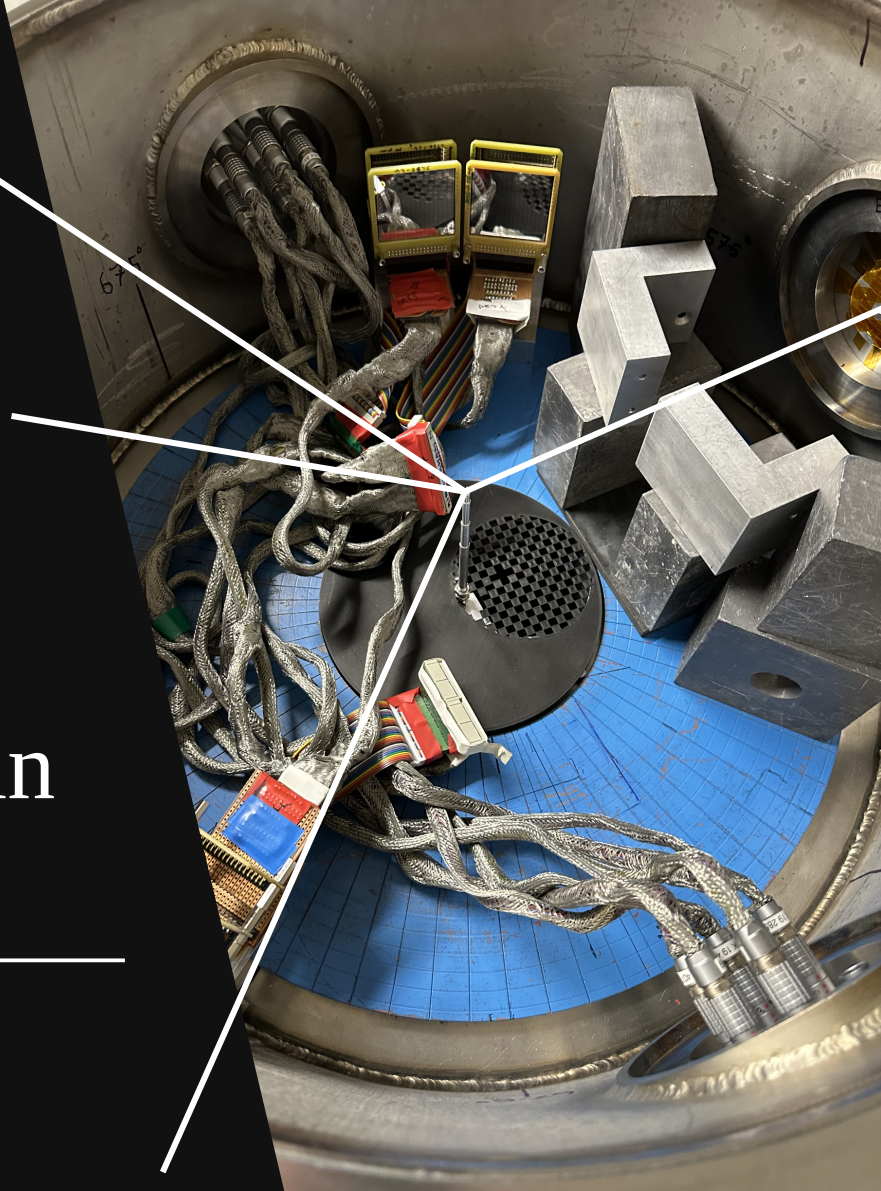
UNIVERSITY OF BIRMINGHAM

Evidence of the ^{9}B($1/2^{+}$) state in the ^{12}C(p,α)^{9}B reaction

A.D. Brooks, *et al.*

2026 IOP Nuclear Physics Conference



Background – Reflecting on differences

Mirror nuclei are a pair of nuclei which have the same A, opposite N & Z

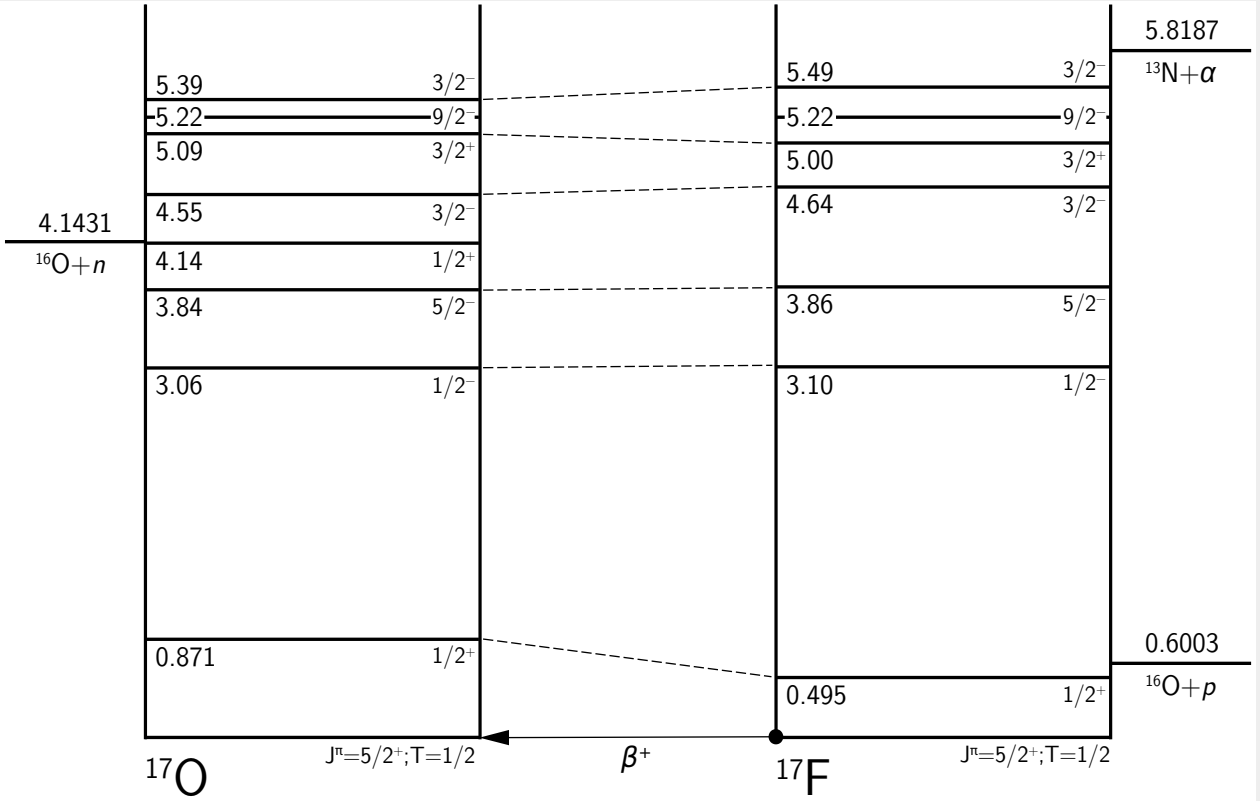


Figure 1: Low-excitation-energy analogue states in the A=17 single proton-neutron mirror system. Recreated from currently available ENSDF data. [Nucl. Phys. A. **564** (1993)]

Background – Reflecting on differences

Mirror nuclei are a pair of nuclei which have the same A, opposite N & Z

This symmetry manifests as near identical energy levels between each nucleus. Differences arise from Coulomb effects and are known as TE-shifts.

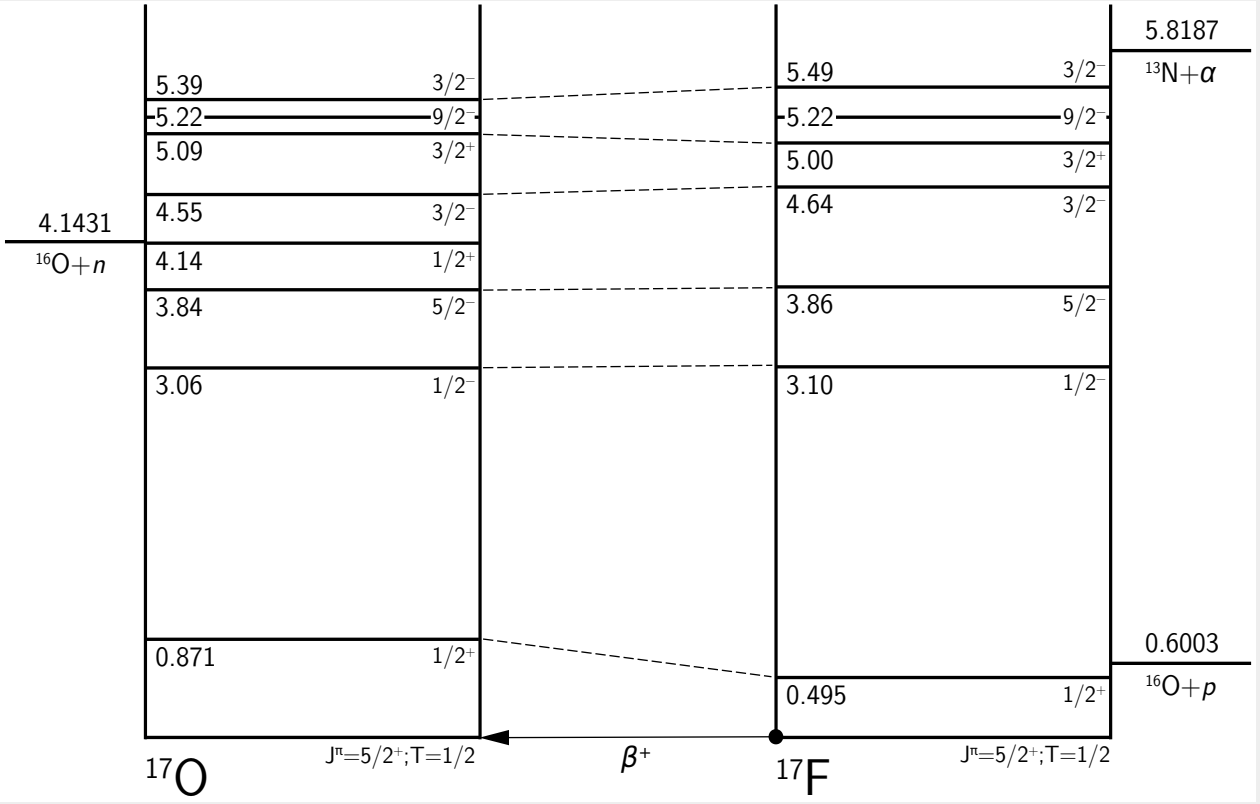
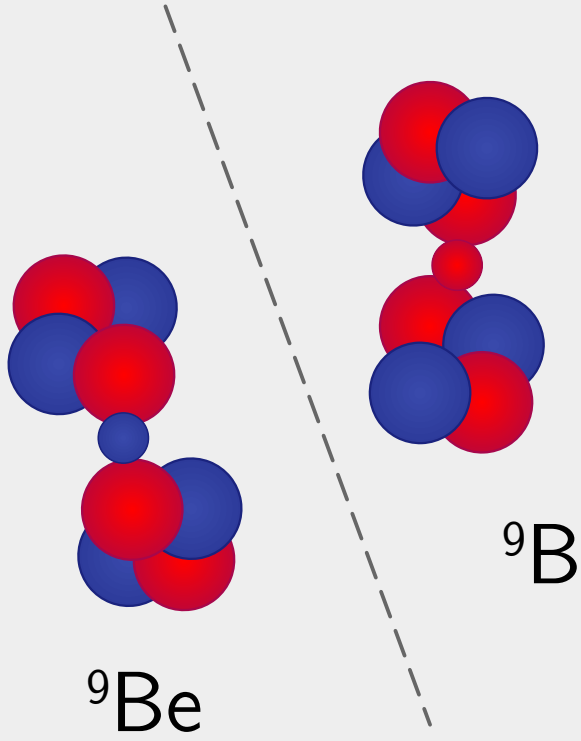


Figure 1: Low-excitation-energy analogue states in the A=17 single proton-neutron mirror system. Recreated from currently available ENSDF data. [Nucl. Phys. A. **564** (1993)]

Background – What is the point?

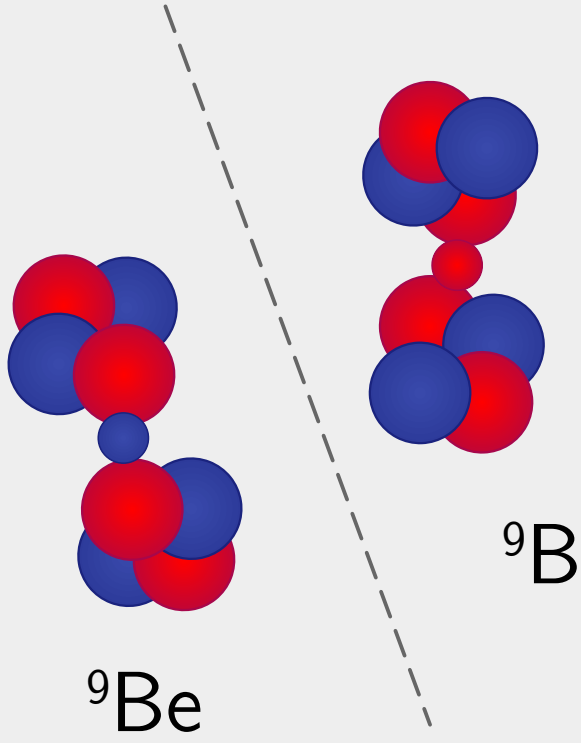
Mirror nuclei are important for studying the displayed charge independence of the nuclear force



Background – What is the point?

Mirror nuclei are important for studying the displayed charge independence of the nuclear force

Largely this is known to hold, however the $A = 9$ system (^{9}Be – ^{9}B) appears to display a breaking of isospin symmetry!

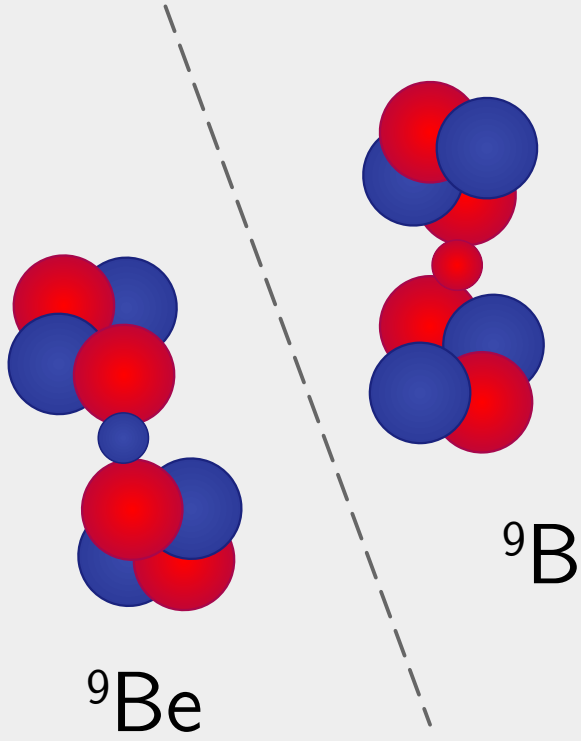


Background – What is the point?

Mirror nuclei are important for studying the displayed charge independence of the nuclear force

Largely this is known to hold, however the $A = 9$ system (^{9}Be – ^{9}B) appears to display a breaking of isospin symmetry!

System exists in a mass range explorable through *ab-initio* calculations



Background – Confused and scared

States are well known in ^{9}Be – stable and relatively easy to study

Location of the first excited state is at 1.684 MeV

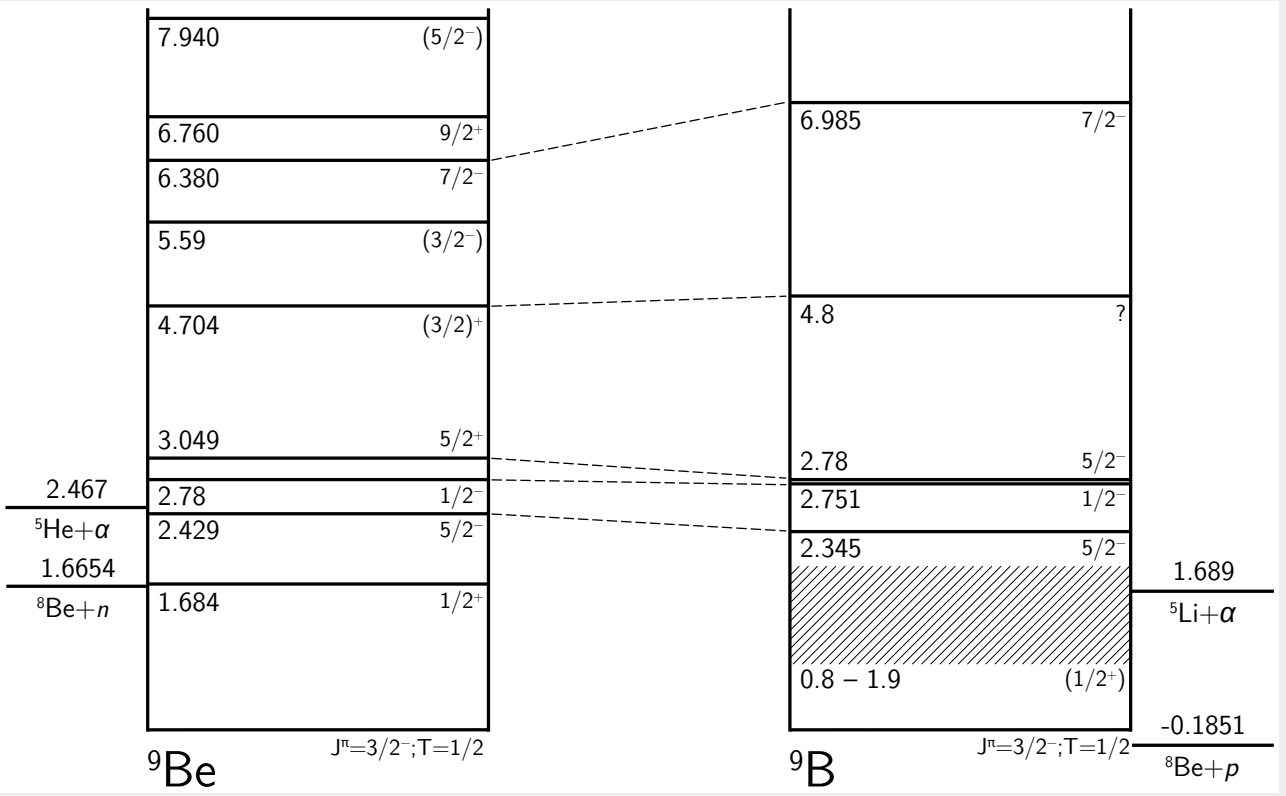


Figure 2: Low-excitation-energy analogue states in the A = 9 single proton-neutron mirror system. Recreated from currently available ENSDF data. [Nucl. Phys. A. **754** (2004)]

Background – Confused and scared

States are well known in ^{9}Be – stable and relatively easy to study

Location of the first excited state is at 1.684 MeV

The analogue state has not been conclusively observed in ^{9}B and six decades of experiments report two conflicting possibilities!

~0.8 – 1.0 MeV & ~1.8 MeV

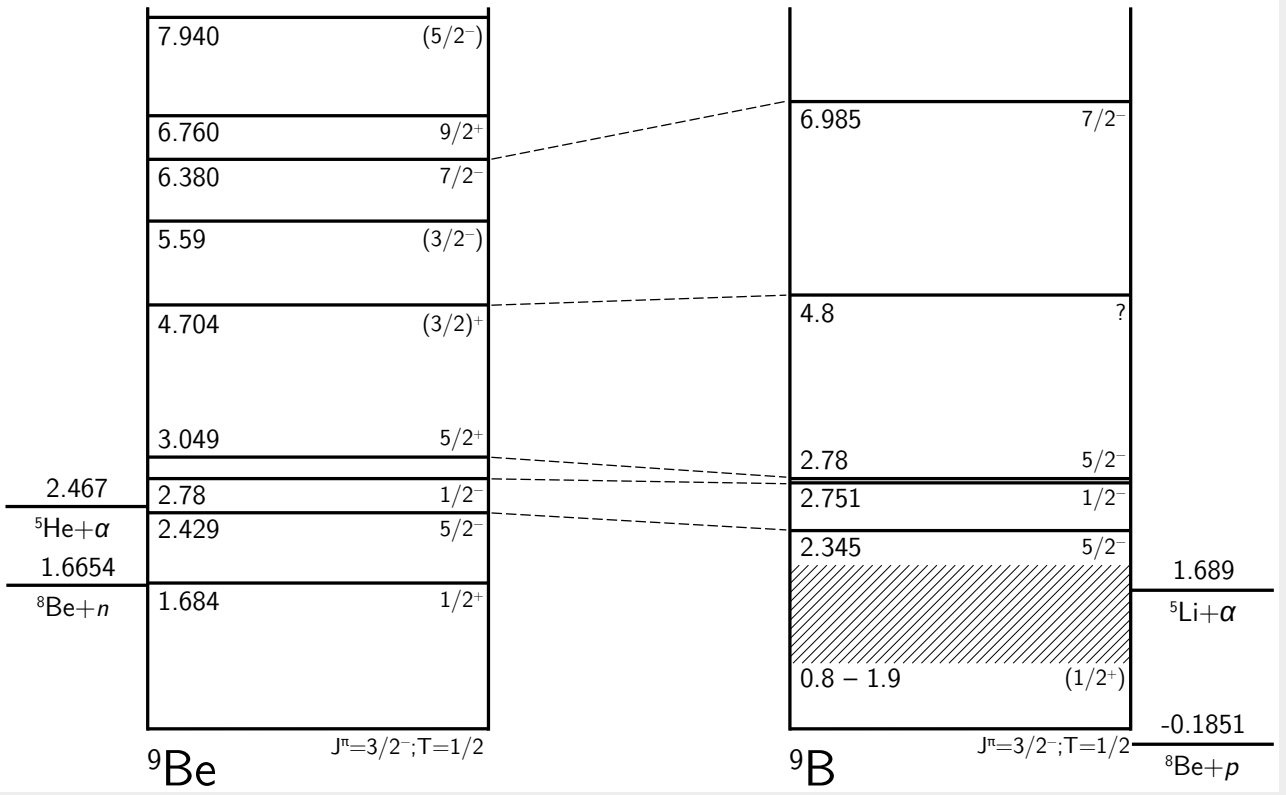


Figure 2: Low-excitation-energy analogue states in the A = 9 single proton-neutron mirror system. Recreated from currently available ENSDF data. [Nucl. Phys. A. **754** (2004)]

Experimental Investigation – Grease monkey

Utilise $^{12}C(p,\alpha)^{9}B$ reaction to populate $1/2^{+}$ state

Tag reactions through detection of α-particle and ^{9}B break-up (^{8}Be+p)

Multiple detection angles for spin-parity assignment

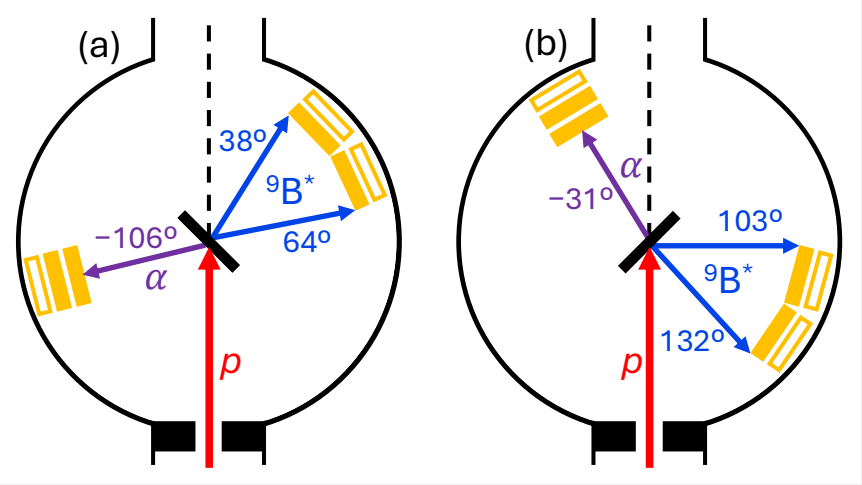


Figure 3: Diagram of (a) 106° detector setup and (b) 31° detector setup.

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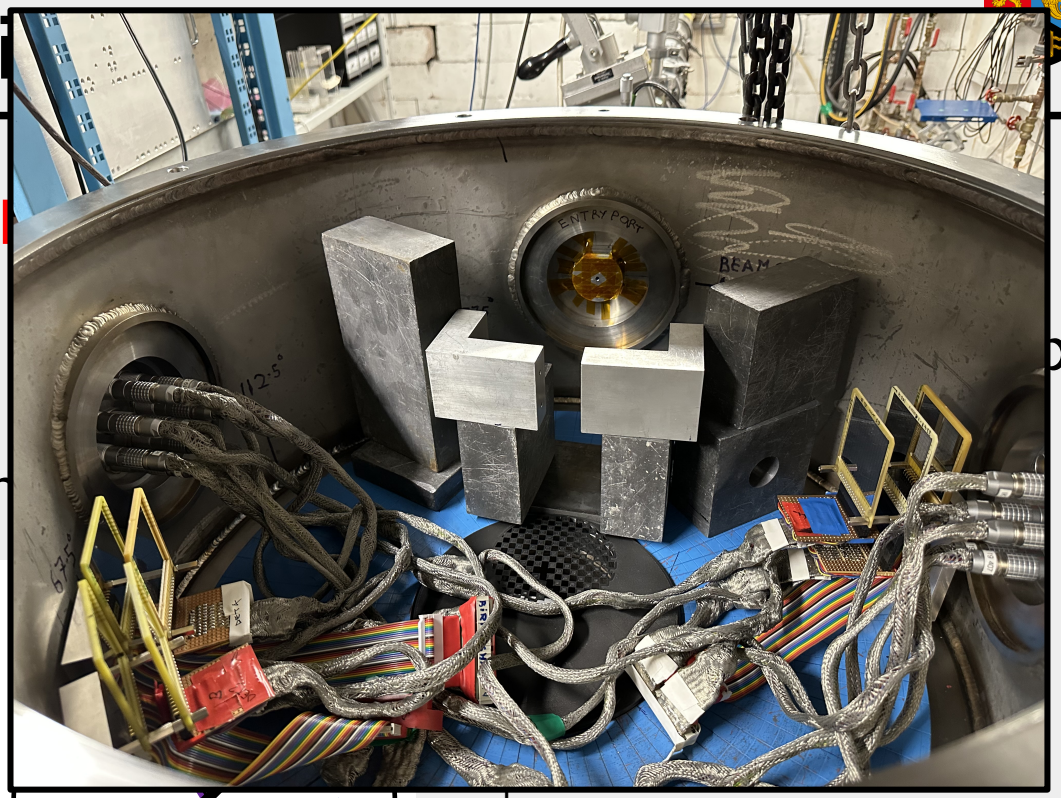
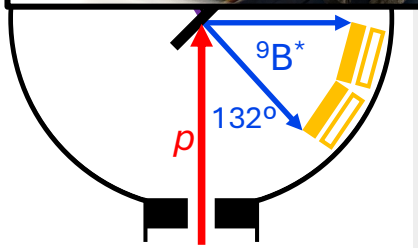
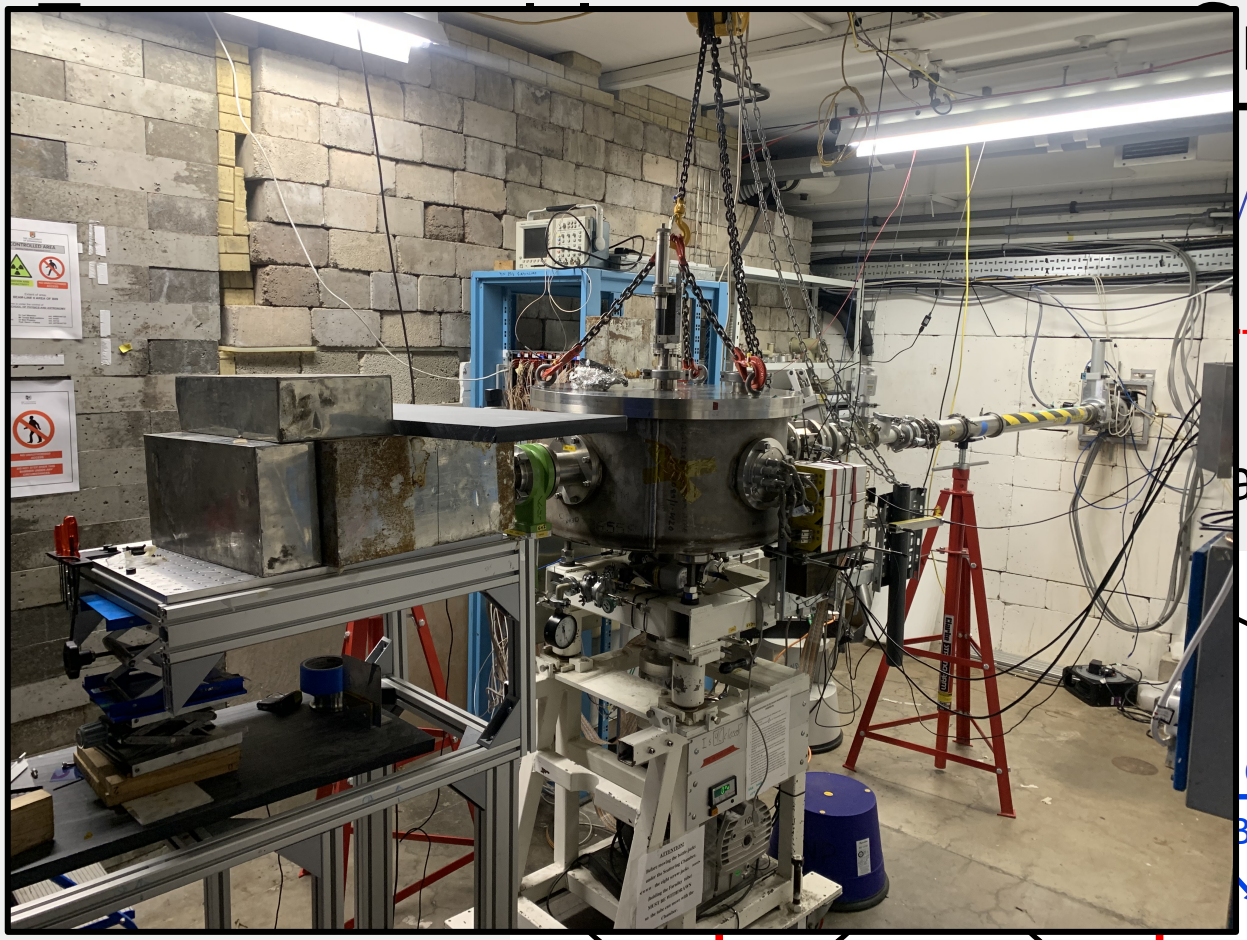
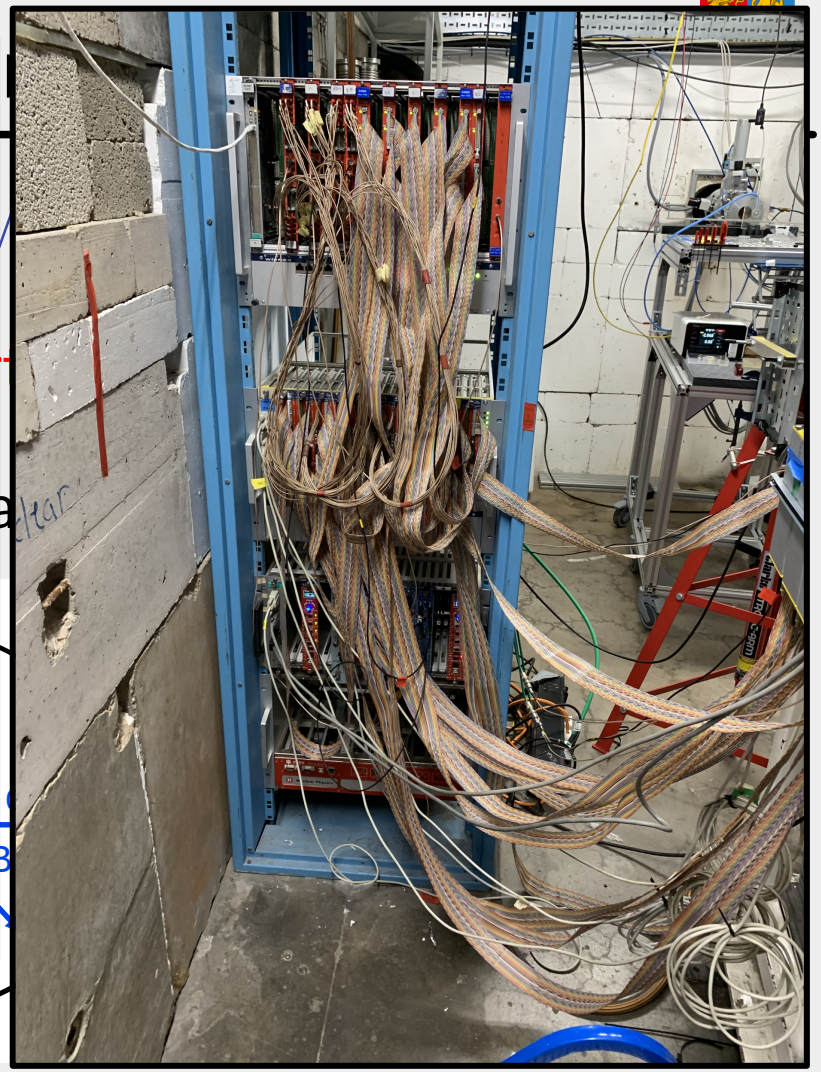








Experimental Investigation – Insomniac

Data collection took place at the MC40 Cyclotron over 3 weeks of overnight runs for sufficient stats. (~105 hours of data taken)

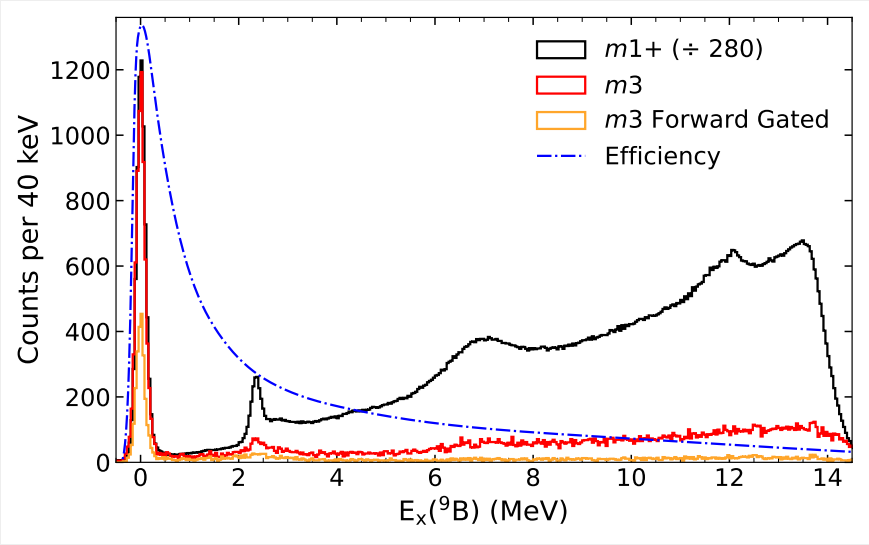


Figure 4: Excitation spectra from 31° setup for $m1$, $m3$, and $m3+$ data.

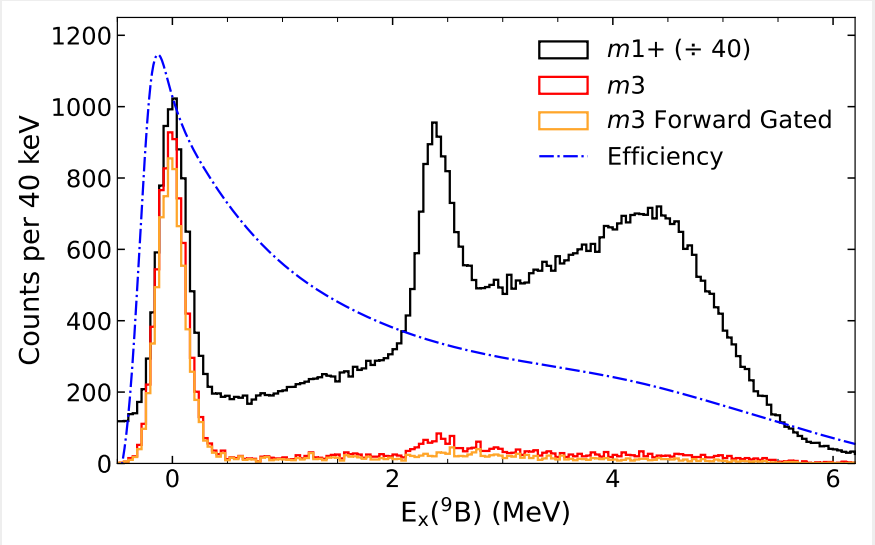


Figure 5: Excitation spectra from 106° setup for $m1$, $m3$, and $m3+$ data.

Experimental Investigation – To be or not to be

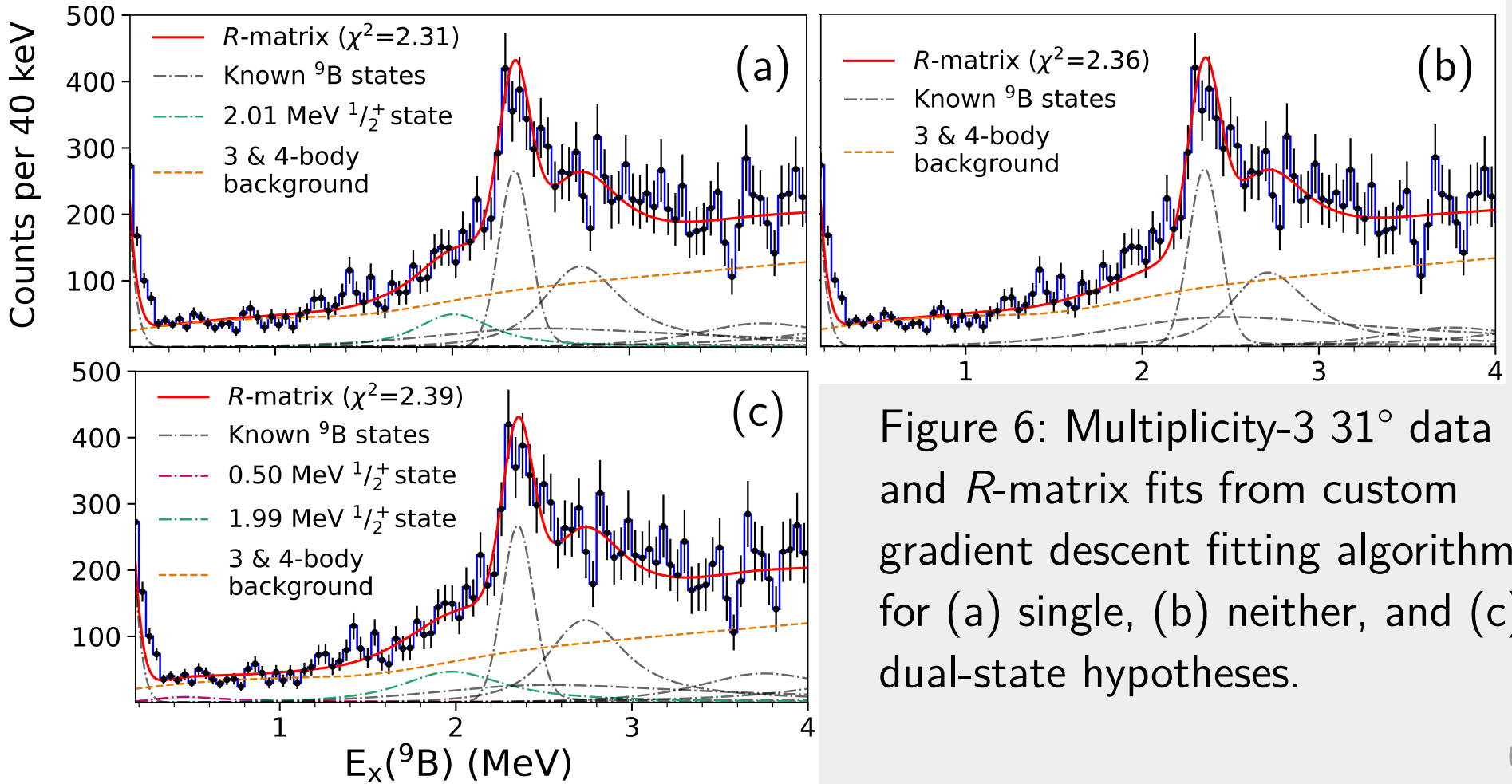
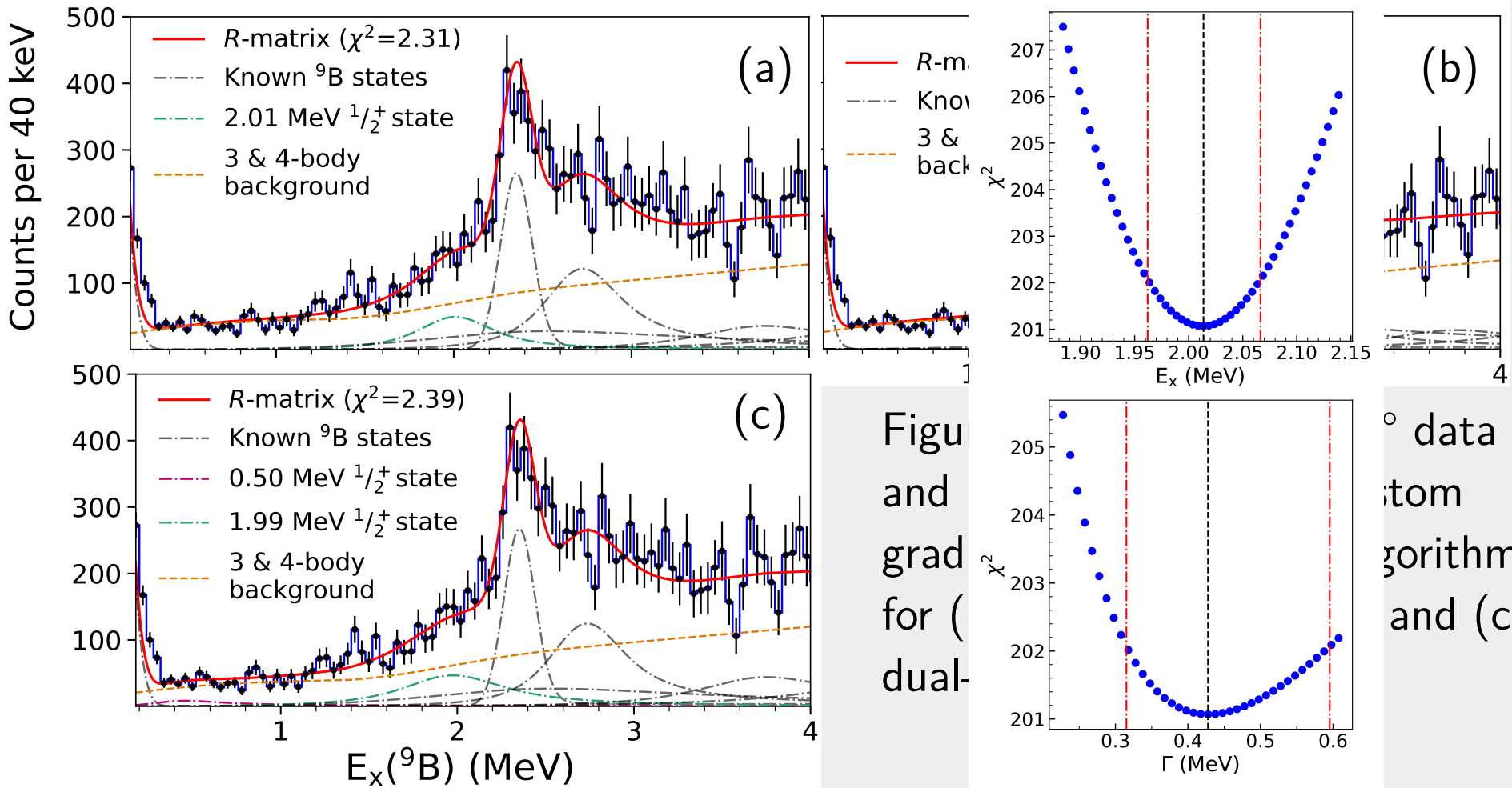


Figure 6: Multiplicity-3 31° data and *R*-matrix fits from custom gradient descent fitting algorithm for (a) single, (b) neither, and (c) dual-state hypotheses.

Experimental Investigation – To be or not to be



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Experimental Investigation – To be or not to be

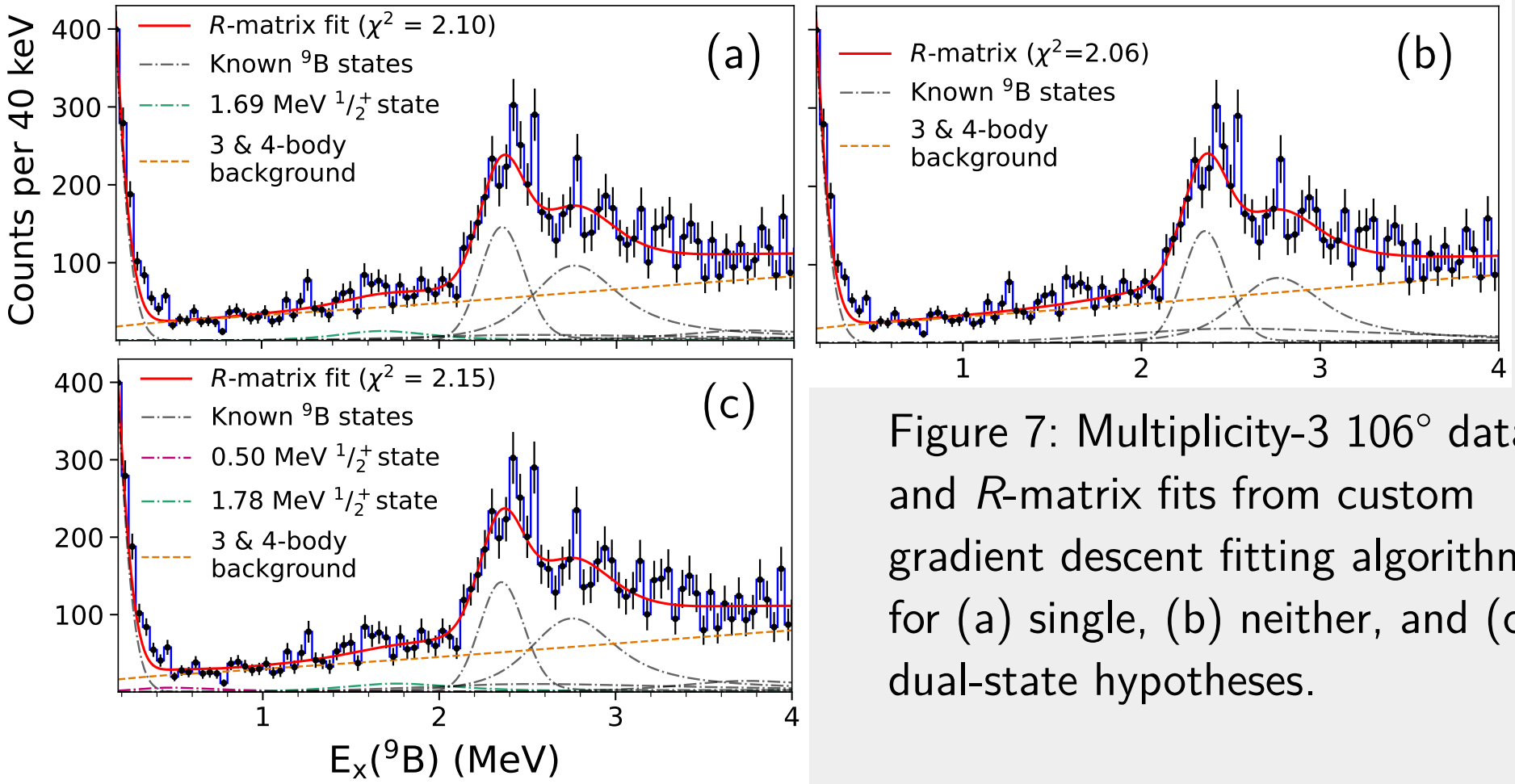


Figure 7: Multiplicity-3 106° data and *R*-matrix fits from custom gradient descent fitting algorithm for (a) single, (b) neither, and (c) dual-state hypotheses.

Experimental Investigation – To be or not to be

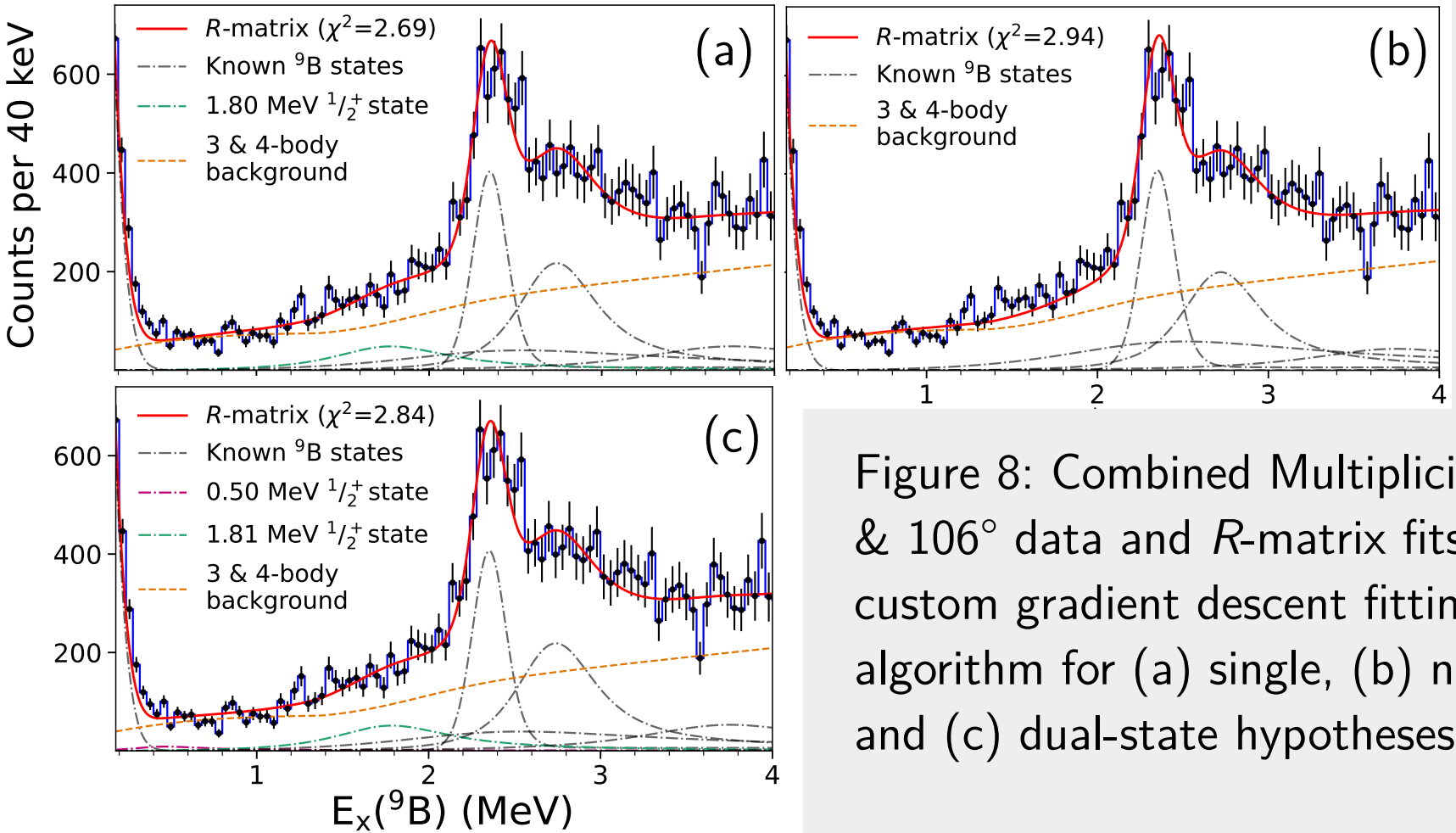
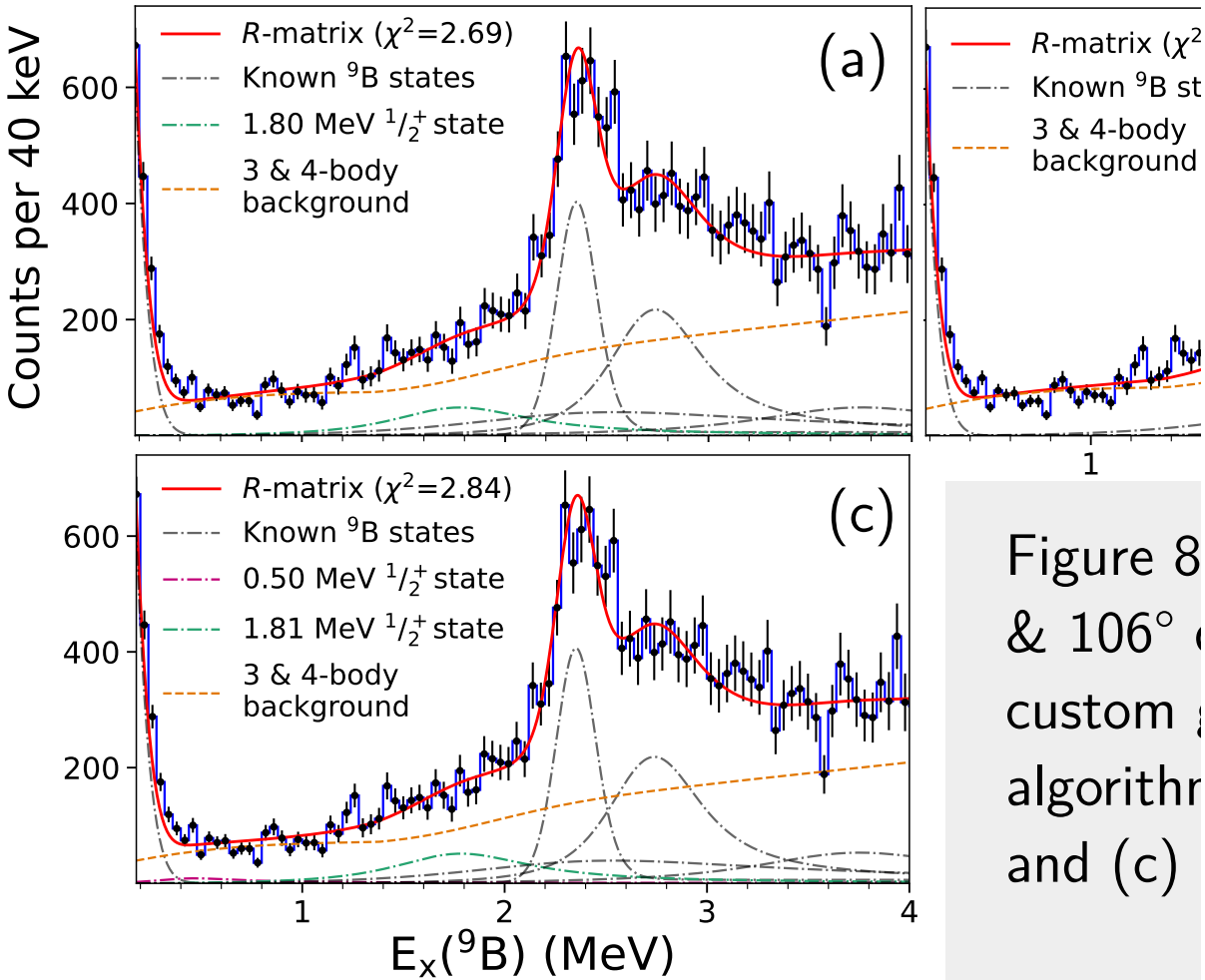
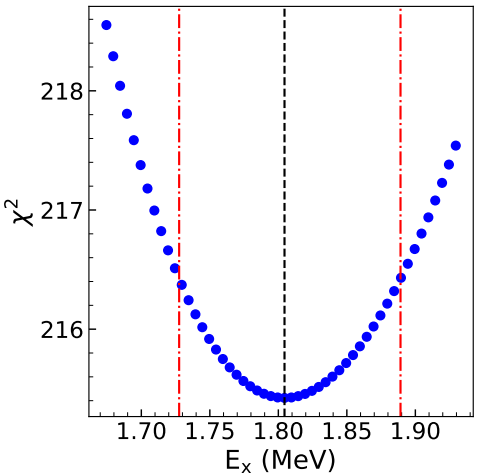


Figure 8: Combined Multiplicity-3 31° & 106° data and *R*-matrix fits from custom gradient descent fitting algorithm for (a) single, (b) neither, and (c) dual-state hypotheses.

Experimental Investigation – To be or not to be





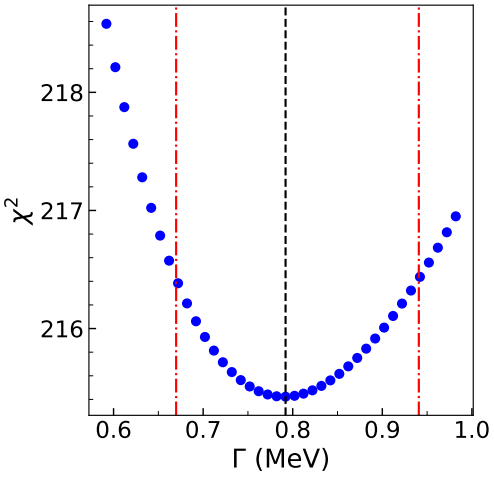


Figure 8
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Experimental Investigation – To be or not to be

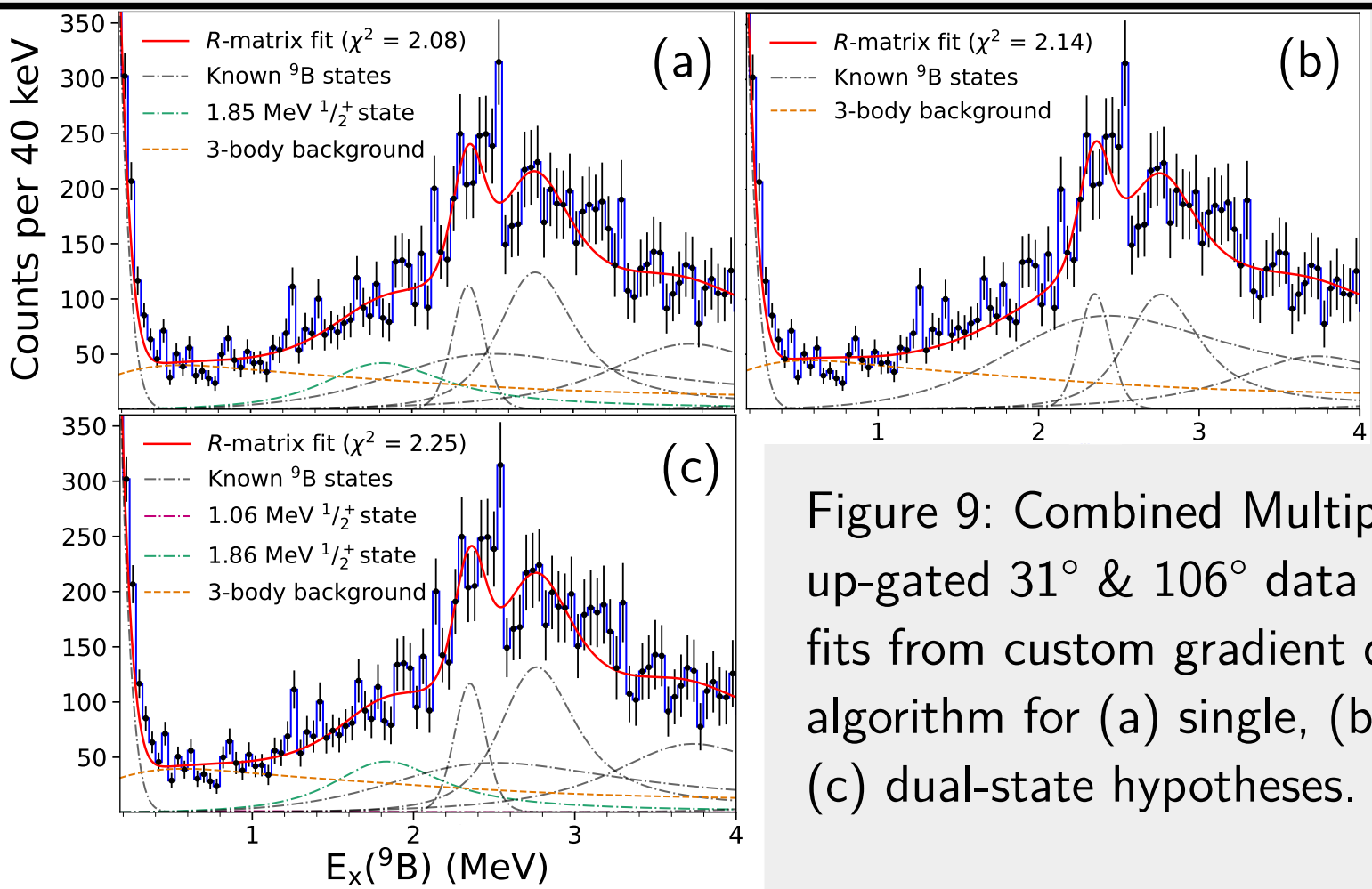
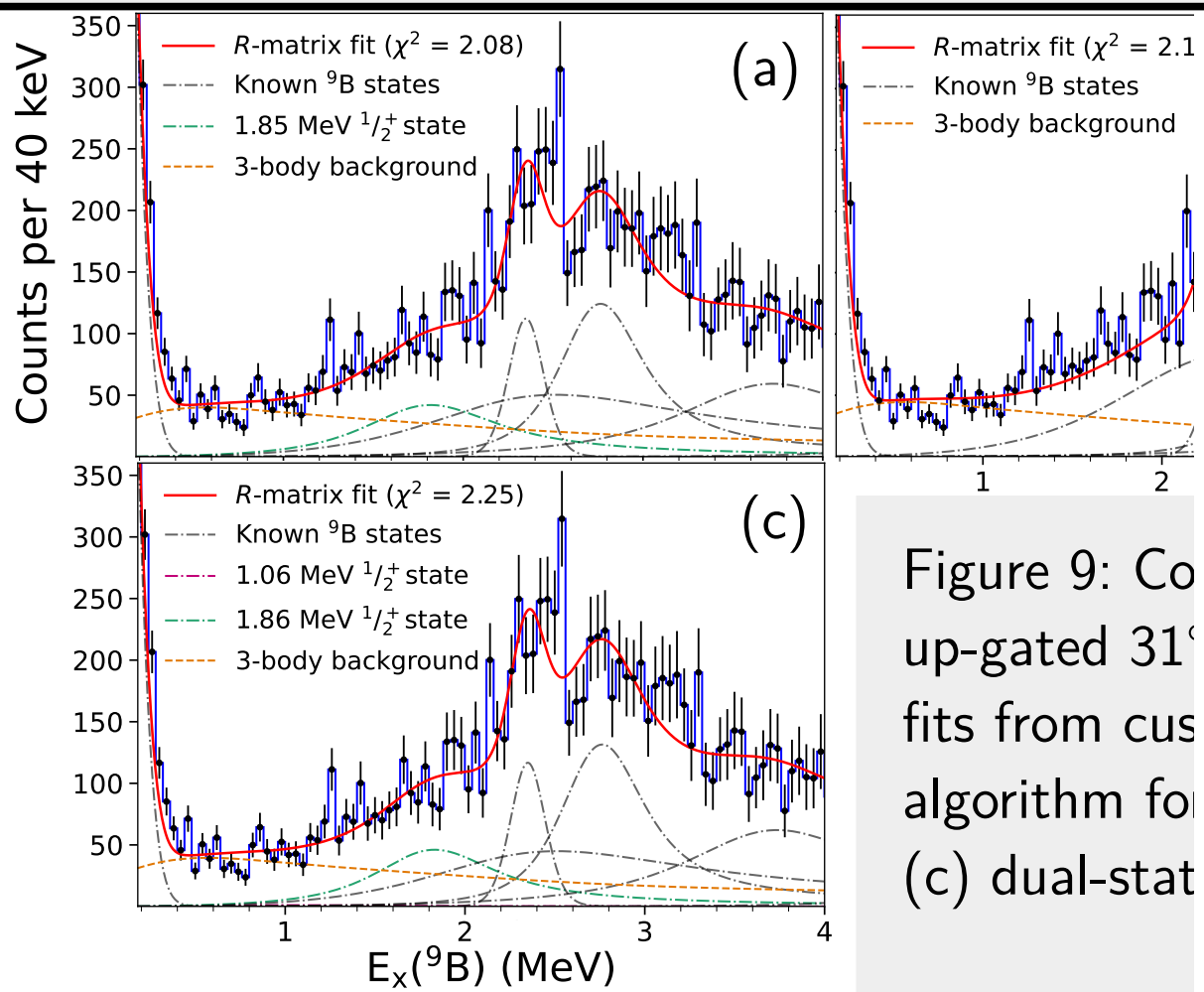
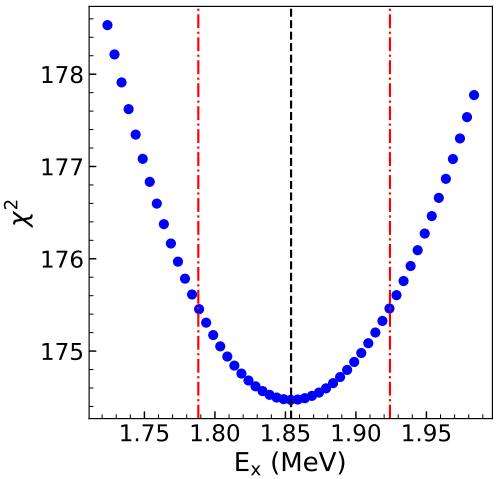


Figure 9: Combined Multiplicity-3 break-up-gated 31° & 106° data and *R*-matrix fits from custom gradient descent fitting algorithm for (a) single, (b) neither, and (c) dual-state hypotheses.

Experimental Investigation – To be or not to be





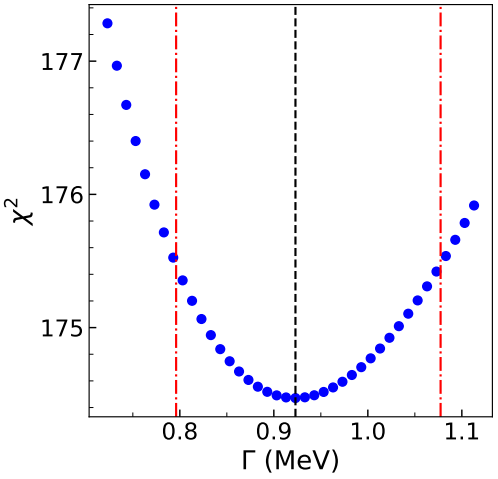


Figure 9: Co break-up-gated 31 matrix fits from cus fitting algorithm fo r, and (c) dual-stat

Experimental Investigation – To be or not to be

"Evidence" of $1/2^+$ state is identified at an excitation energy of 1.83 ± 0.05 MeV and width of 850^{+110}_{-88} keV. Averaging with previous results gives $E_x = 1.84 \pm 0.04$ MeV and $\Gamma = 740^{+77}_{-66}$ keV

$a \rightarrow$ m3 31°

$b \rightarrow$ m3 Comb°

$c \rightarrow$ m3 Comb° + decay

$d \rightarrow$ Average of b & c

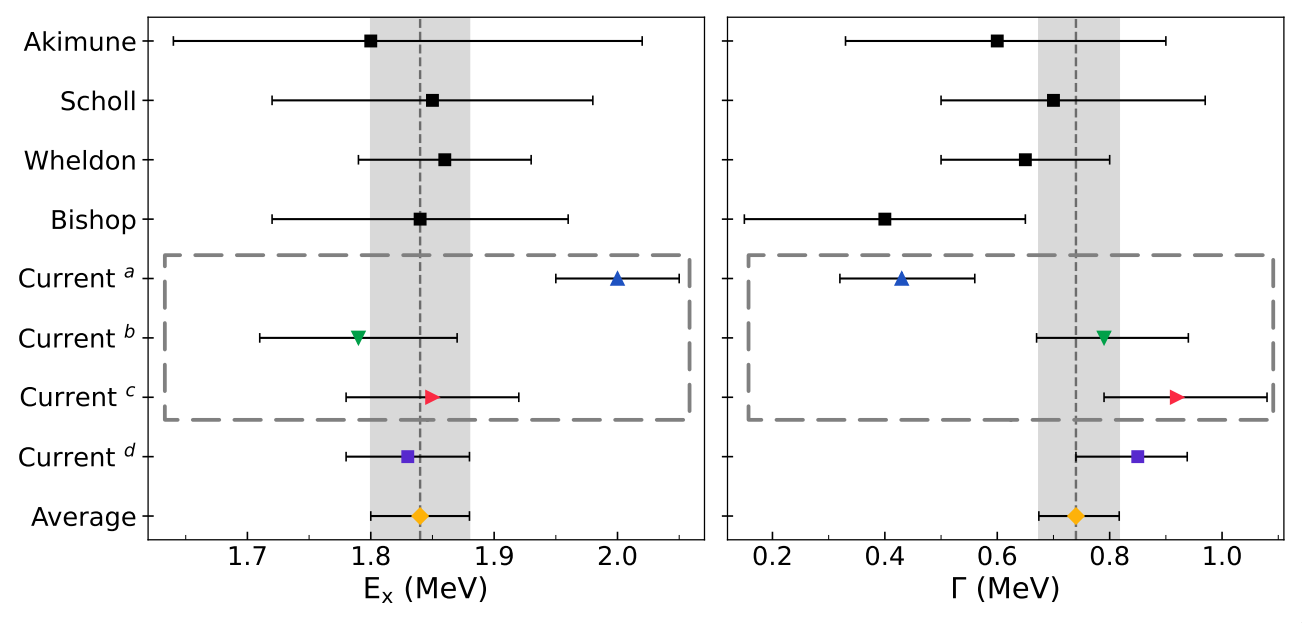
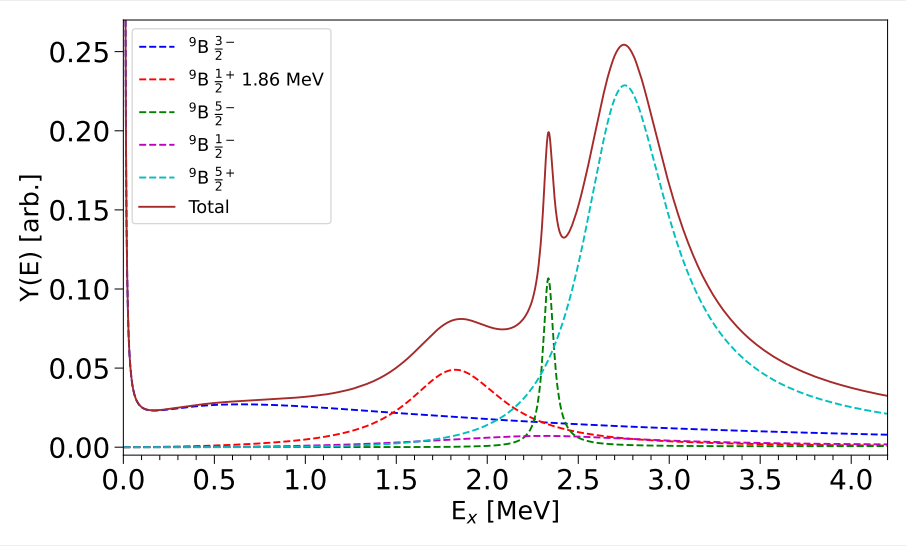


Figure 10: Excitation energy and widths of previously reported 1.8 MeV 1/2+ states with current results and averages.

Experimental Investigation – 0.8 MeV fake news



PHYSICAL REVIEW C **111**, 024002 (2025)

Solution to the ^{9}B$(1/2^+)$ state problem using the *R*-matrix formalism

A. D. Brooks,* J. Bishop, Tz. Kokalova, and C. Wheldon
School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, England, United Kingdom

DOI: 10.1103/PhysRevC.111.024002

Journal of Physics G: Nuclear and Particle Physics

Coulomb energy differences in ^{9}B using a molecular model

AD Brooks*, J Bishop, Tz Kokalova, S Pirrie and C Wheldon

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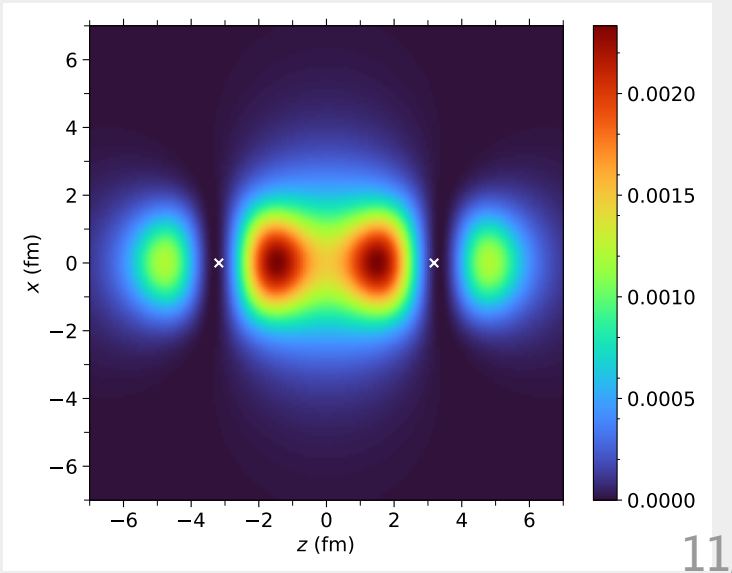
Journal of Physics G: Nuclear and Particle Physics, Volume 53, Number 2
Citation AD Brooks *et al* 2026 *J. Phys. G: Nucl. Part. Phys.* **53** 025103
DOI 10.1088/1361-6471/ae42d8



Acknowledgements

The supervisory council:

(J. Bishop, S. Pirrie, Tz. Kokalova, C. Wheldon)

Experimental collaborators:

(N. Curtis, D. Stajkowski)

Cyclotron staff:

(B. Phoenix)

The End

Full paper currently available in Phys. Rev. C:

PHYSICAL REVIEW C **113**, 034303 (2026)

Evidence of the ^{9}B$(1/2^{+})$ state in the ^{12}C(p, α) ^{9}B reaction

A. D. Brooks, * J. Bishop, S. Pirrie, Tz. Kokalova, C. Wheldon, N. Curtis, B. Phoenix, and D. Stajkowski
School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom

(Received 27 October 2025; accepted 9 February 2026; published 2 March 2026)

The low-lying excitation region in ^{9}B has been studied through the ^{12}C(p, α) ^{9}B reaction with a proton beam energy of 33 MeV at the Birmingham MC40 Cyclotron. Coincident recoil α-particle and ^{9}B breakup products were detected by a silicon double-sided strip detector array and reconstructed to identify signatures of the elusive ^{9}B$(1/2^{+})$ state. Data were collected for two distinct α-particle recoil angles, 31° and 106°, with a total beam exposure of ≈0.52 mC. *R*-matrix analysis indicates the presence of a state at $E_x = 1.83 \pm 0.05$ MeV with a width of $\Gamma = 850 \pm^{110}_{88}$ keV with a confidence level of 99.1% and no signature of any lower-lying state. This result is shown to be consistent with four previous measurements over the last 25 years, signifying strong evidence that the first excited state in ^{9}B lies at a weighted average excitation of $E_x = 1.84 \pm 0.04$ MeV with $\Gamma = 740 \pm^{77}_{66}$ keV.

DOI: 10.1103/5rny-7zbk

Experimental analysis – Nitty Gritty

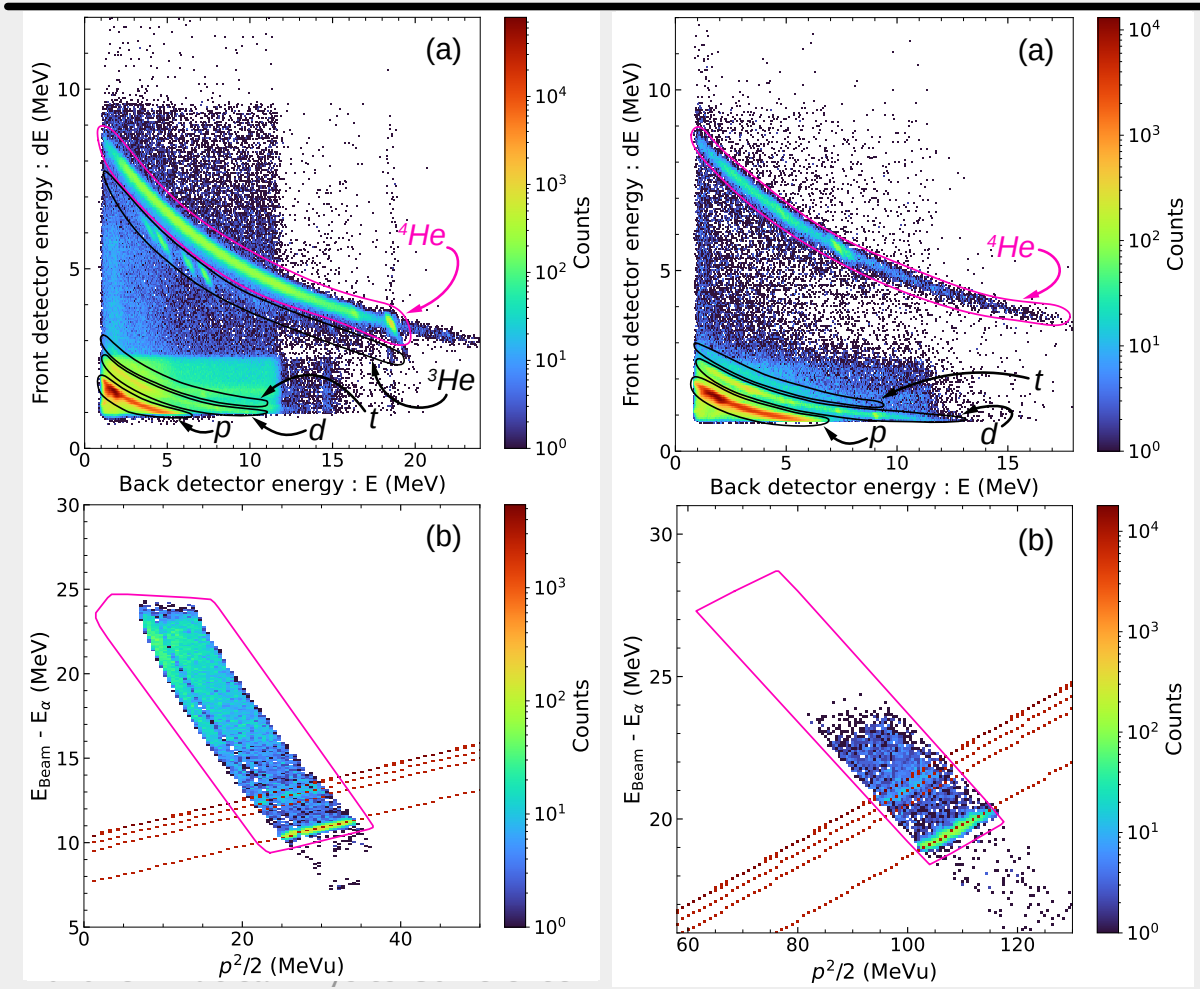


Figure 11: dE-E telescope PID plots and ^{9}B Catania plots for (a) 31° and (b) 106° detector configurations.

Experimental analysis – Nitty Gritty

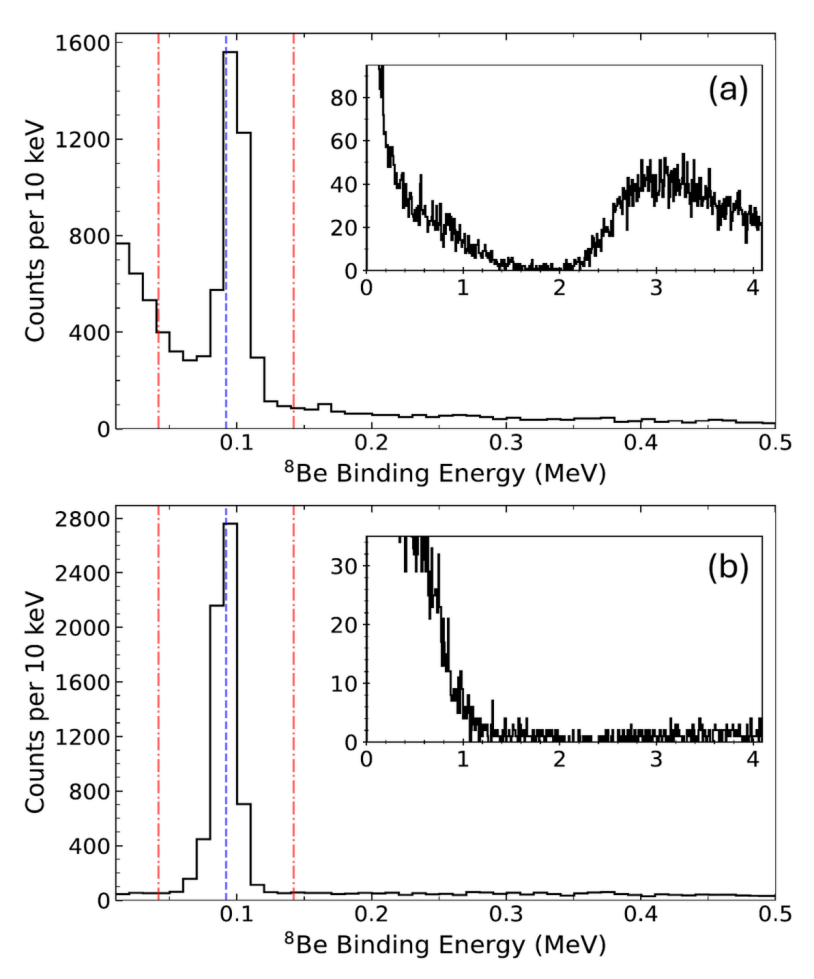


Figure 12: Reconstructed decay break-up Q-value for (a) 31° and (b) 106° detector configurations.

R-matrix Fitting – AZURE2 not included

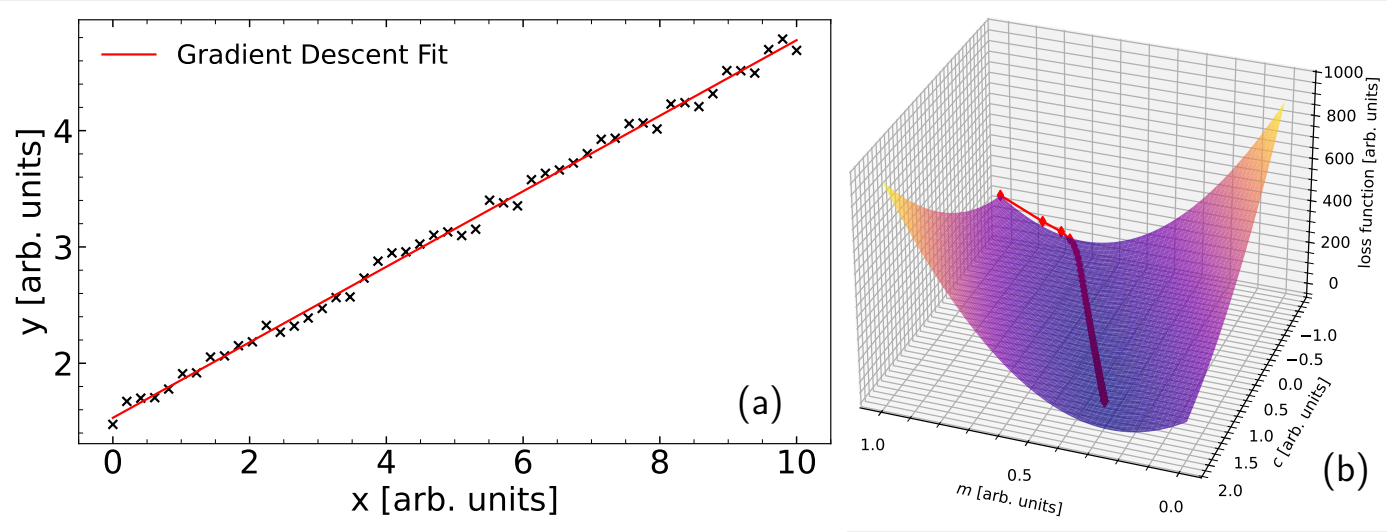
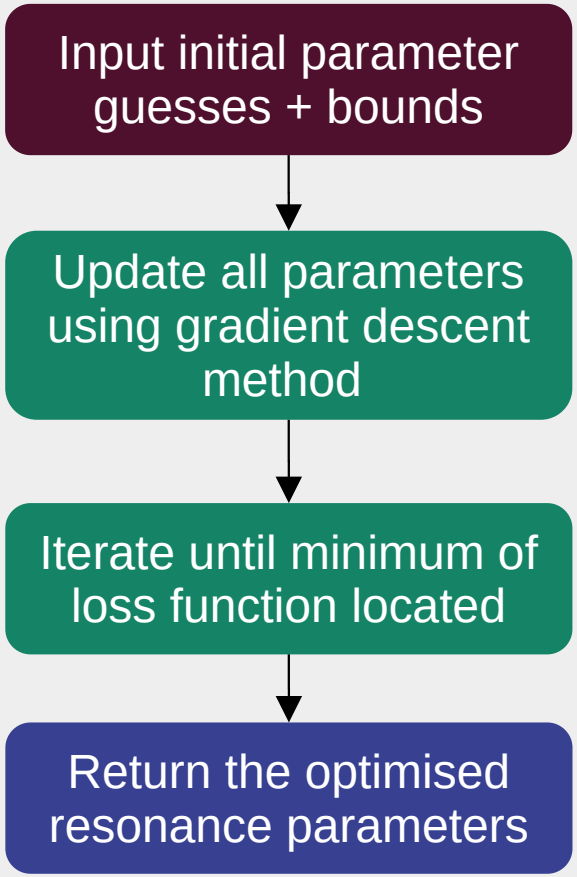


Figure 13: An example of ReverseSisyphus fitting to (a) generated linear data and (b) the resulting loss function surface.



Experimental Investigation – To be or not to be

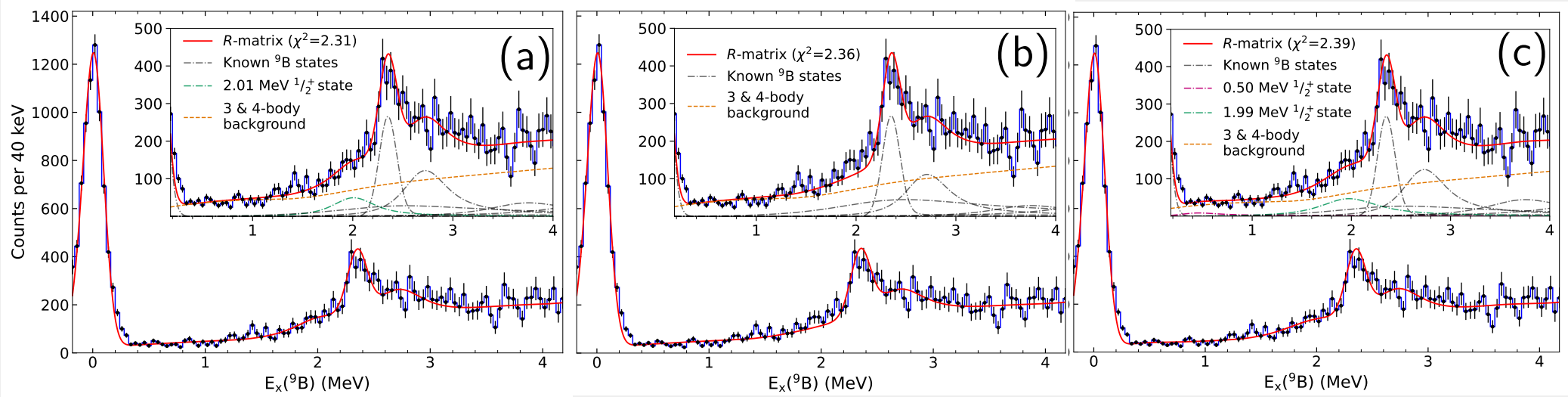


Figure 14: Multiplicity-3 31° data and *R*-matrix fits from custom gradient descent fitting algorithm for (a) single, (b) neither, and (c) dual-state hypotheses.

Experimental Investigation – To be or not to be

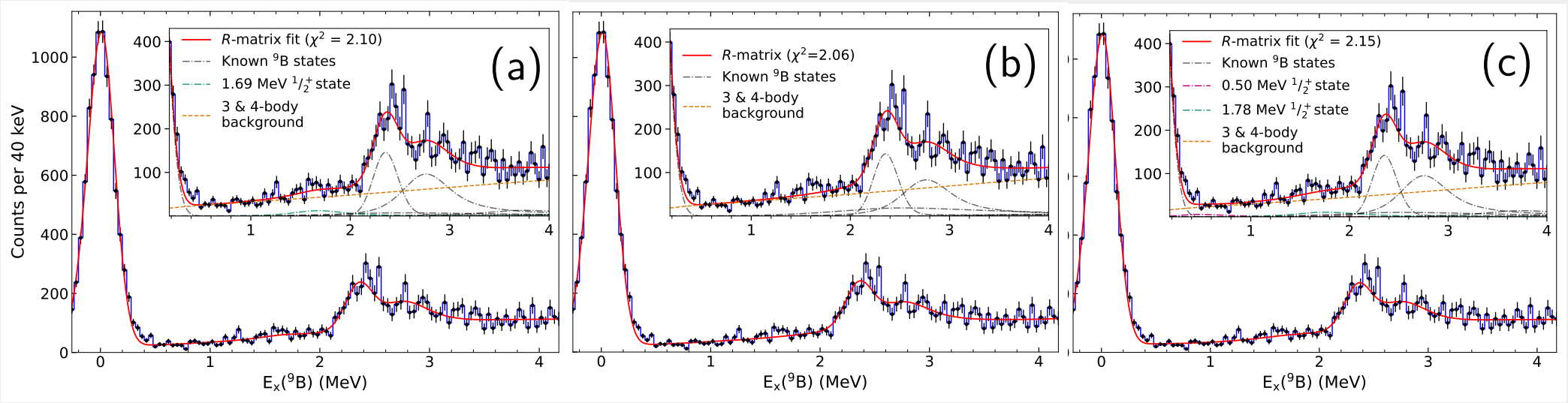


Figure 15: Multiplicity-3 106° data and *R*-matrix fits from custom gradient descent fitting algorithm for (a) single, (b) neither, and (c) dual-state hypotheses.

Experimental Investigation – To be or not to be

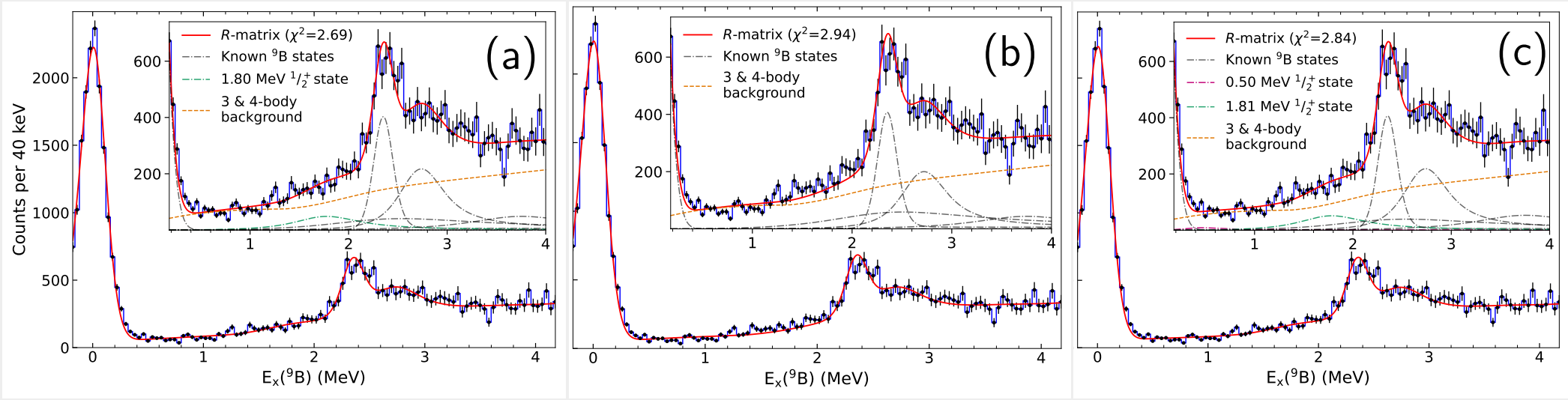


Figure 16: Combined Multiplicity-3 31° and 106° data and *R*-matrix fits from custom gradient descent fitting algorithm for (a) single, (b) neither, and (c) dual-state hypotheses.

Experimental Investigation – To be or not to be

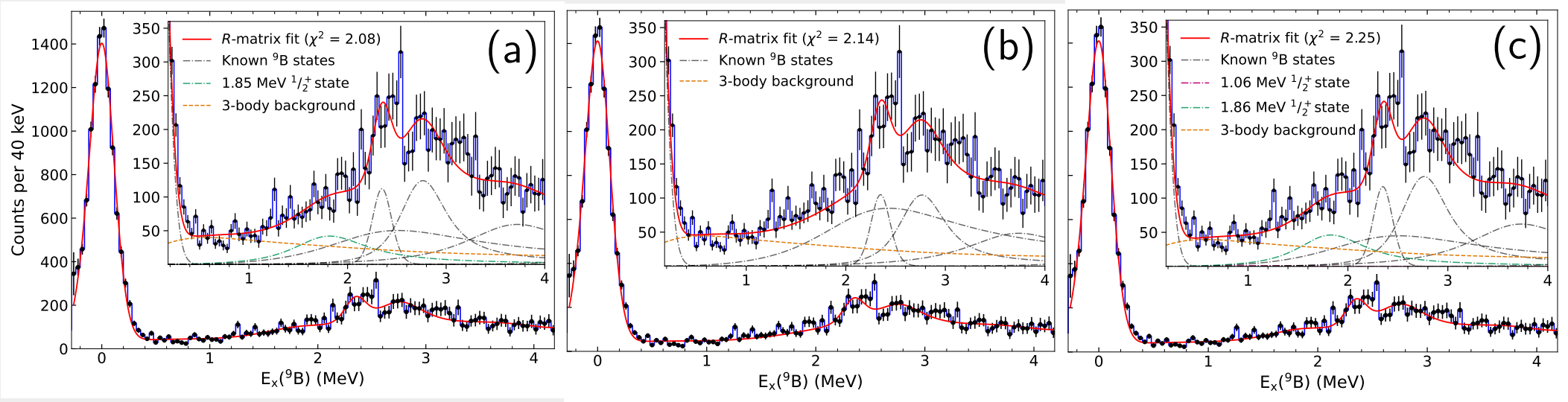


Figure 17: Combined Multiplicity-3 decay-gated 31° and 106° data and *R*-matrix fits from custom gradient descent fitting algorithm for (a) single, (b) neither, and (c) dual-state hypotheses.

Histogramming – Four counts Jeremy!

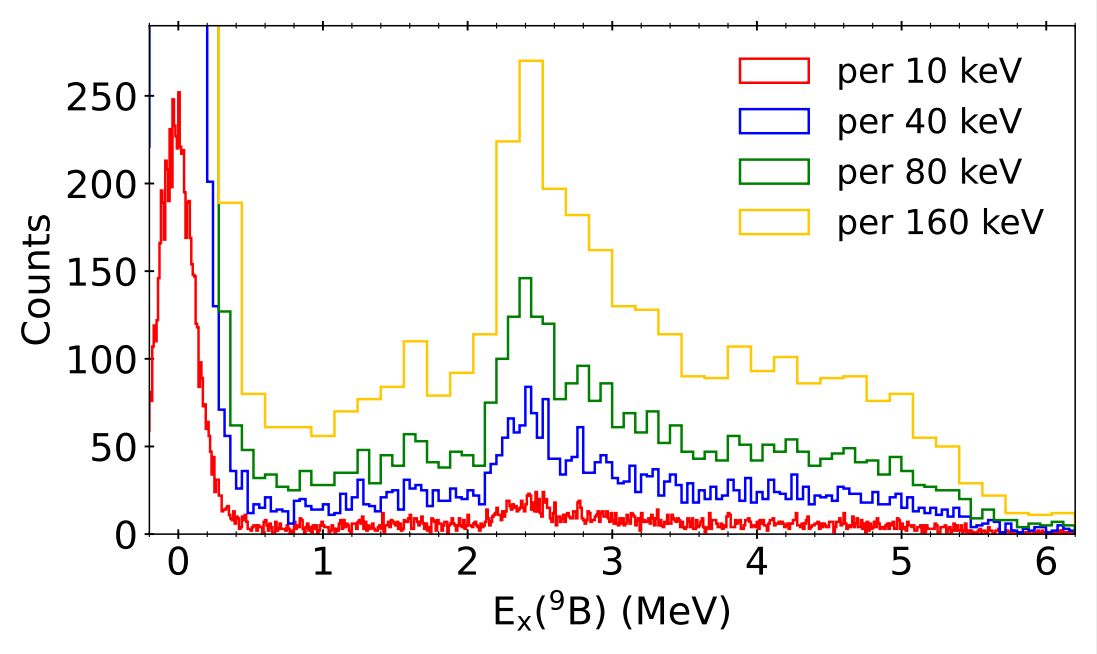


Figure 18: Bin size effect on final 106° histogram.

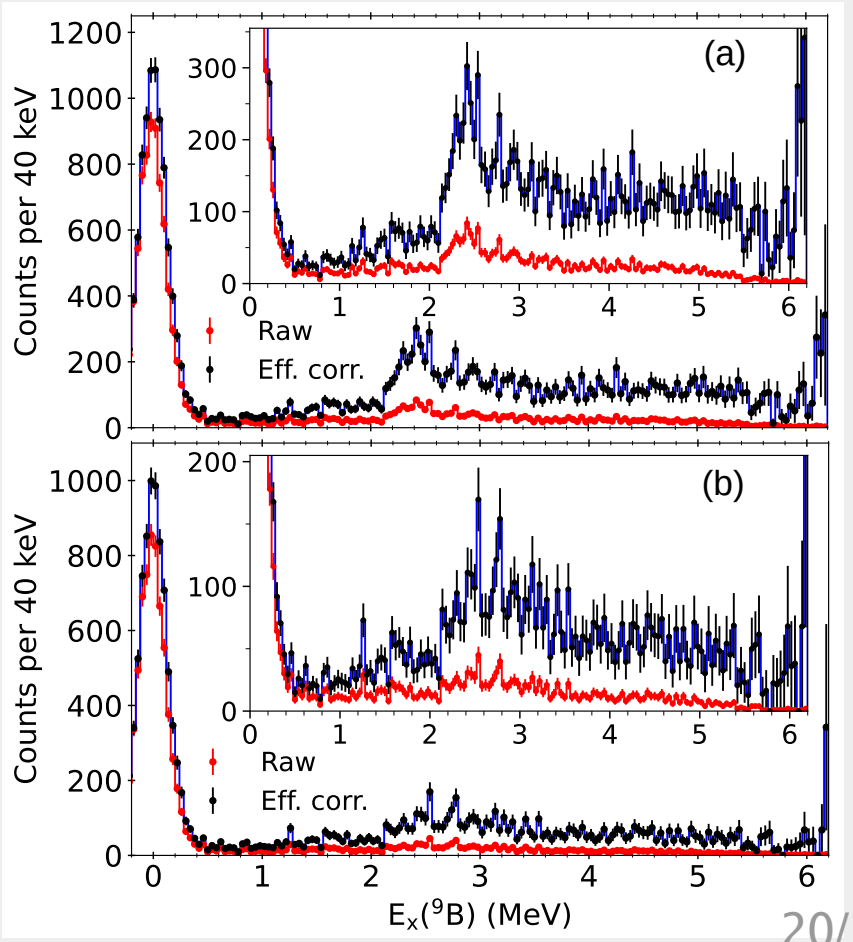


Figure 19: Efficiency correction effect on 106° (a) m3 and (b) m3+gated spectra.

Experimental Investigation – You spin me round

Relative population of g.s. calculated to be 0.204±0.085 and for observed $1/2^+$ state is 0.226±0.122

Compound + fusion evapouration ratio is 0.796.

triton-transfer ratios are 0.0013, 0.0006 and 0.0082 for l = 0,1,2 transitions

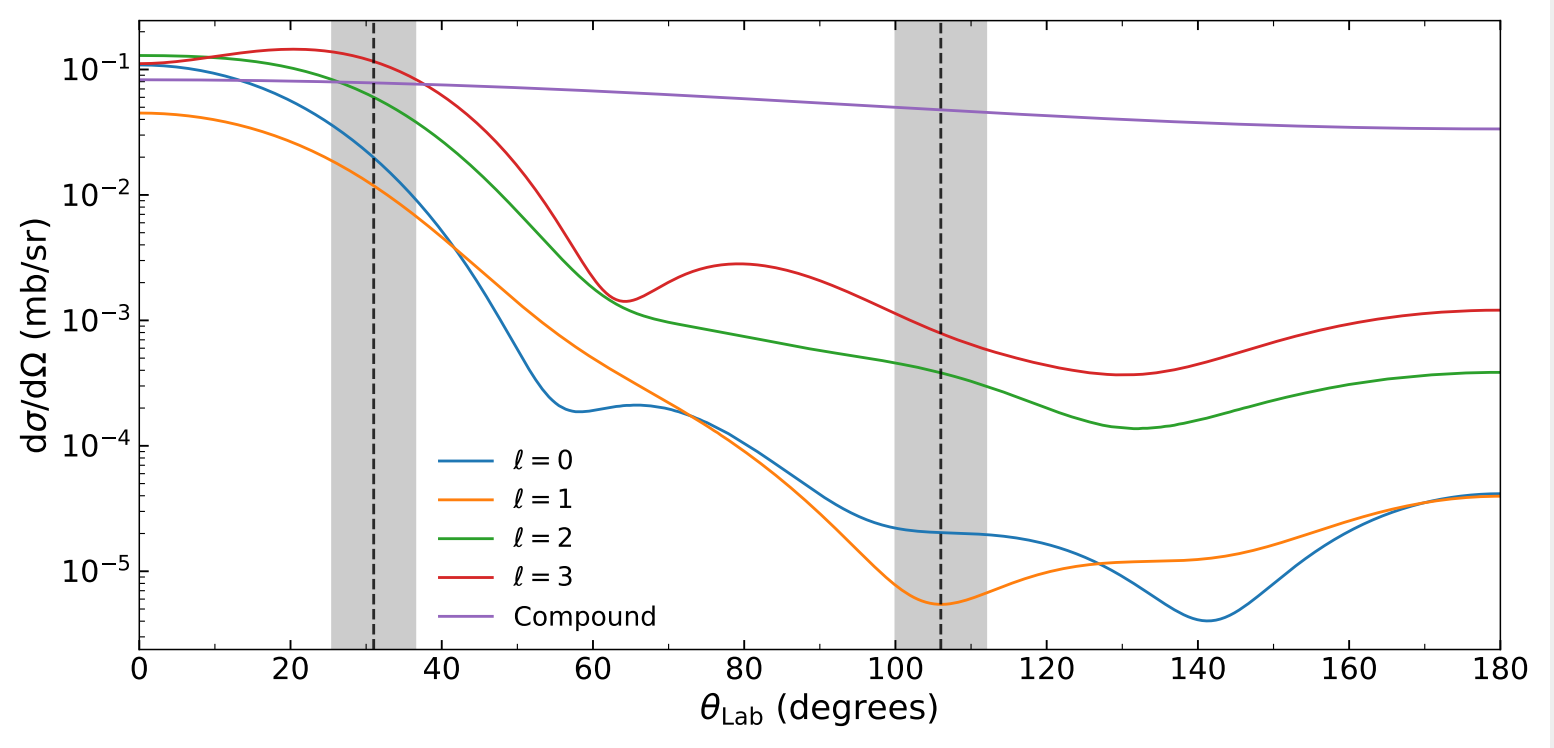


Figure 17: DWBA angular distribution calculations for $^{12}C(p,\alpha)^{9}B$ reaction at different momentum transfers. Shaded regions show angular coverage for each detector configuration. Compound nucleus + fusion evapouration angular distribution is shown in purple.