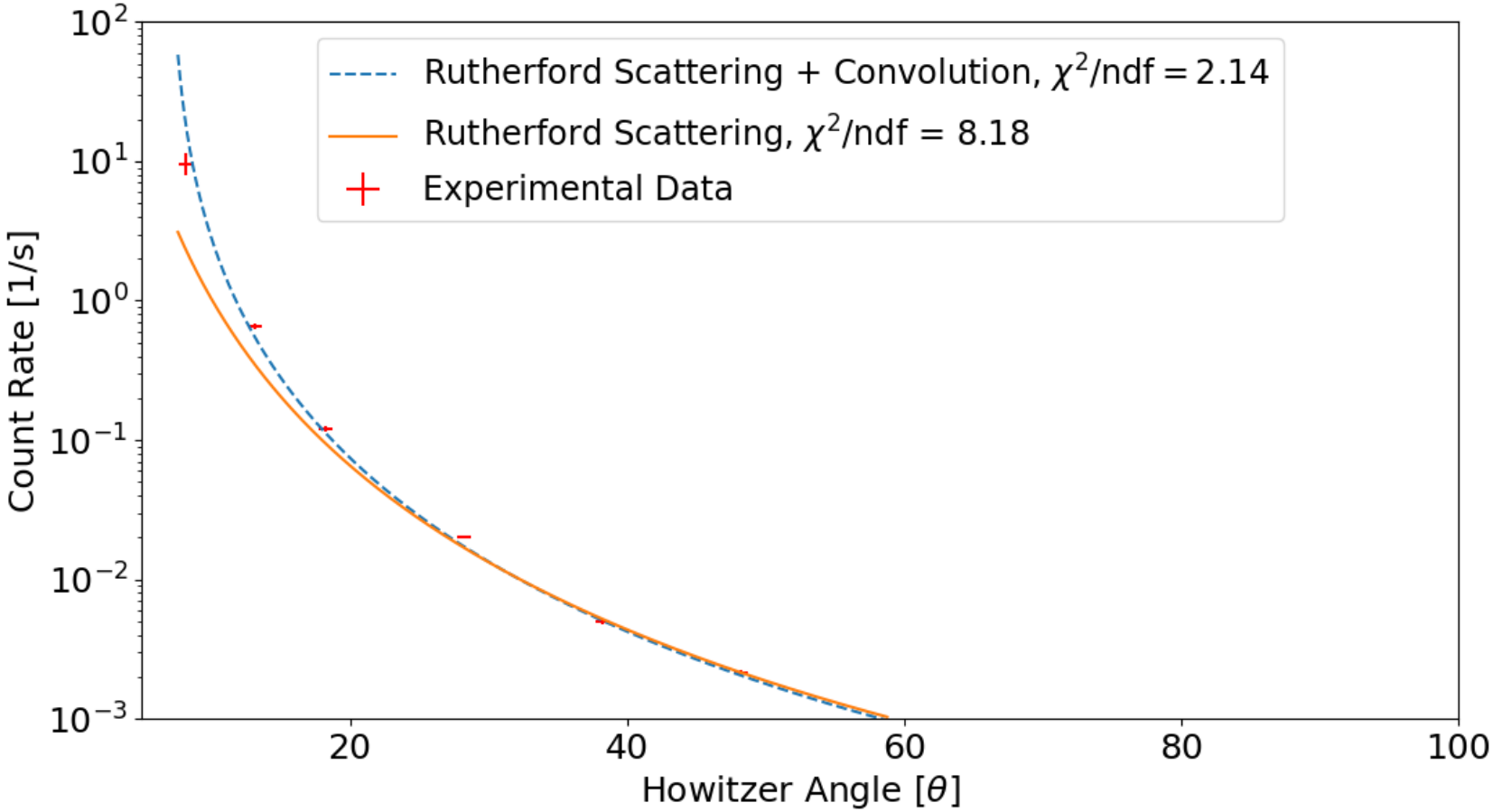
Rutherford Model Predicts High-Angle Scattering

- Thomson's plum pudding model is unable to predict scattering trends at high angles.
- Rutherford model predicts these trends more accurately, leading one to suspect a Rutherford-like atomic model

Rutherford Model Predicts High-Angle Scattering

- Thomson's plum pudding model is unable to predict scattering trends at high angles.
- Rutherford model predicts these trends more accurately, leading one to suspect a Rutherford-like atomic model
- When detecting scattering rates with non-point detectors and beams, angular response function allows for more accurate data modeling

Convolution Improves Results from Raw Rutherford Fit



Thomson with Free θ_m Unable to Capture Data