Mössbauer Spectroscopy

Jay Lawhorn

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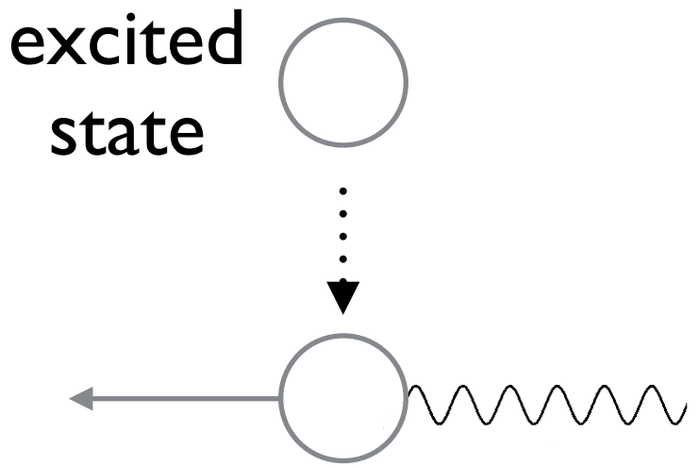
Free atom:



photon emission
and nuclear recoil

Photon not energetic enough to excite same transition

Atom in lattice:

- "Recoilless" Emission: transferred momentum dispersed across lattice
- Negligible photon energy loss
- Nuclear resonance absorption possible

Mössbauer Effect in ^{57}Fe

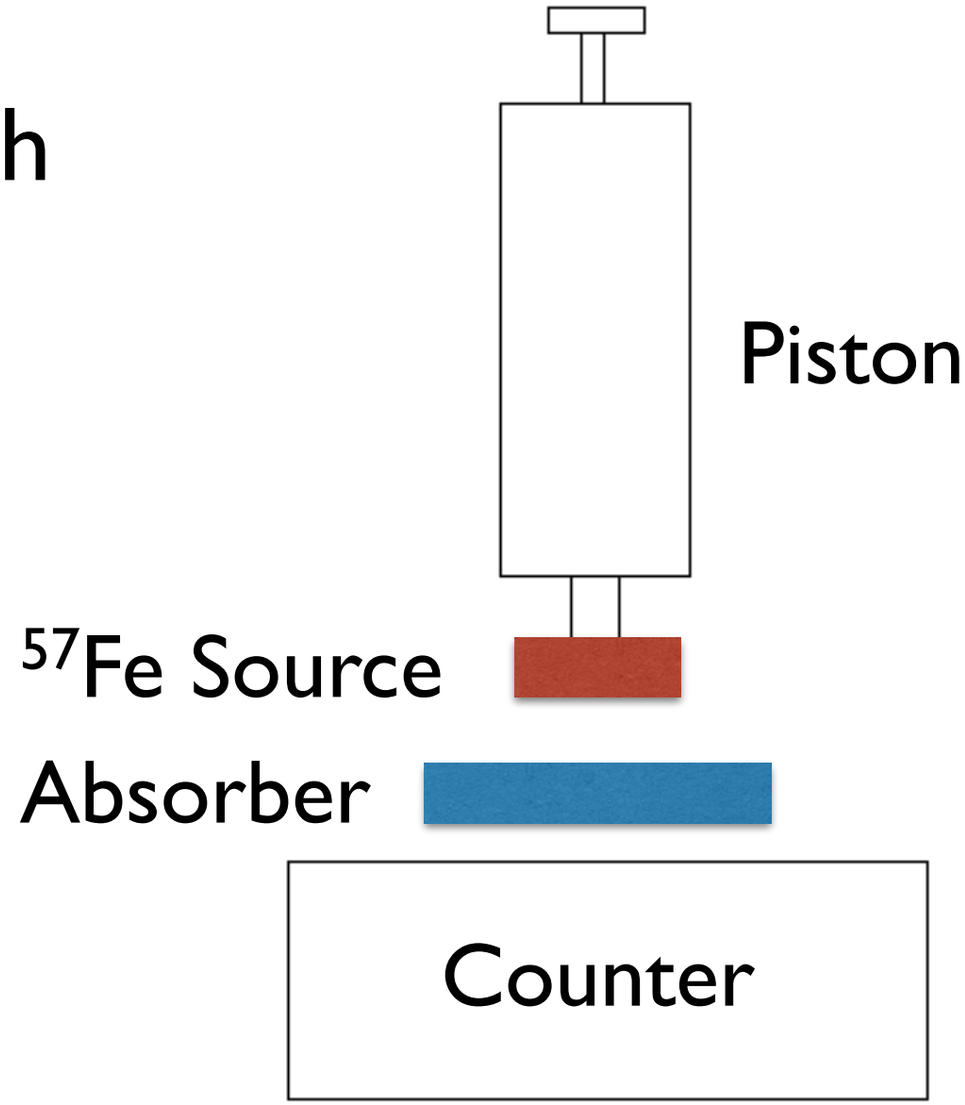
- Deposit ^{57}Co in platinum substrate
- ^{57}Co decays to excited state of ^{57}Fe
- **90%** of emitted 14.4 keV photons recoilless
- 14.4 keV line very narrow: 4.7×10^{-9} eV
- **Fractional resolution $\sim 10^{-12}$**

Mössbauer Apparatus

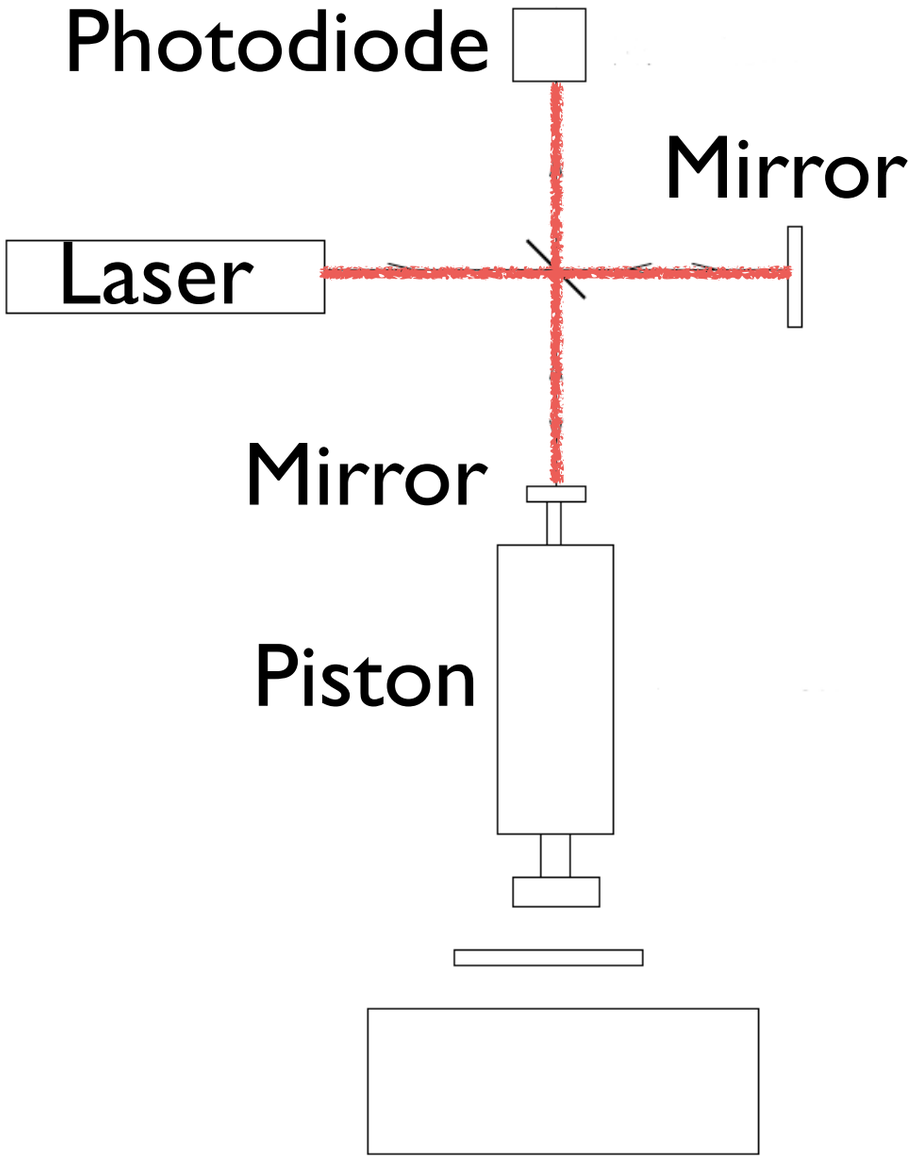
- Source mounted on piston oscillating with sawtooth velocity
- Emitted photons doppler shifted:

$$E' = E(1 + \frac{V}{c})$$

- Analyze absorption lines from absorber



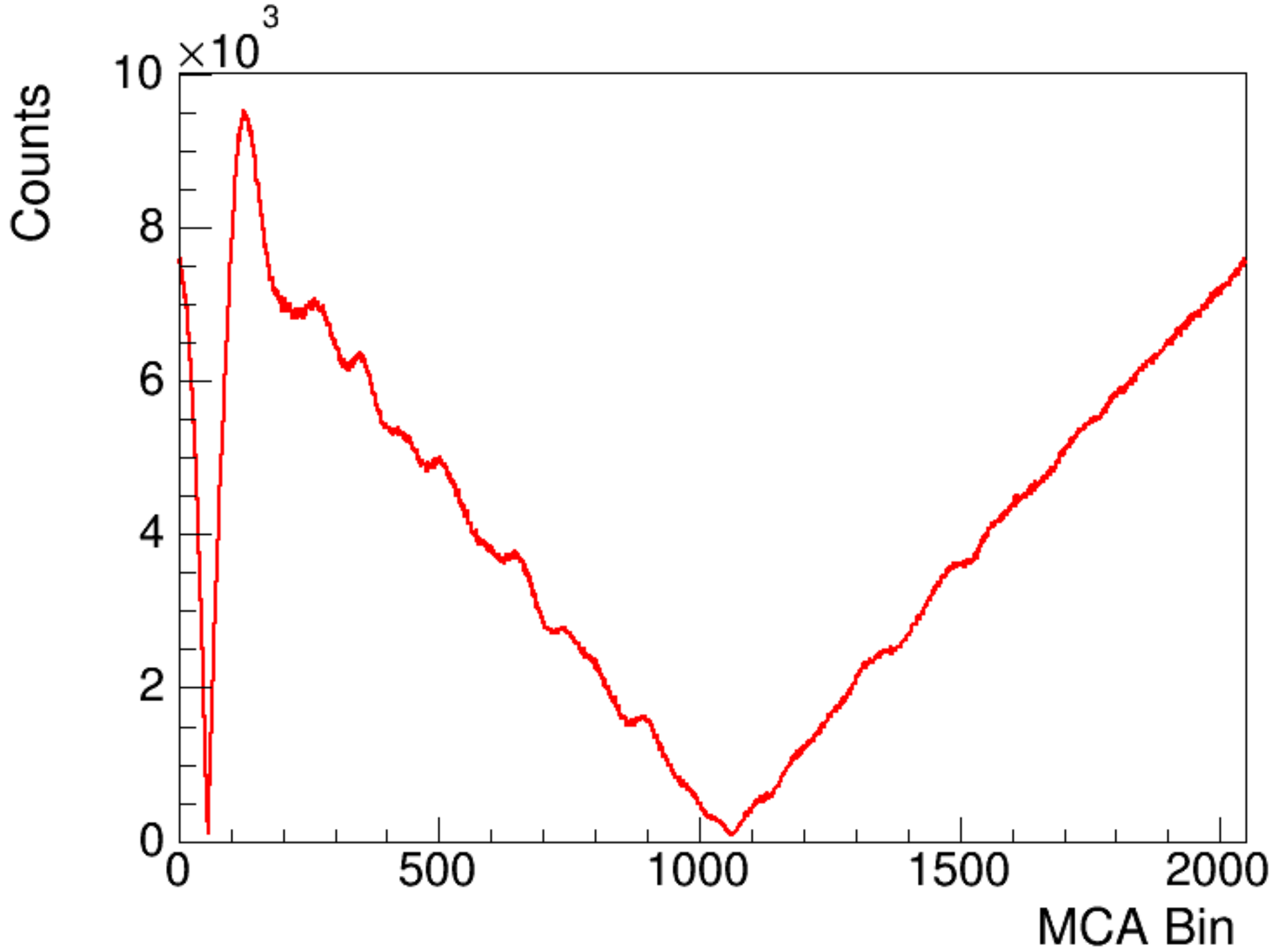
Velocity Calibration



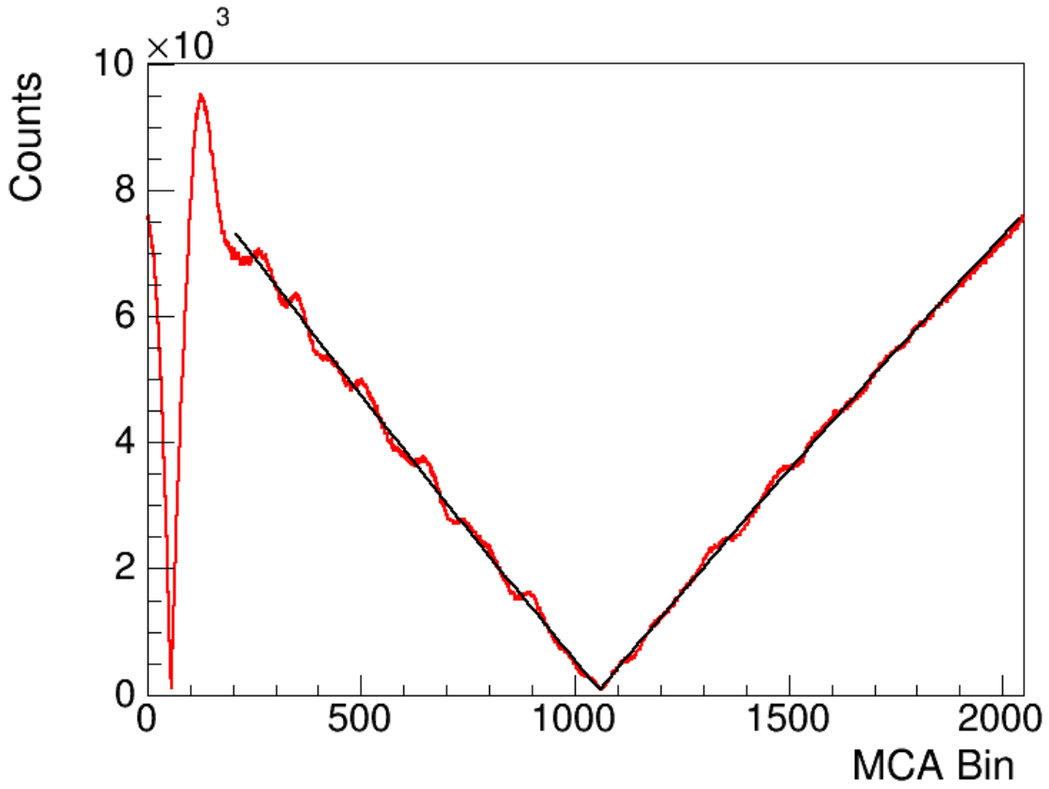
- Interferometric measurement of piston velocity
- Count number of voltage maxima per time interval:

$$V_i = \frac{C\lambda}{2NT}$$

Absolute Velocity Measurement



Absolute Velocity Measurement



Nominal fit:

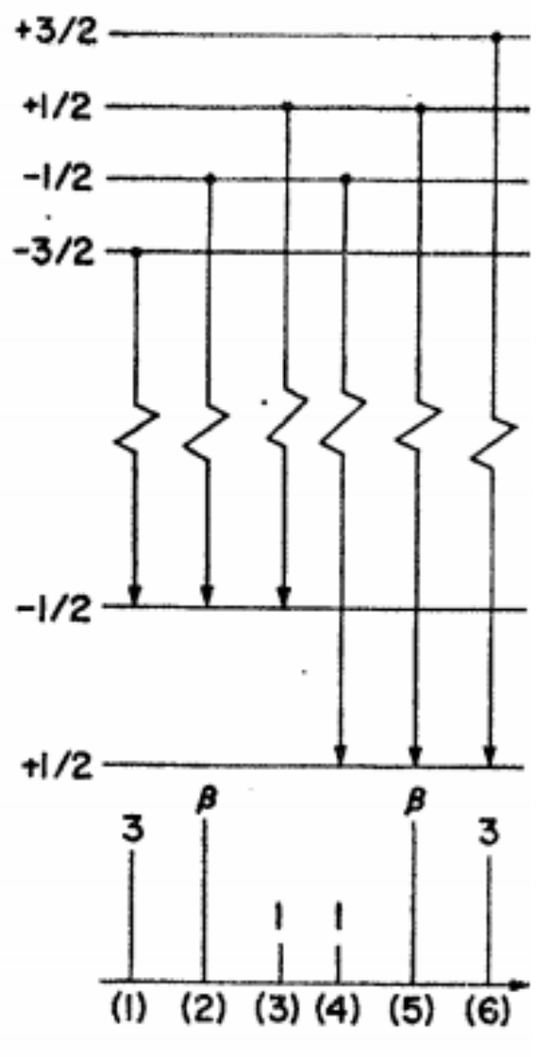
$$a + |b(x-c) + d(x-c)^2|$$

- Subtract constant background term

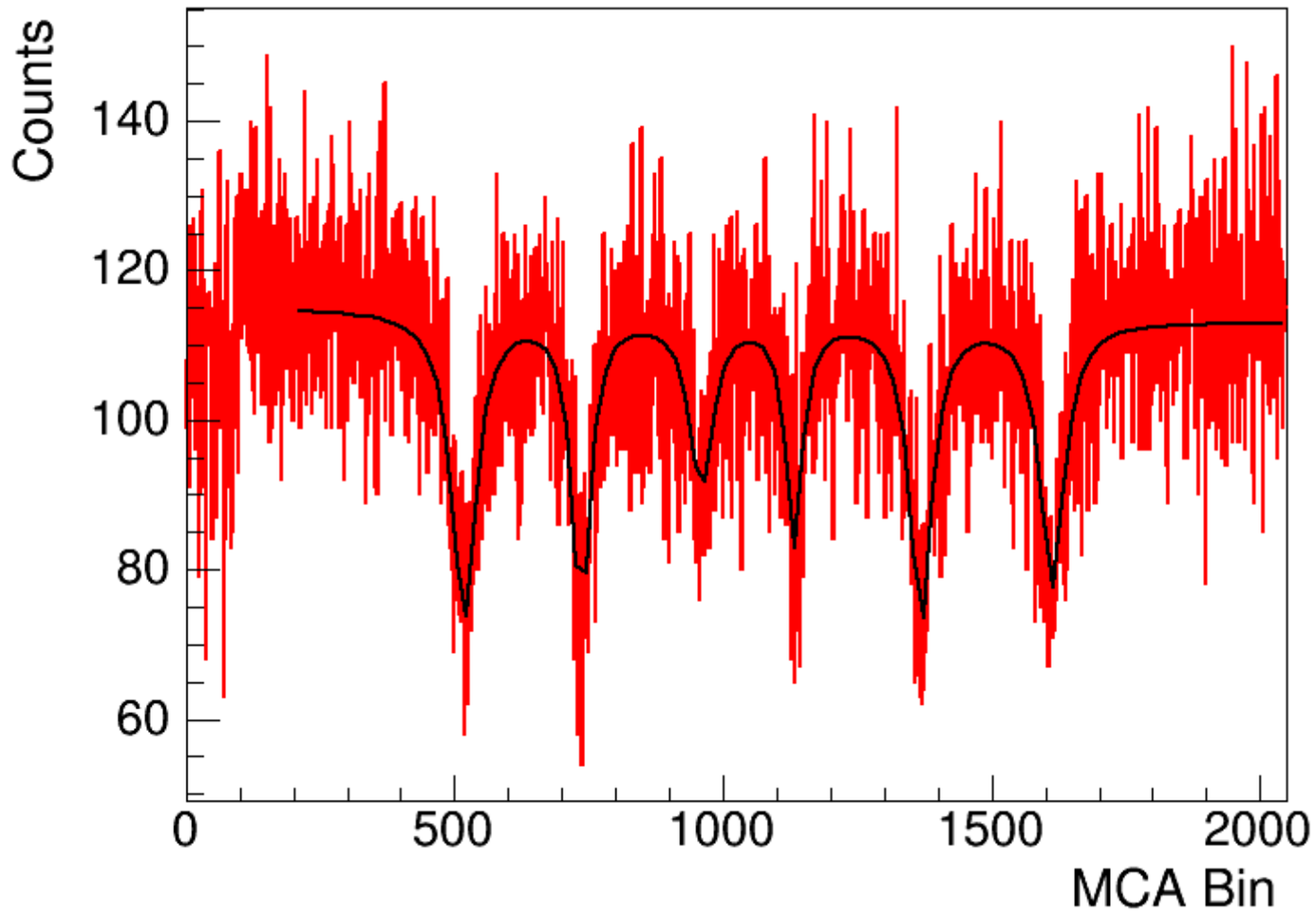
- Uncertainty from functional form: fit two regions to lines on either side of cusp
  - **<8%; largest near cusp**
- Uncertainty from selection of fit region
  - ~1%

Metallic ^{57}Fe

- Internal magnetic field causes Zeeman splitting
- Six transitions allowed by magnetic-dipole selection rules
- Determine splitting energies from differences in absorption peak velocities

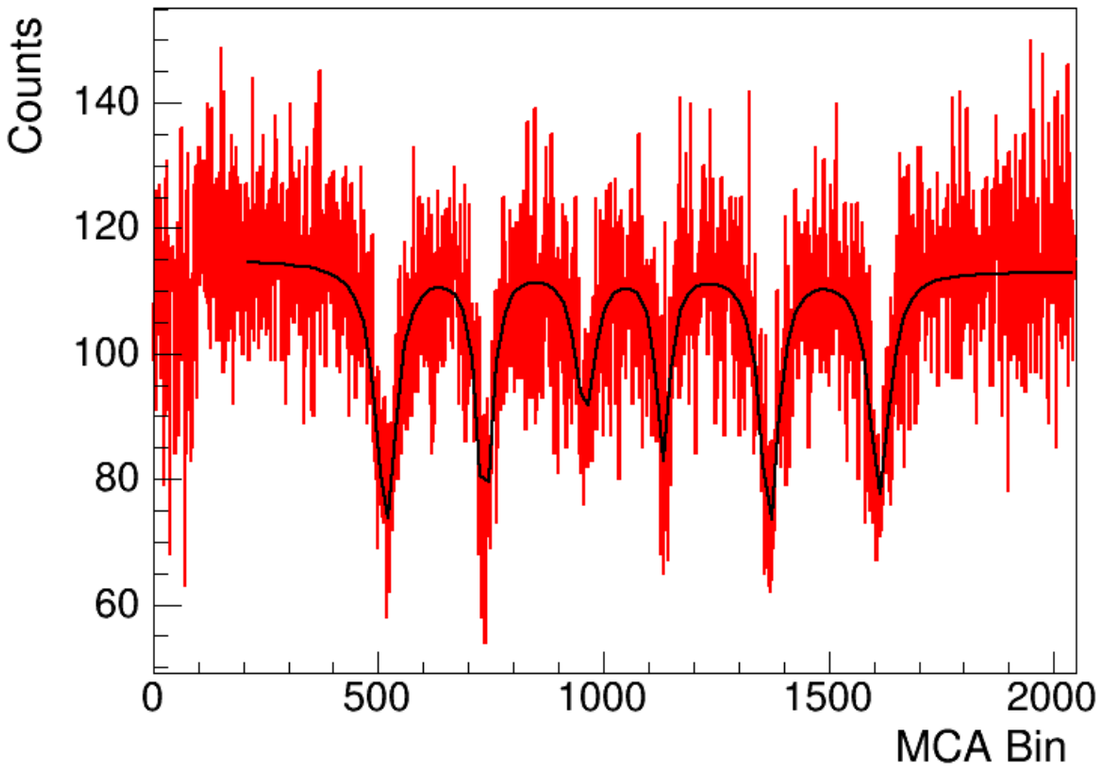


Metallic ^{57}Fe Data



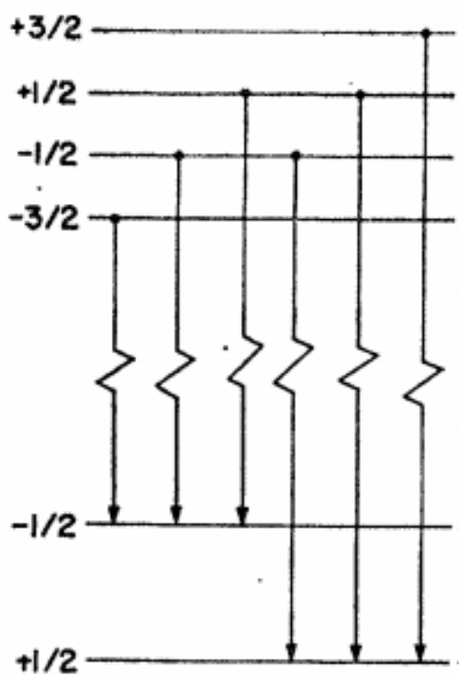
- Fit six Lorentzians and quadratic background
- Restrict to range from velocity calibration

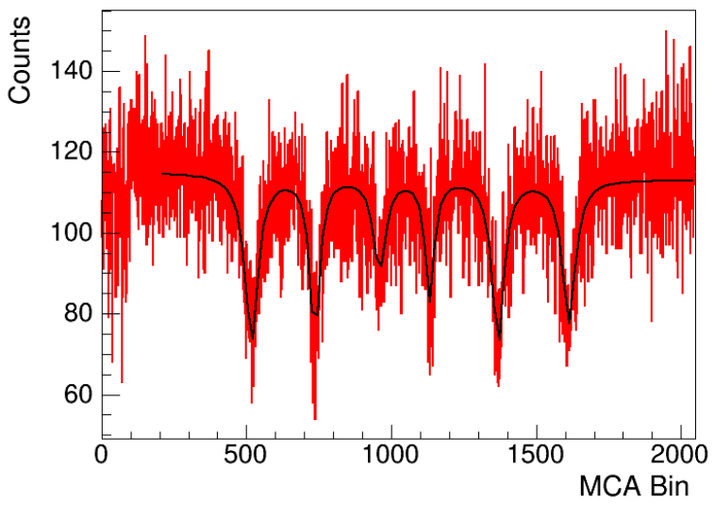
Metallic ^{57}Fe Analysis



- Peak location from center of Lorentzian
- **Uncertainty in peak value** ($\sqrt{\Gamma}$): 2-8%
- Uncertainty from velocity calibration: 0.2-7%

Metallic ^{57}Fe Results





- Energy level splittings in ground and excited state:

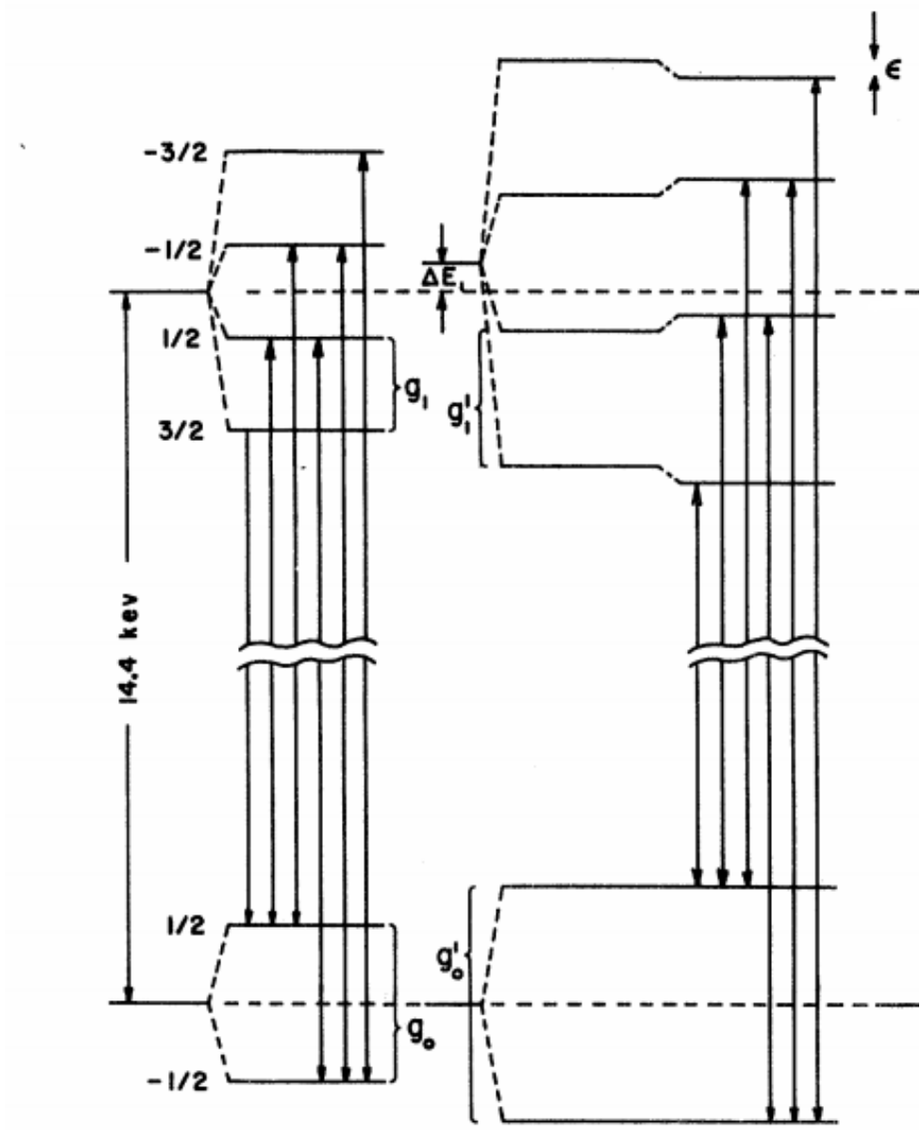
$$\Delta E_0 = (2.13 \pm 0.05) \times 10^{-7}\ \text{eV}$$
$$\Delta E_1 = (1.21 \pm 0.04) \times 10^{-7}\ \text{eV}$$

- Ratio of magnetic moments in first excited and ground states:

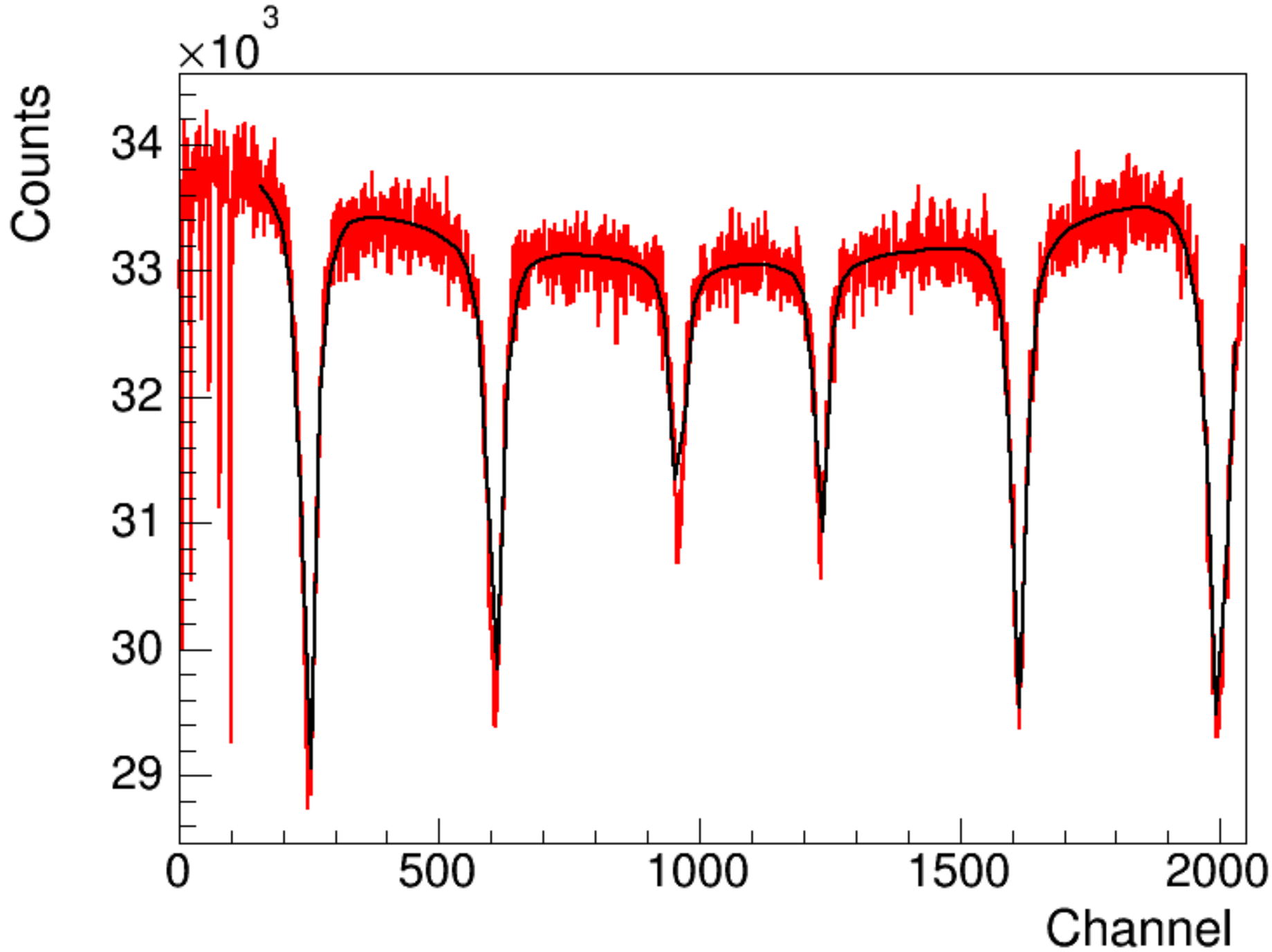
$$\mu_1/\mu_0 = -3\Delta E_1/\Delta E_0 = -1.71 \pm 0.07$$

Fe_2O_3

- Zeeman splitting with additional shifts from electric quadrupole moments

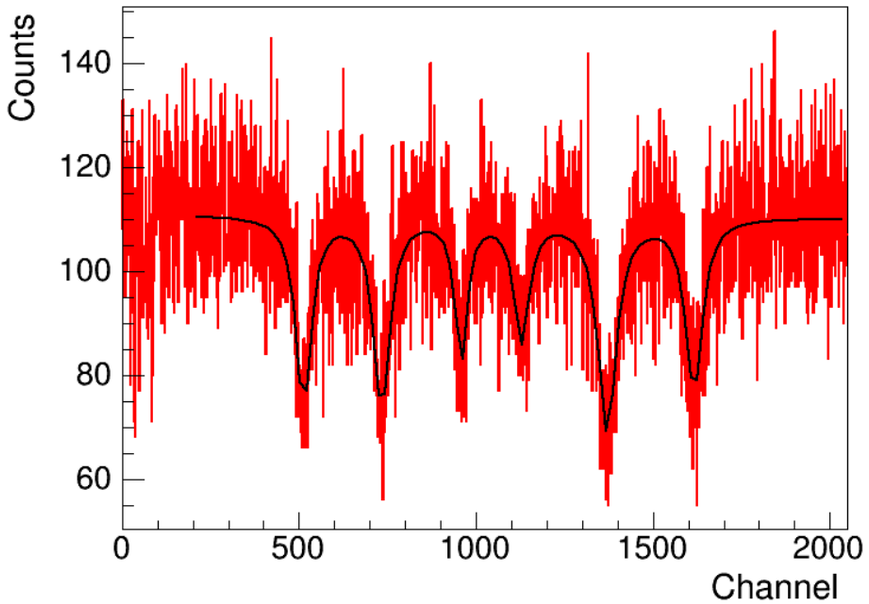


Fe_2O_3 Data

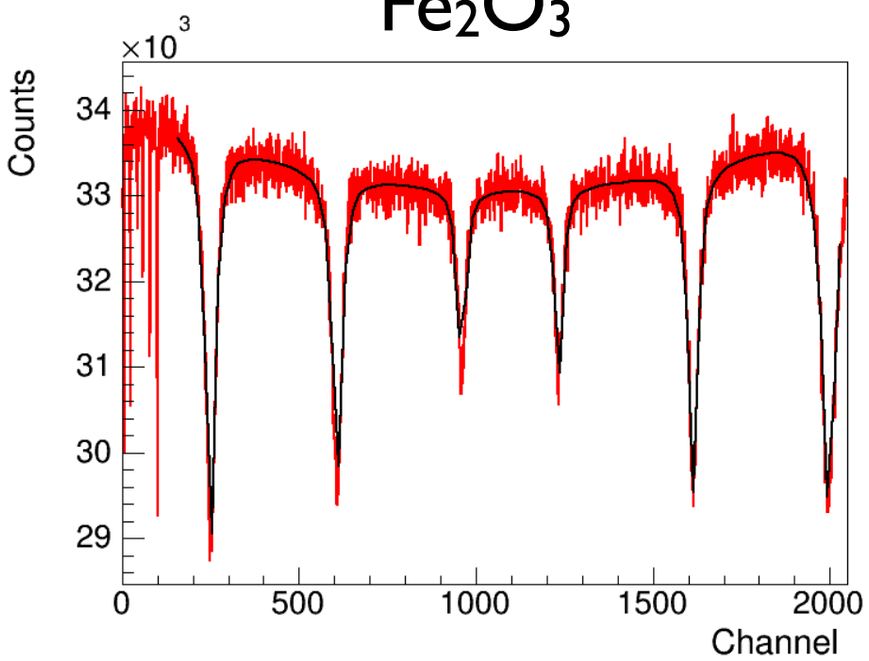


Fe_2O_3 Analysis

Calibration

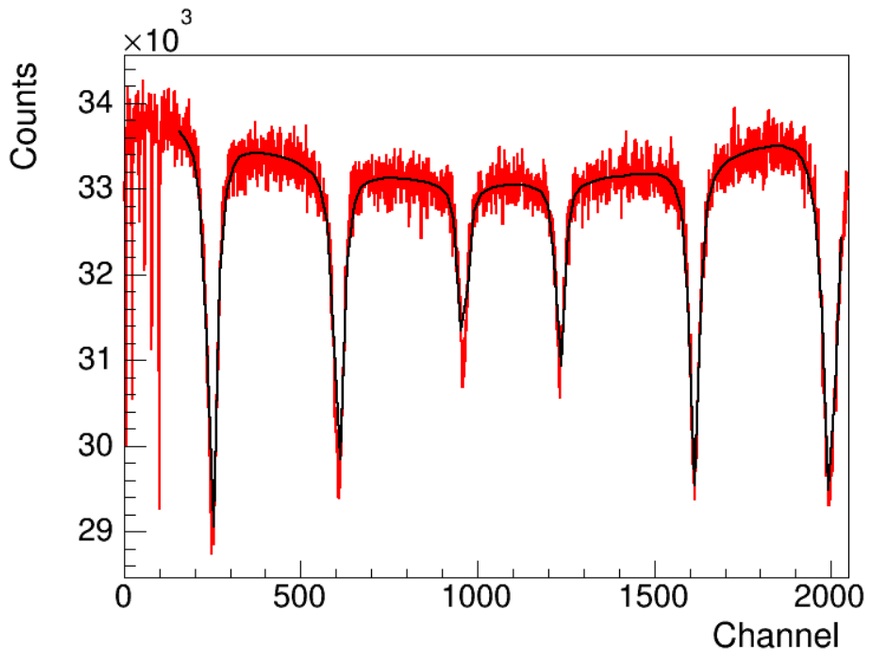


Fe_2O_3



- Use six peaks in ^{57}Fe spectrum and known velocities to fit quadratic
- For each peak, calculate difference between known velocity and fit result
- Uncertainties on velocity determination from quadratic fit to differences

Fe_2O_3 Results



- Uncertainty on peak location: 1-7%
- **Uncertainty on velocity**: 6-10%

$$\Delta E_0 = (3.34 \pm 0.06) \times 10^{-7}\ \text{eV}$$
$$\Delta E_1 = (1.91 \pm 0.06) \times 10^{-7}\ \text{eV}$$
$$\epsilon = (6 \pm 9) \times 10^{-9}\ \text{eV}$$
$$\mu_1/\mu_0 = -1.72 \pm 0.07$$

Summary

- Metallic ^{57}Fe:

$$\Delta E_0 = (2.13 \pm 0.05) \times 10^{-7}\ \mathrm{eV}$$
$$\Delta E_1 = (1.21 \pm 0.04) \times 10^{-7}\ \mathrm{eV}$$
$$\mu_1/\mu_0 = -1.71 \pm 0.07$$

- Fe_2O_3:

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