

# Neutrino Nucleosynthesis of Exotic Nuclides $^{138}\text{La}$ and $^{180}\text{Ta}$

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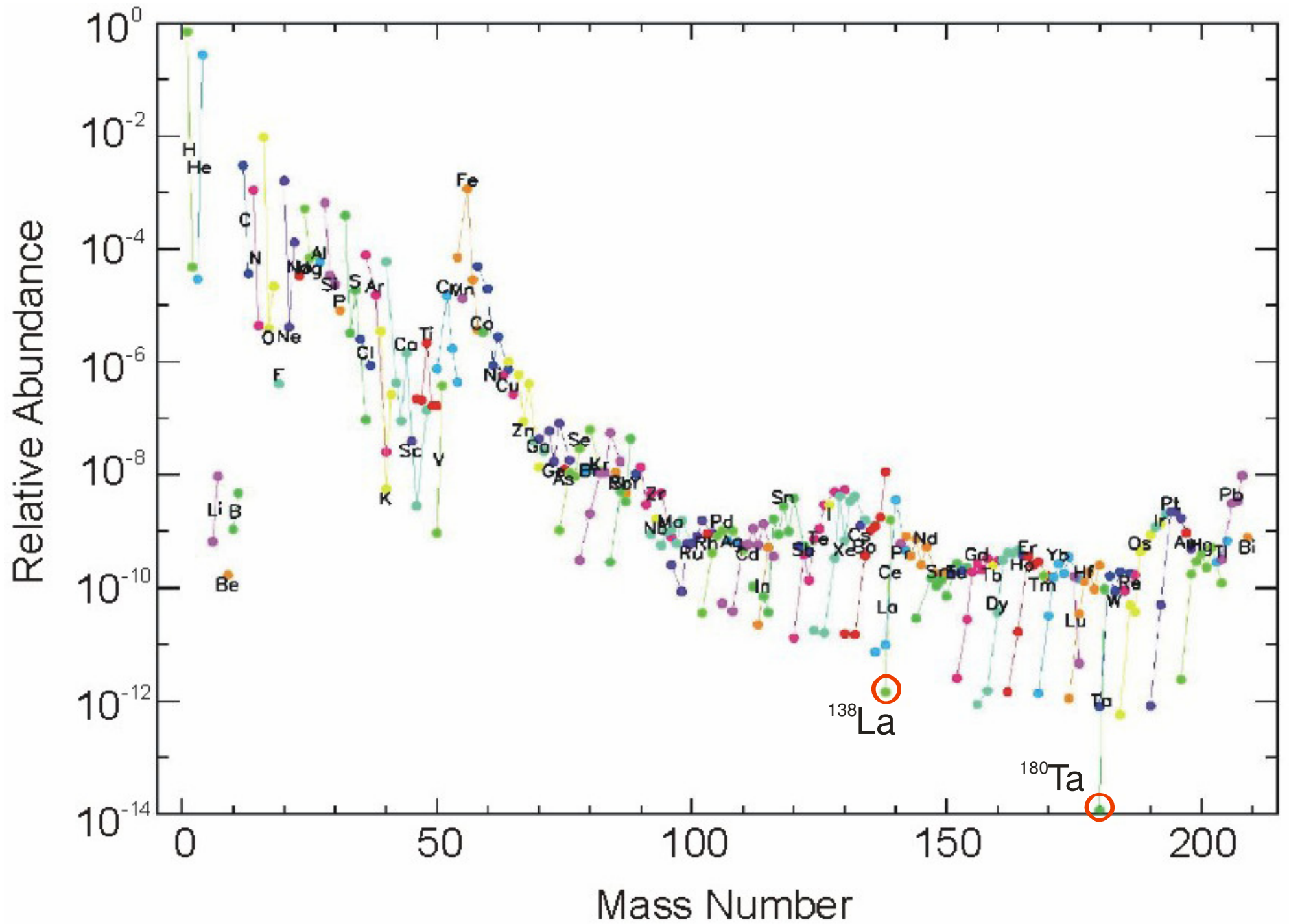
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# Outline

- Motivation
- Theoretical predictions
- Experimental requirements and setup
- Results vs. RPA calculations
- Summary and outlook

# Exotic Nuclides



# Nucleosynthesis of $^{138}\text{La}$

<b>Nd137</b> 38.5 m 1/2+ *	<b>Nd138</b> 5.04 h 0+	<b>Nd139</b> 29.7 m 3/2+ *	<b>Nd140</b> 3.37 d 0+	<b>Nd141</b> 2.49 h 3/2+ *	<b>Nd142</b> 0+ 27.13	<b>Nd143</b> 7/2- 12.18	<b>Nd144</b> 2.29E+15 y 0+ $\alpha$ 23.80	<b>Nd145</b> 7/2- 8.30	<b>Nd146</b> 0+ 17.19	<b>Nd147</b> 10.98 d 5/2- $\beta^-$
<b>Pr136</b> 13.1 m 2+	<b>Pr137</b> 1.28 h 5/2+	<b>Pr138</b> 1.45 m 1+ *	<b>Pr139</b> 4.41 h 5/2+	<b>Pr140</b> 3.39 m 1+	<b>Pr141</b> 5/2+ 100	<b>Pr142</b> 19.12 h 2- *	<b>Pr143</b> 13.57 d 7/2+ $\beta^-$	<b>Pr144</b> 17.28 m 0- *	<b>Pr145</b> 5.984 h 7/2+ $\beta^-$	<b>Pr146</b> 24.15 m (2)- $\beta^-$
<b>Ce135</b> 17.7 h 1/2(+) *	<b>Ce136</b> 0+ 0.19	<b>Ce137</b> 9.0 h 3/2+ *	<b>Ce138</b> 0+ 0.25 *	<b>Ce139</b> 137.640 d 3/2+ *	<b>Ce140</b> 0 88.48	<b>Ce141</b> 32.501 d 7/2- $\beta^-$	<b>Ce142</b> 5E+16 y 0+ 11.08	<b>Ce143</b> 33.039 h 3/2- $\beta^-$	<b>Ce144</b> 284.893 d 0+ $\beta^-$	<b>Ce145</b> 3.01 m (3/2)- $\beta^-$
<b>La134</b> 6.45 m 1+	<b>La135</b> 19.5 h 5/2+	<b>La136</b> 9.87 m 1+ *	<b>La137</b> 6E4 y 7/2- *	<b>La138</b> 1.05E+11 y 5+ EC, $\beta^-$ 0.0902	<b>La139</b> 7/2+ 99.9098	<b>La140</b> 1.6781 d $\beta^-$	<b>La141</b> 3.92 h (7/2+) $\beta^-$	<b>La142</b> 91.1 m 2- $\beta^-$	<b>La143</b> 14.2 m (7/2)+ $\beta^-$	<b>La144</b> 40.8 s (3)- $\beta^-$
<b>Ba133</b> 10.51 y 1/2+ *	<b>Ba134</b> 0 2.417	<b>Ba135</b> 3/2+ 6.592 *	<b>Ba136</b> 0+ 7.854 *	<b>Ba137</b> 3/2+ 11.23 *	<b>Ba138</b> 0 71.70	<b>Ba139</b> 7/2- 83.06 m $\beta^-$	<b>Ba140</b> 0+ 12.752 d $\beta^-$	<b>Ba141</b> 3/2- 18.27 m $\beta^-$	<b>Ba142</b> 0+ 10.6 m $\beta^-$	<b>Ba143</b> 5/2- 14.33 s $\beta^-$
<b>Cs132</b> 6.479 d 2+ EC, $\beta^-$	<b>Cs133</b> 7/2+ 100	<b>Cs134</b> 2.9648 y 4+ *	<b>Cs135</b> 2.3E+6 y 7/2+ *	<b>Cs136</b> 13.16 d 5+ *	<b>Cs137</b> 59.07 y 7/2+ $\beta^-$	<b>Cs138</b> 33.41 m 3+ *	<b>Cs139</b> 2.27 m 7/2+ $\beta^-$	<b>Cs140</b> 63.7 s 1+ $\beta^-$	<b>Cs141</b> 24.94 s 7/2+ $\beta^-$	<b>Cs142</b> 1.70 s 0- $\beta^-$
<b>Xe131</b> 3/2+ 21.2 *	<b>Xe132</b> 0+ 26.9 *	<b>Xe133</b> 5.243 d 3/2+ *	<b>Xe134</b> 0+ 10.4 *	<b>Xe135</b> 9.14 h 3/2+ *	<b>Xe136</b> 0+ 2.36E21 y 8.9	<b>Xe137</b> 3.818 m 7/2- $\beta^-$	<b>Xe138</b> 0+ 14.08 m $\beta^-$	<b>Xe139</b> 39.68 s 3/2- $\beta^-$	<b>Xe140</b> 0+ 13.60 s $\beta^-$	<b>Xe141</b> 1.73 s 5/2(-) $\beta^-$

→ s-process

→ r-process

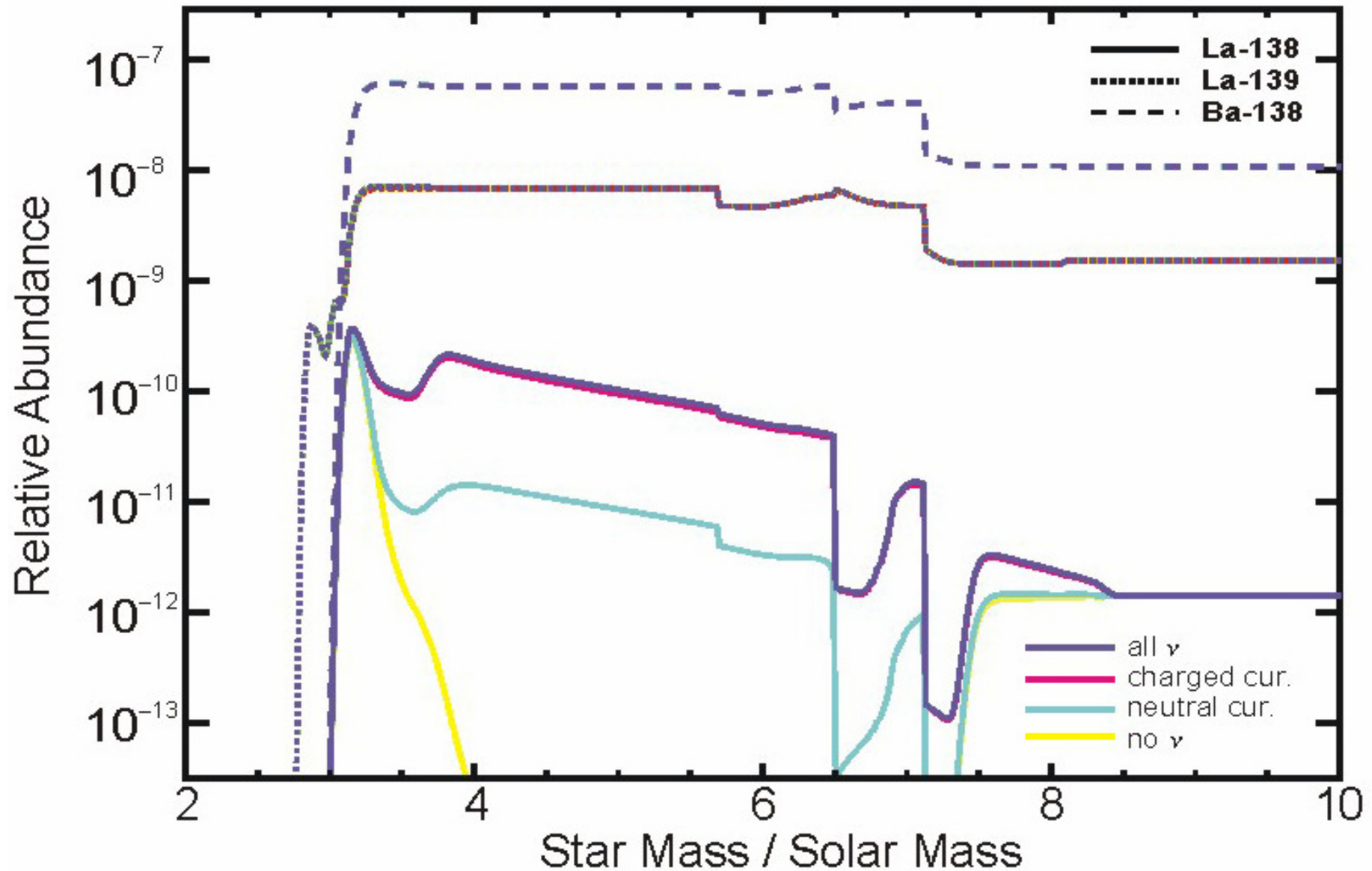
→ p-process

# Production through Neutrino Process

- Neutral current reactions:  $^{139}\text{La}(\nu, \nu' n)^{138}\text{La}$   
 $^{181}\text{Ta}(\nu, \nu' n)^{180}\text{Ta}$
- Charged current reactions:  $^{138}\text{Ba}(\nu_e, e^-)^{138}\text{La}$   
 $^{180}\text{Hf}(\nu_e, e^-)^{180}\text{Ta}$
- Complete stellar evolution in massive stars with the improved RPA calculations for  $\nu$ -nucleus reactions

A. Heger et al., Phys. Lett. B 606 (2005) 258

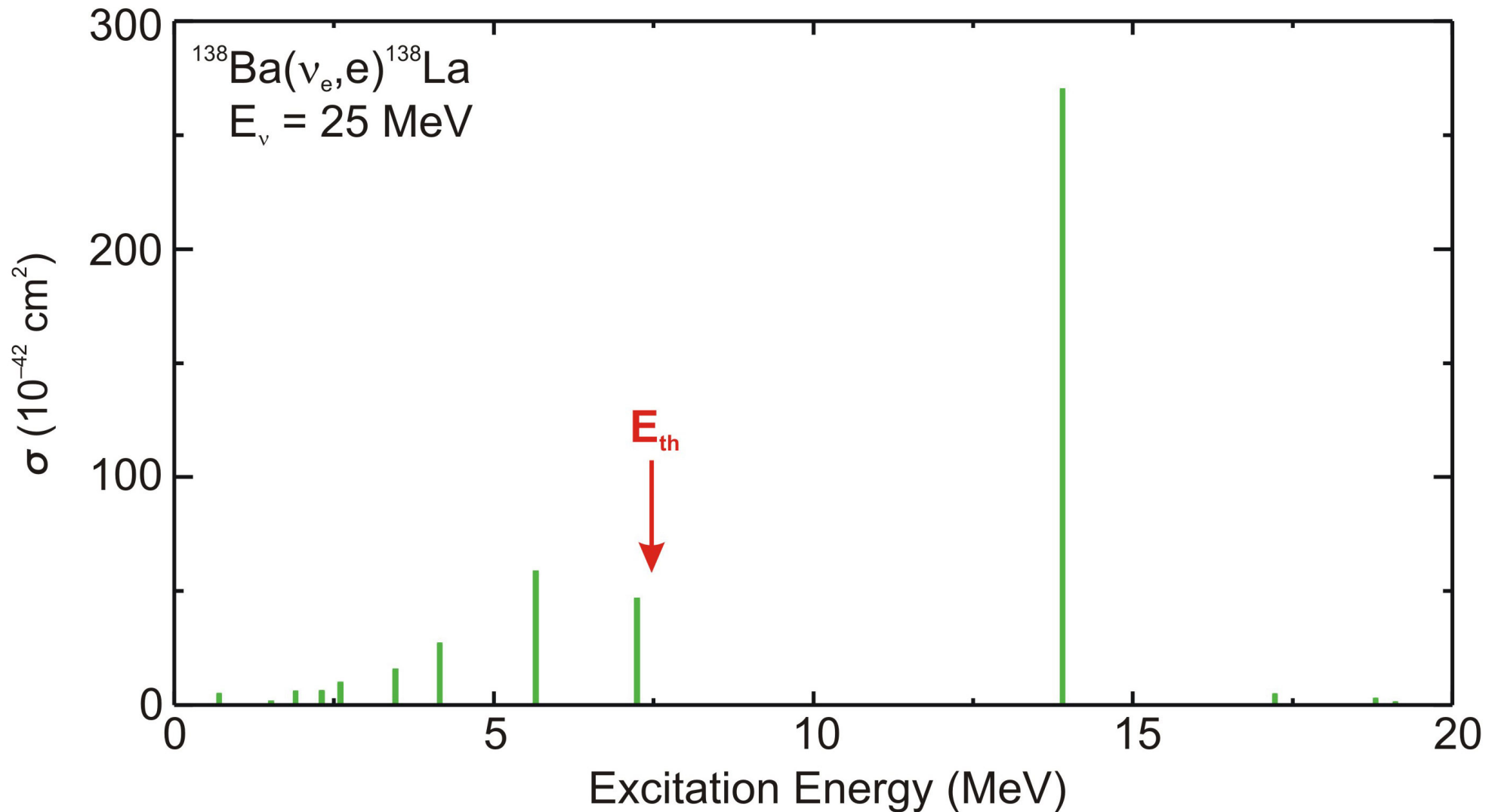
# Different Production Processes of $^{138}\text{La}$



- $^{138}\text{La}$ : pure  $\nu$  process nucleus
- $^{180}\text{Ta}$ : 50% p process, 50%  $\nu$  process (s process also not excluded)

# Prediction

- Low neutrino energies  $\rightarrow$  small  $q \rightarrow \Delta I = 0 \rightarrow$  GT strength
- RPA predicts main GT resonance well above neutron threshold

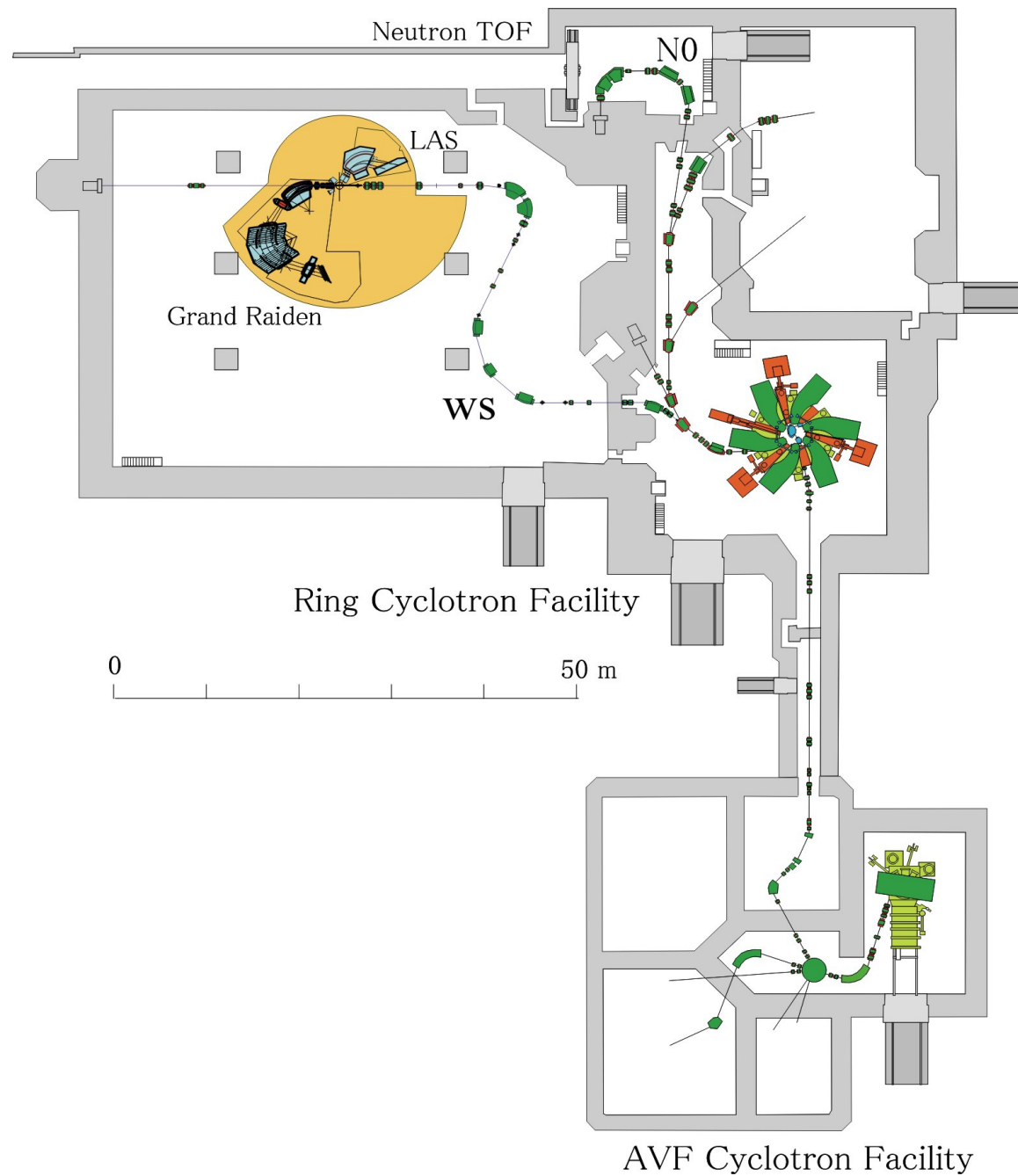


# Experimental Requirements

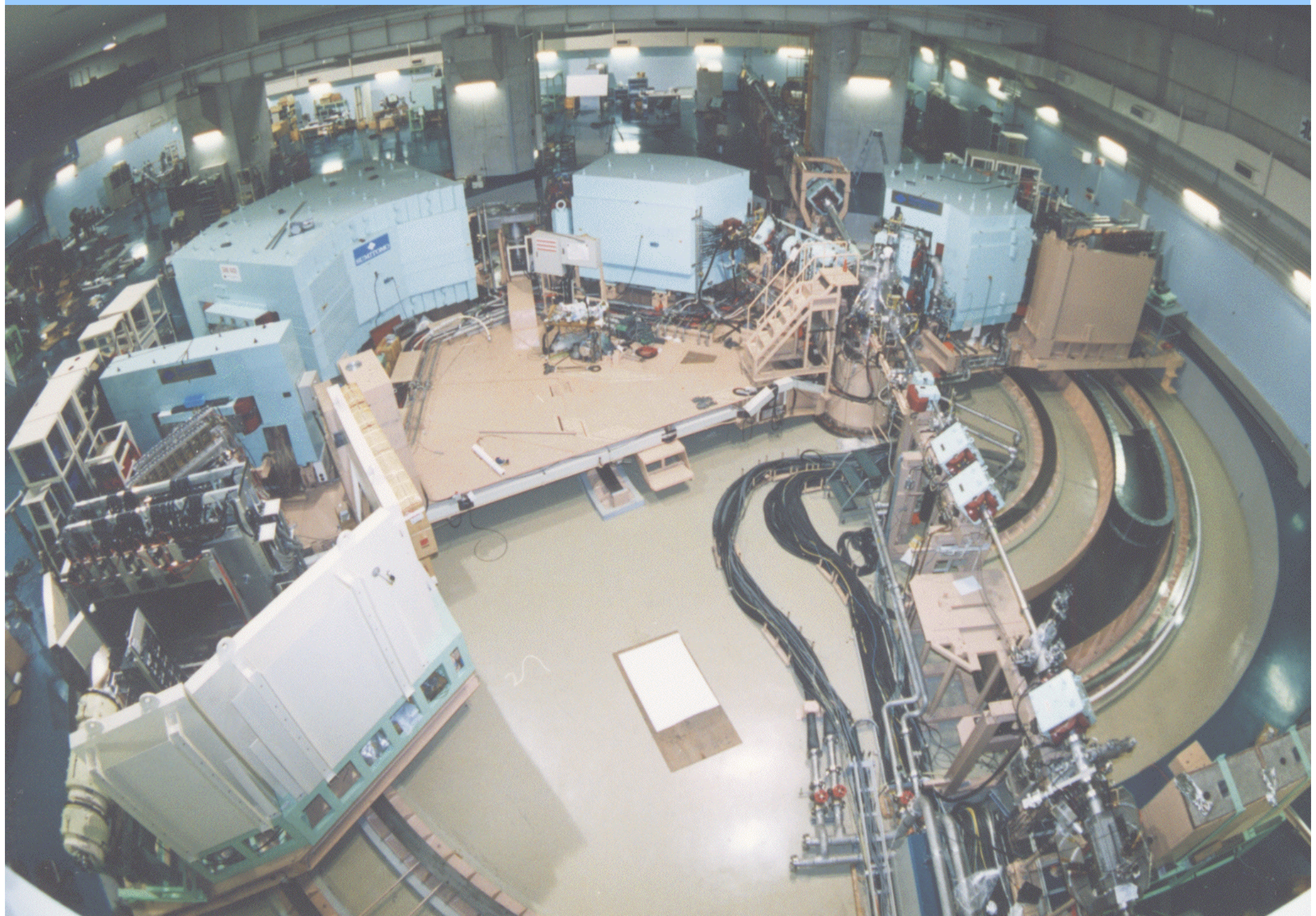
- $(\nu_e, e) \rightarrow$  Gamow-Teller strength  $\leftarrow$   $(p, n)$  or  $({}^3\text{He}, t)$
- Gamow-Teller part  $\rightarrow$  Narrow angle cut around  $0^\circ$
- Simple one step reaction mechanism  $\rightarrow$   
 $\rightarrow$  Intermediate energies



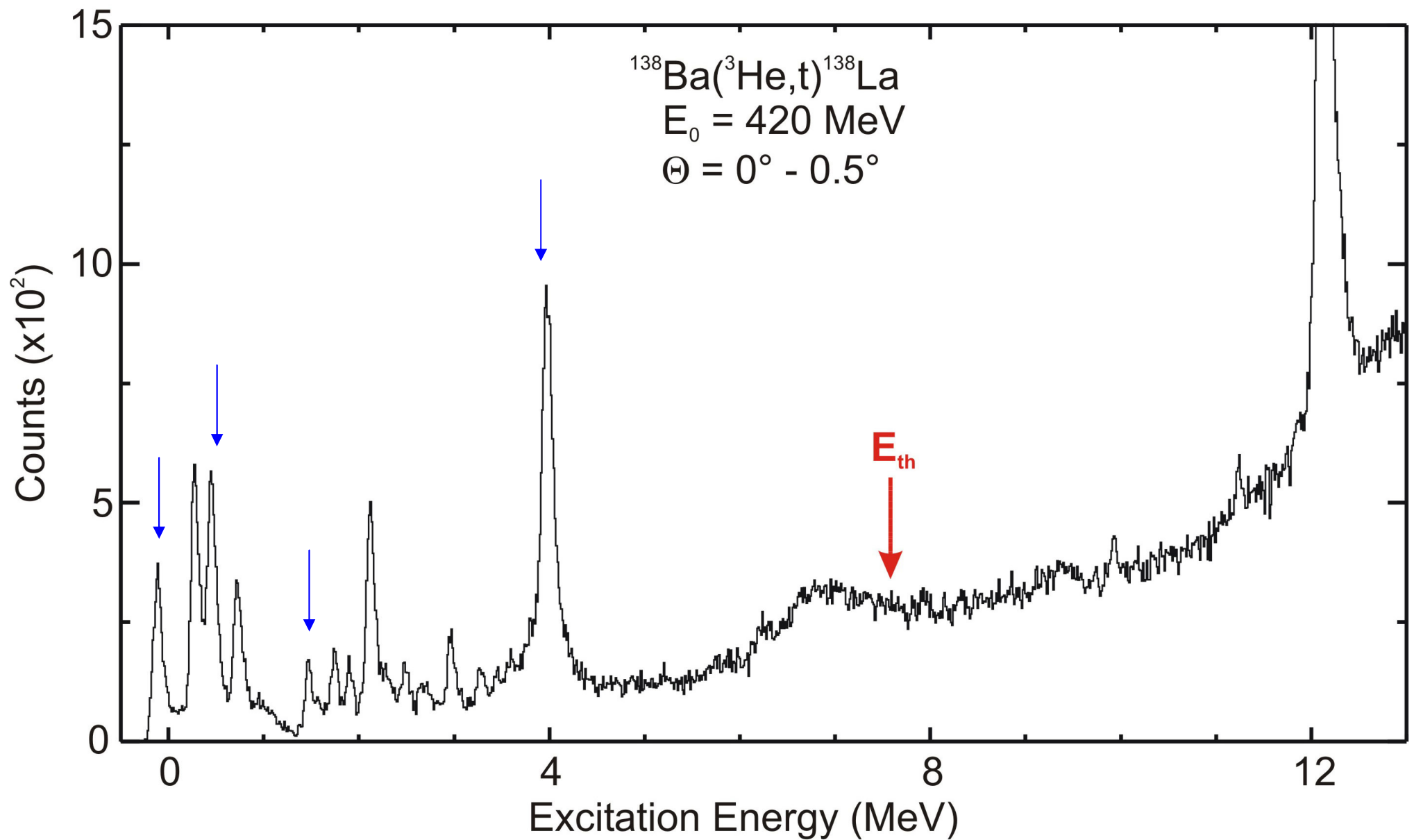
# Experimental Facility at RCNP



# Grand Raiden



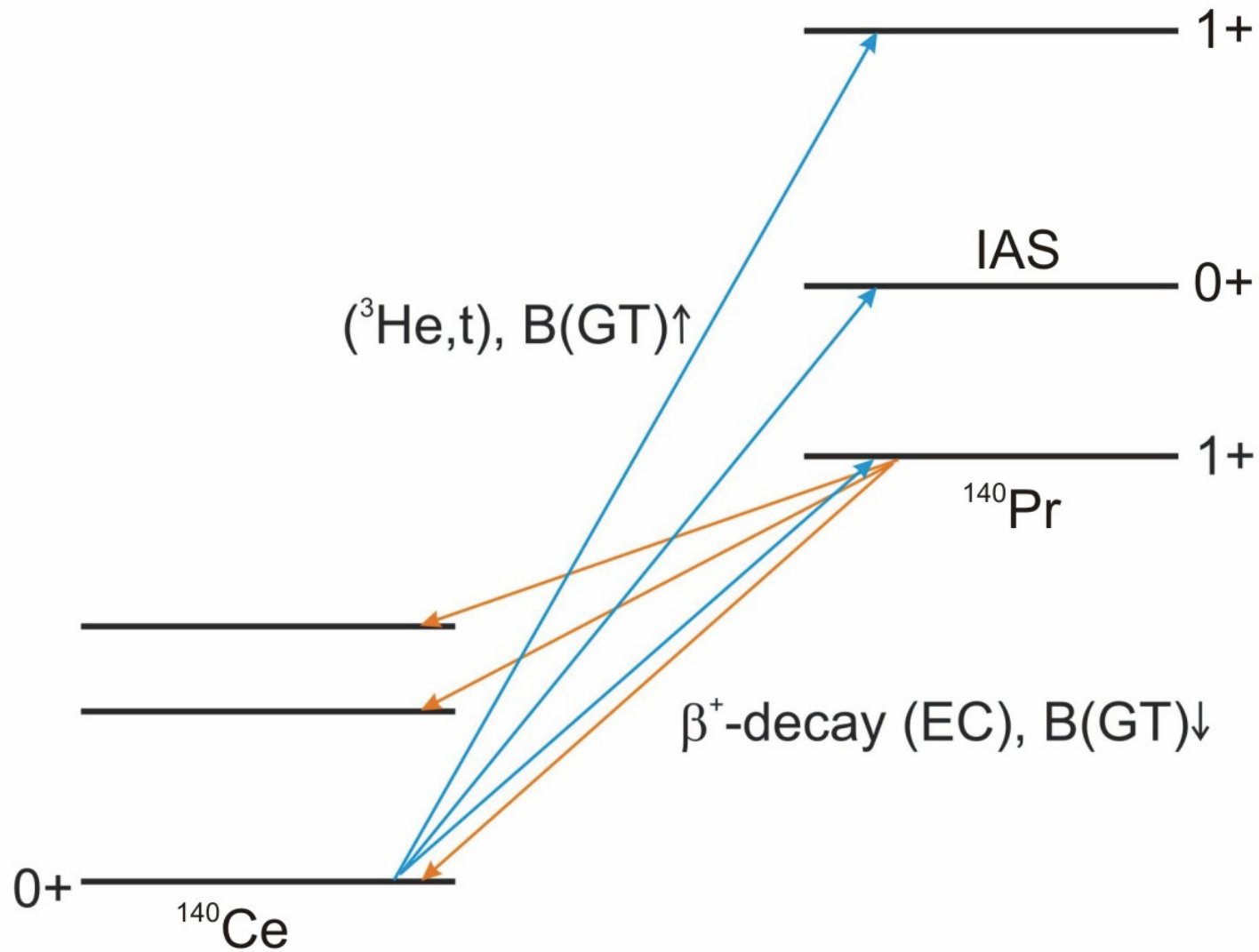
# $^{138}\text{La}$ Spectrum



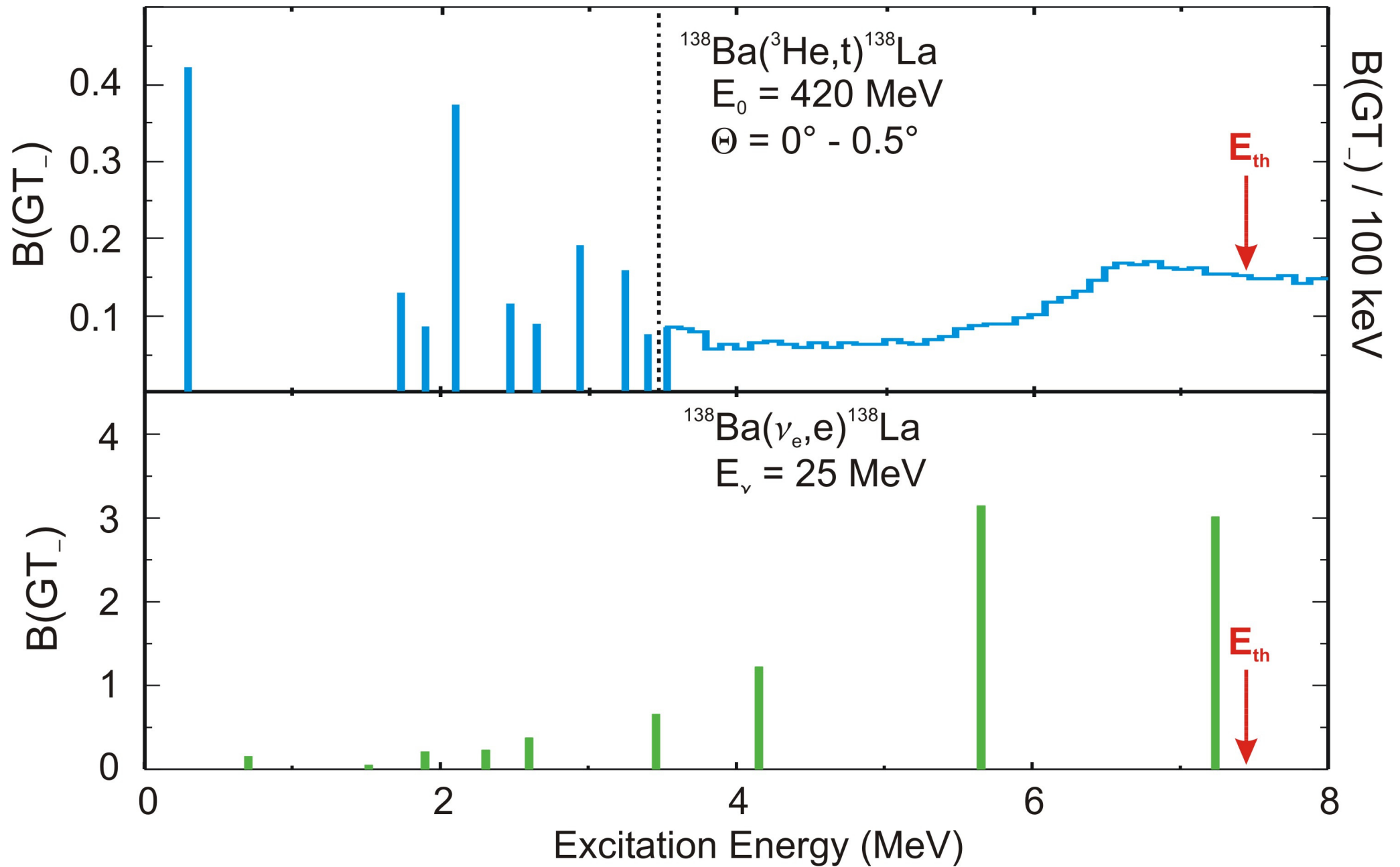
● Target:  $^{138}\text{BaCO}_4$  embedded in polyvinylalcohol

# B(GT) extraction

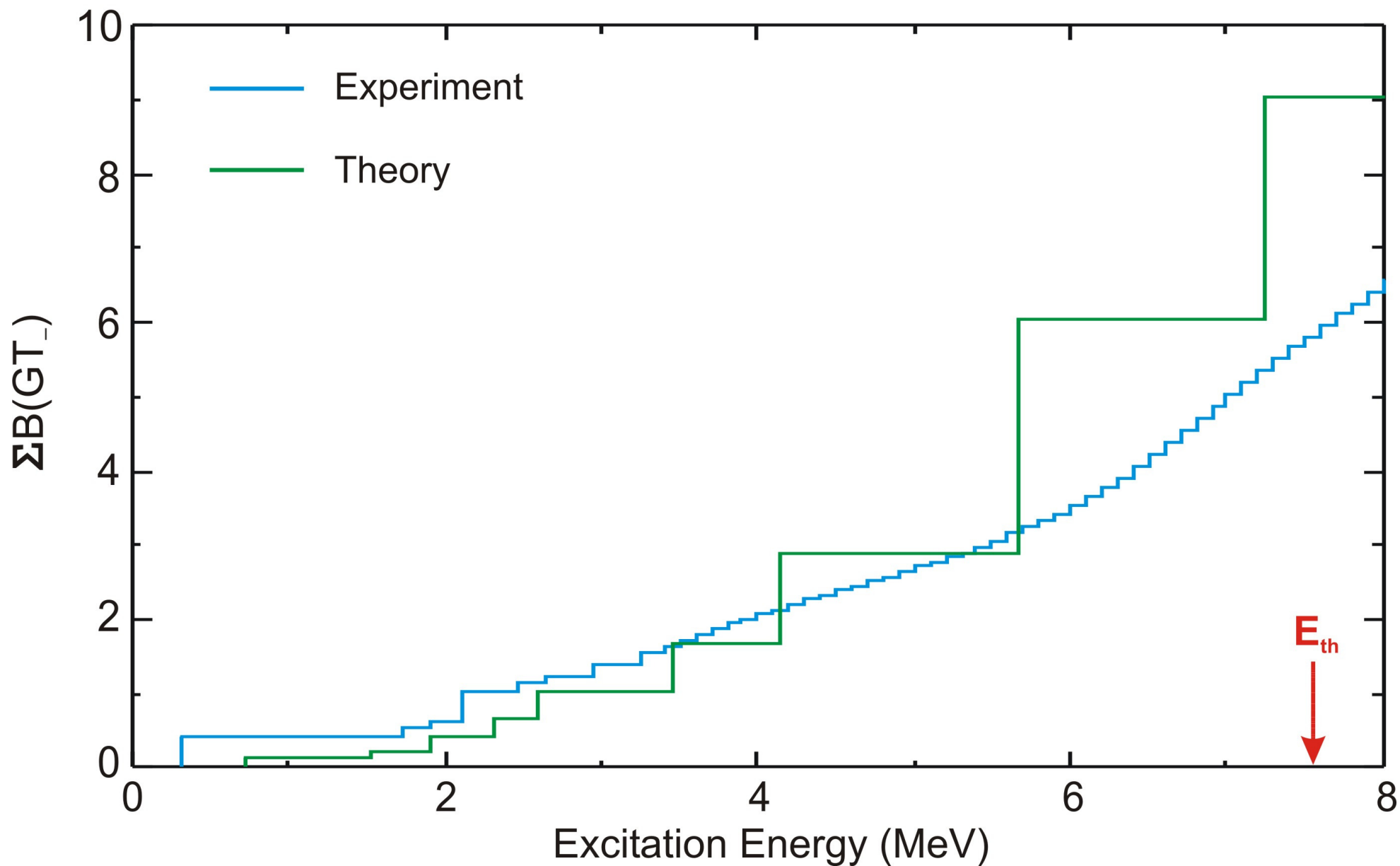
$$\sigma(0^\circ) = K \cdot N_{\text{OT}} |J_{\text{OT}}(0^\circ)|^2 B(\text{GT})$$



# GT Strength Distribution in $^{138}\text{La}$

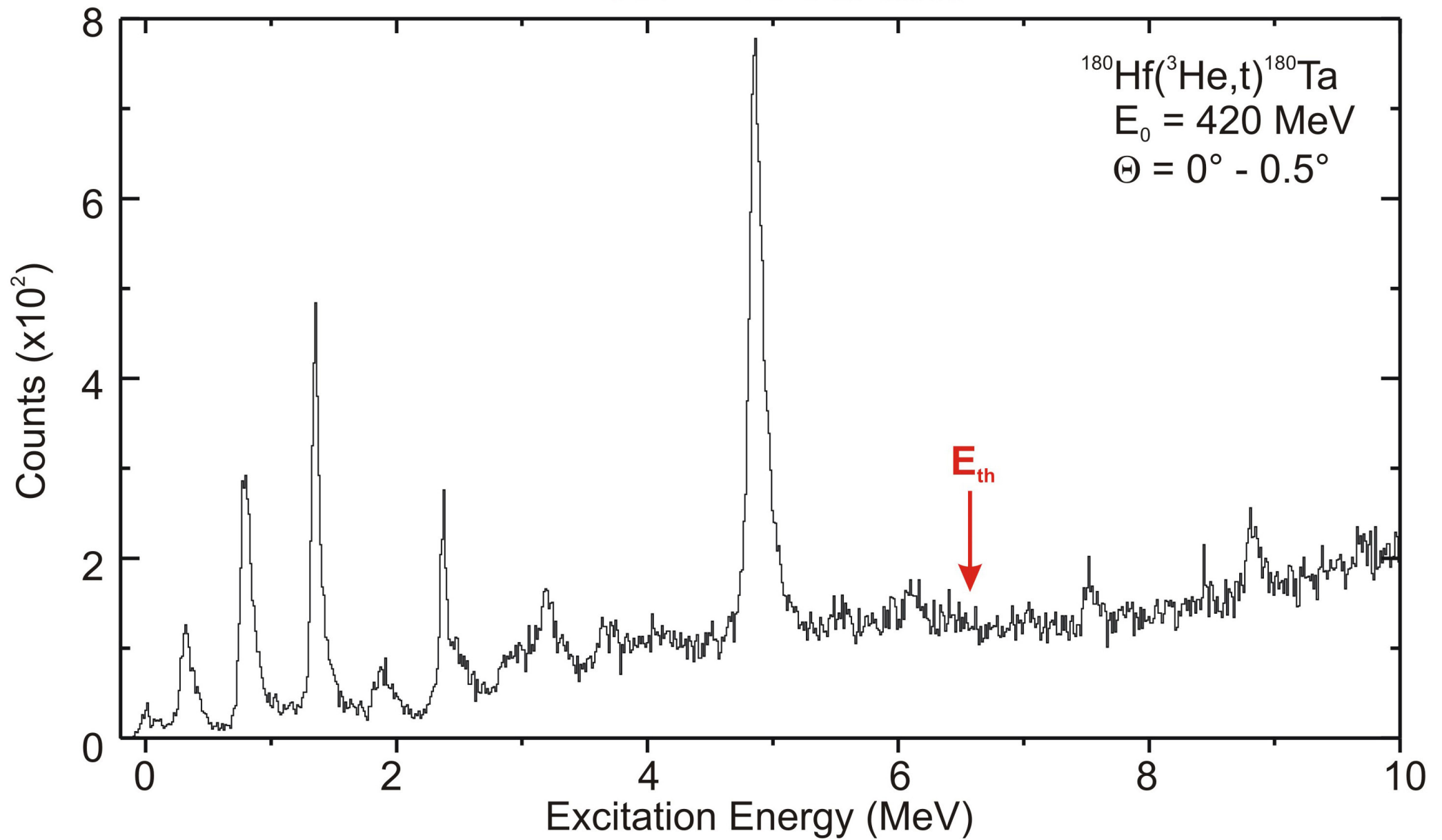


# Comparison Experiment/RPA



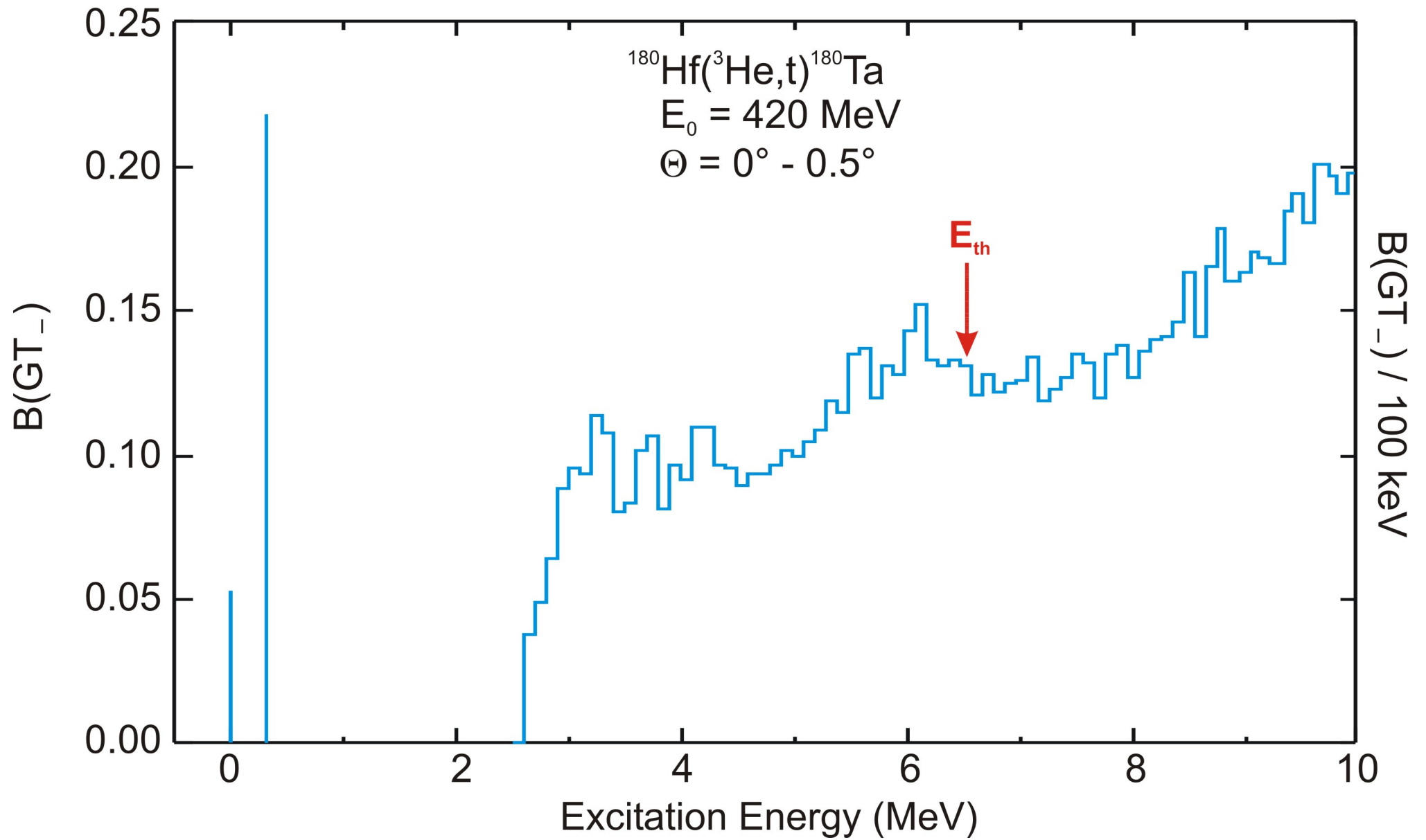
●  $B(GT_-)_{exp} \approx 64\% B(GT_-)_{th}$  at 7.47 MeV

# $^{180}\text{Ta}$ Spectrum



● Target:  $^{180}\text{TaO}_2$  embedded in polyvinylalcohol

# GT Strength Distribution in $^{180}\text{Ta}$

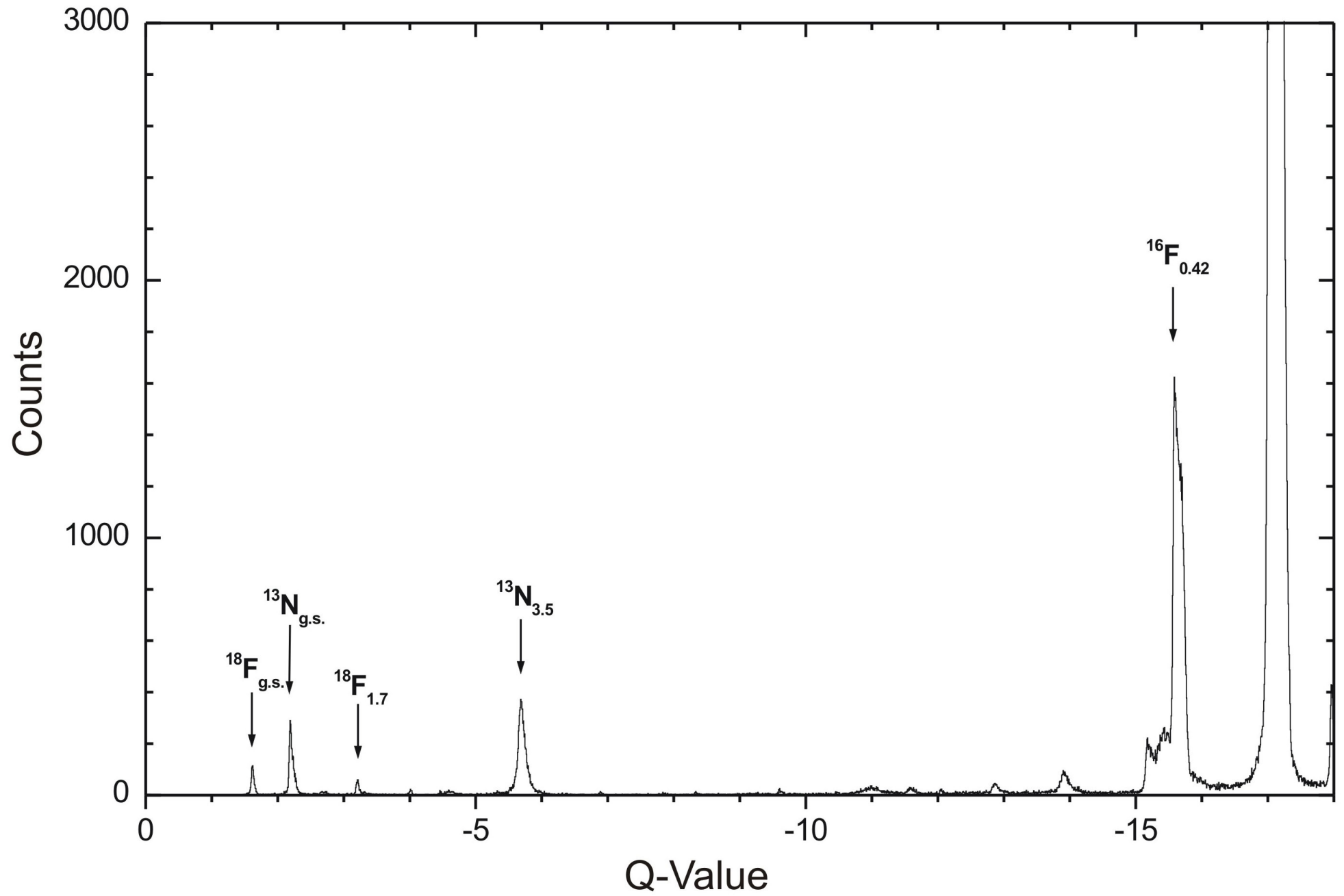




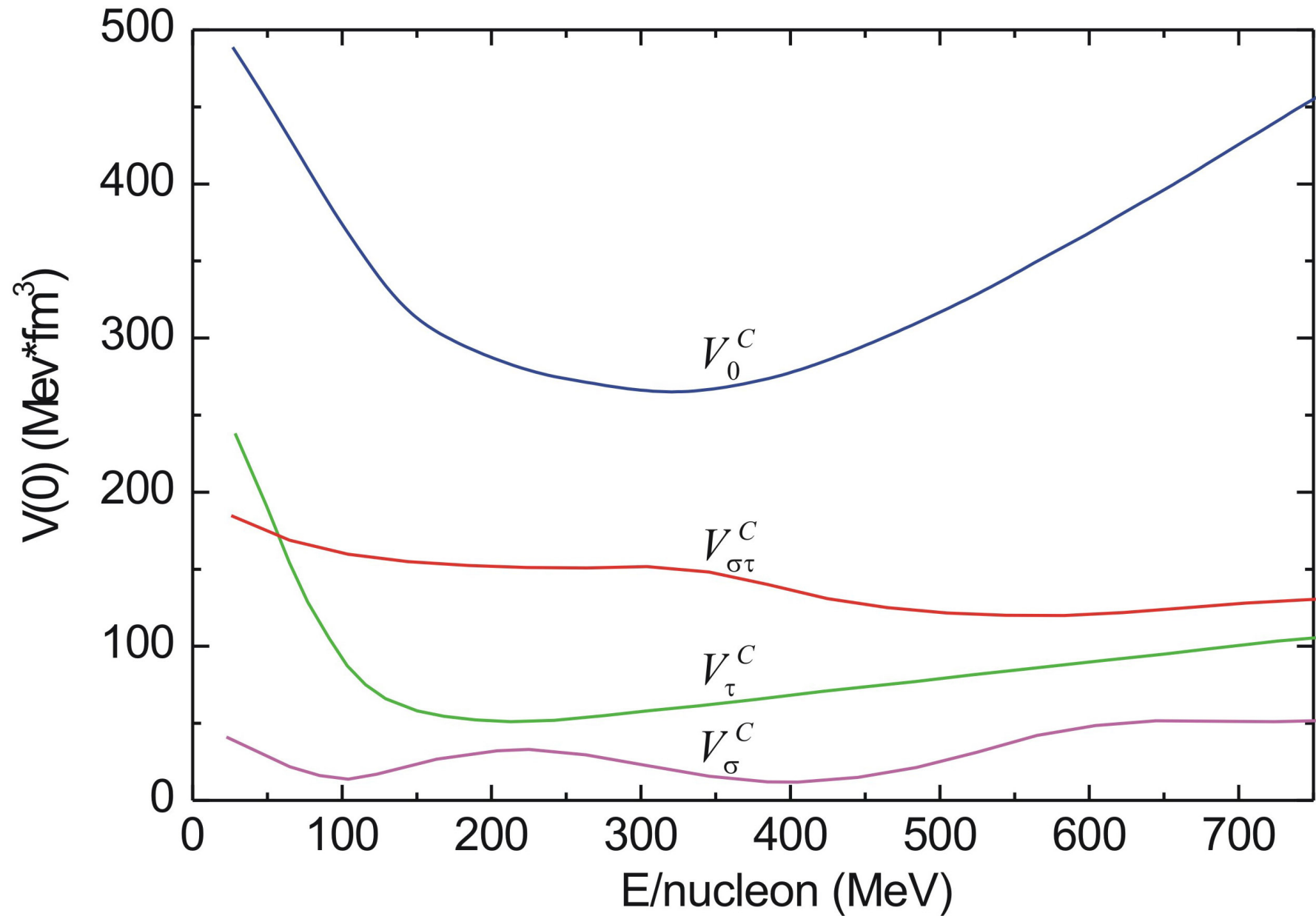
# Summary and Outlook

- Analysis of  $^{138}\text{La}$  and  $^{180}\text{Ta}$  data completed
- Good agreement found for  $^{138}\text{La}$
- Comparison with the theory for  $^{180}\text{Ta}$  underway
- Integration into network calculations underway

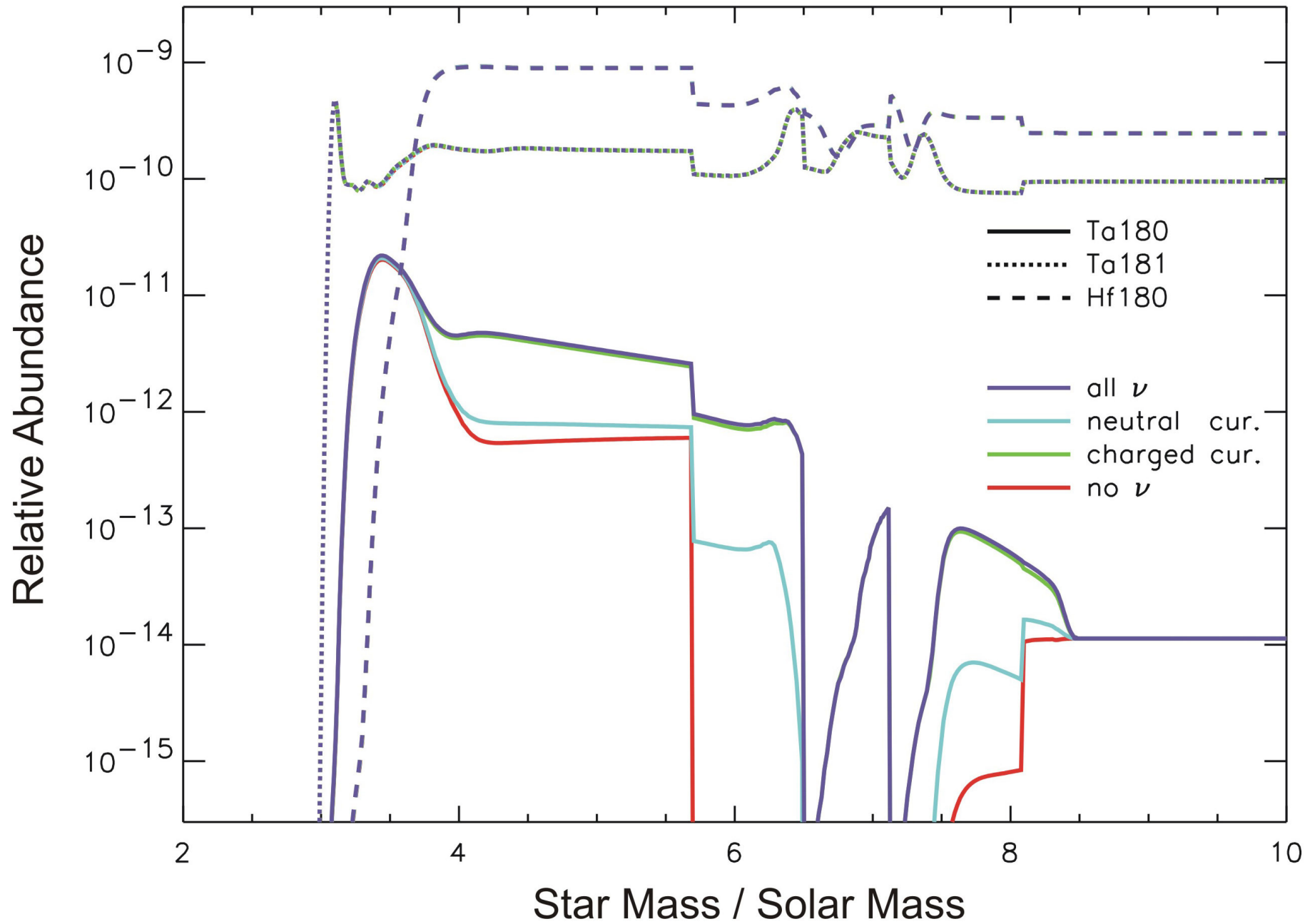
# PVA Spectrum



# Nucleon-Nucleon Interaction: $E_{in}$ Dependence at $q = 0$

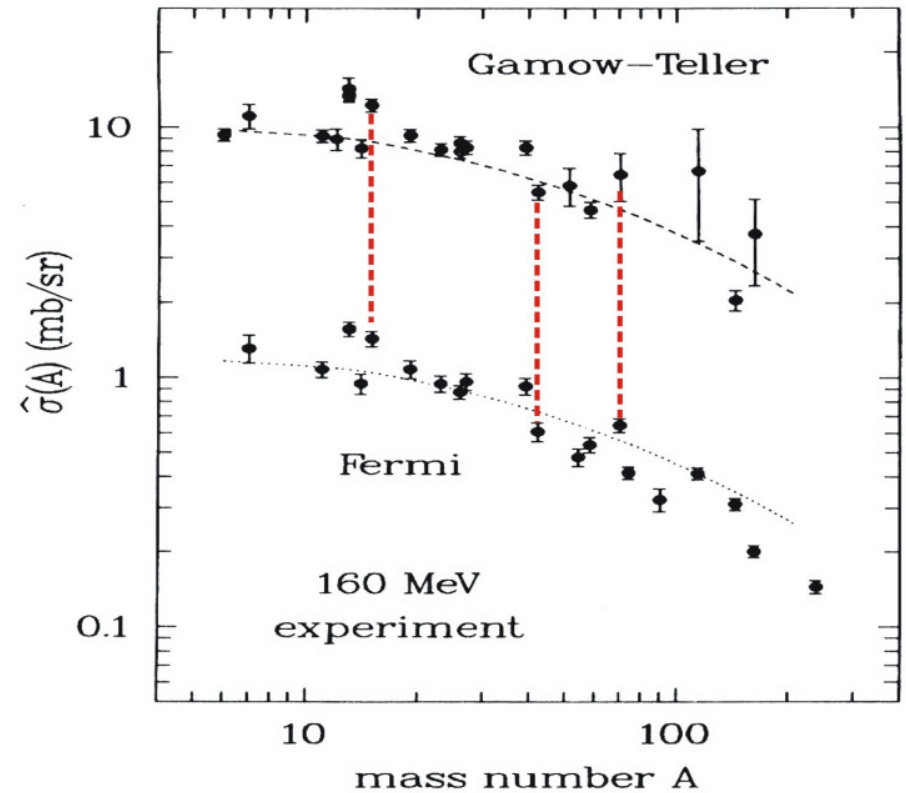
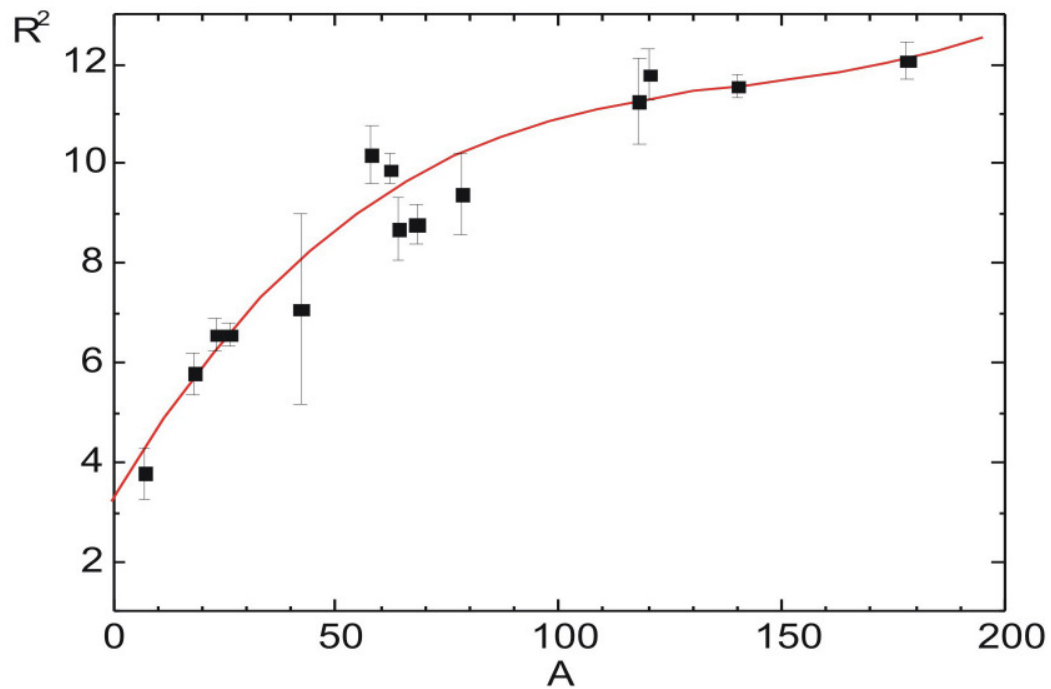


# Production of $^{180}\text{Ta}$

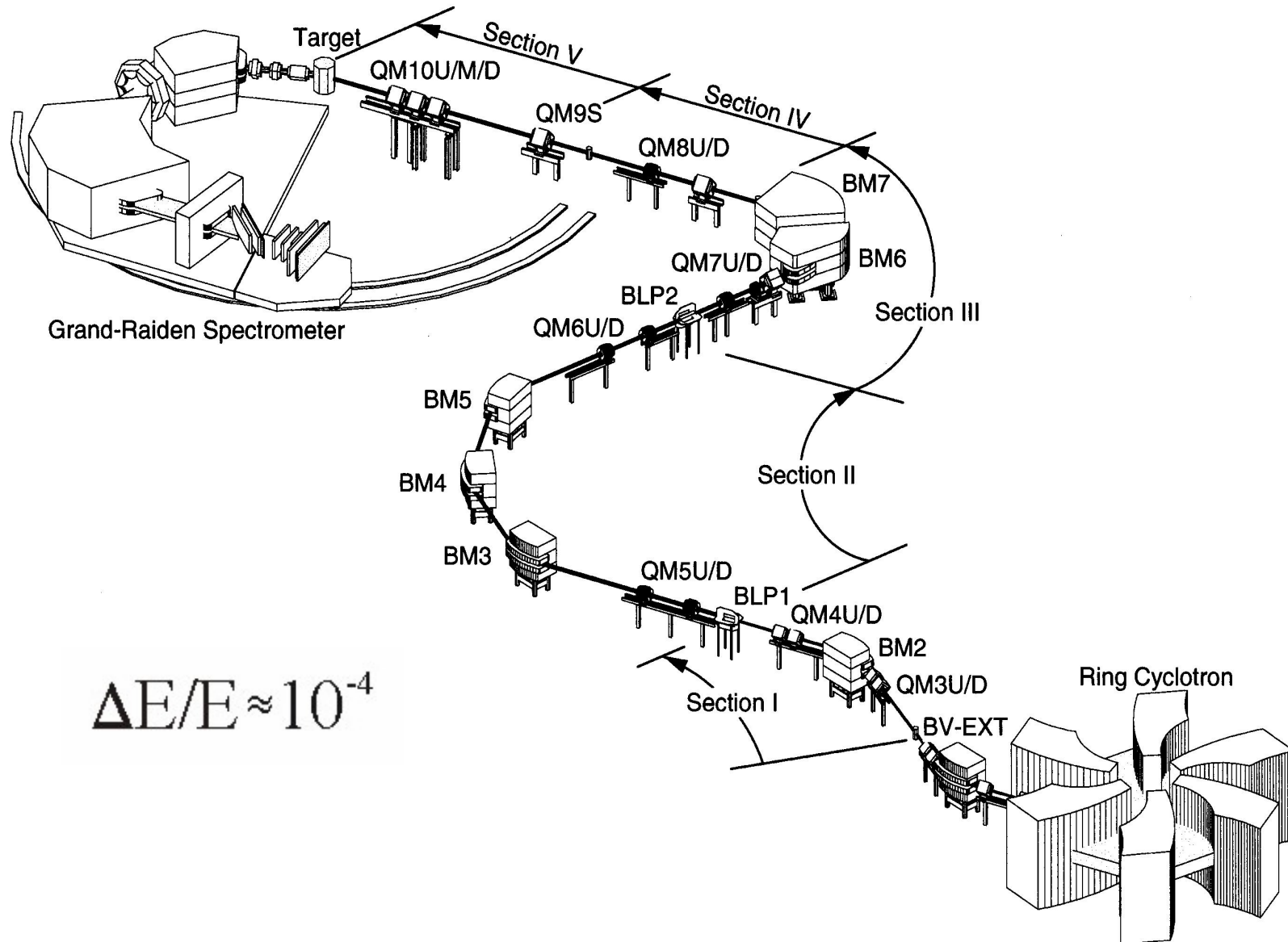


# R<sup>2</sup> Value

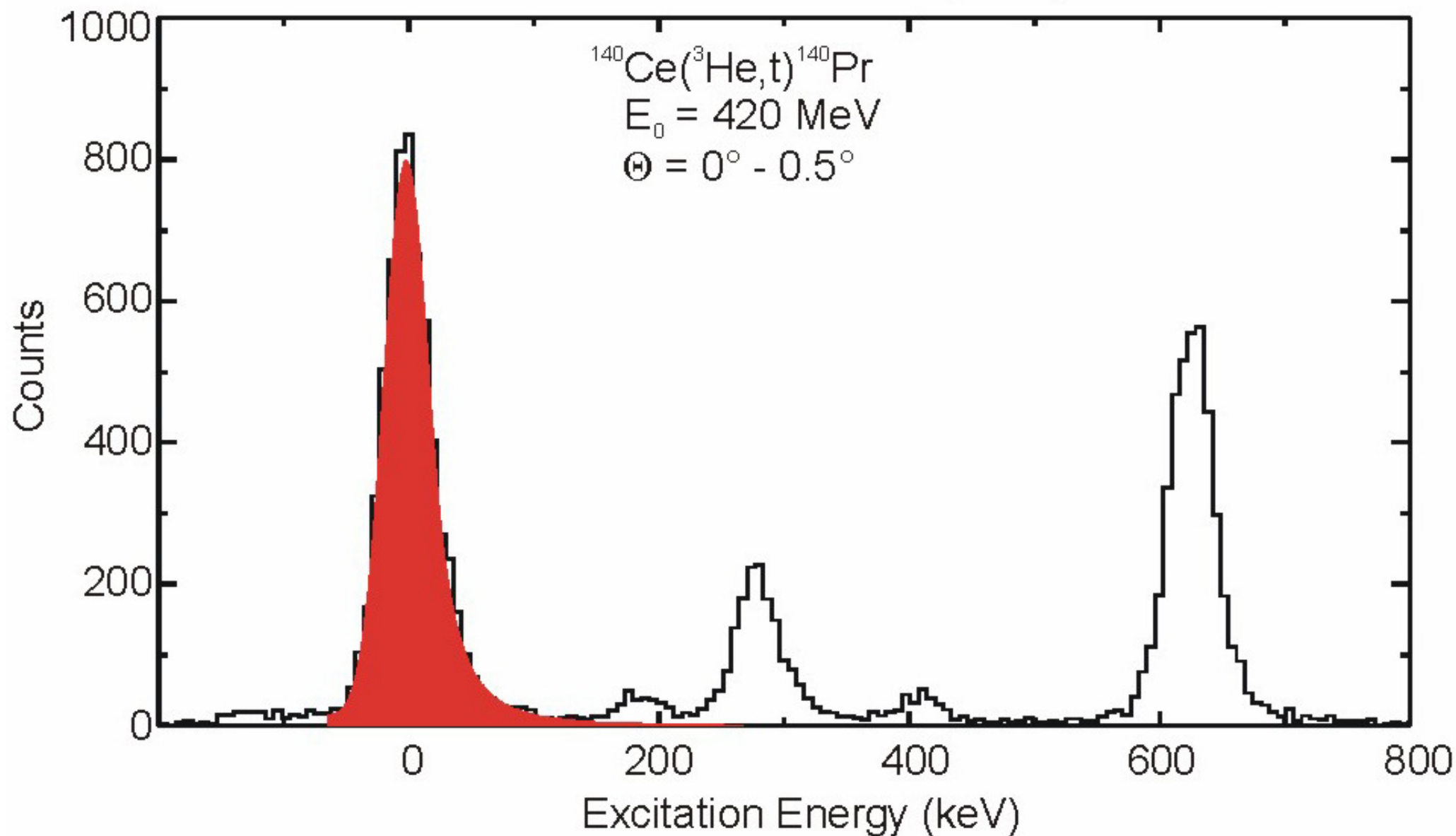
- GT unit cross section: unit  $\sigma_{\text{GT}} = \sigma_{\text{GT}}(0^\circ)/B(\text{GT})$
- Fermi unit cross section: unit  $\sigma_{\text{F}} = \sigma_{\text{F}}(0^\circ)/B(\text{F})$
- Fermi strength is totally concentrated in IAS:  $B(\text{F}) = N - Z$
- R<sup>2</sup> definition:  $R^2 = \text{unit } \sigma_{\text{GT}} / \text{unit } \sigma_{\text{F}}$



# High Resolution WS Course



# Conversion to B(GT)



●  $^{140}\text{Pr}(\text{g.s.}, 1^+) \rightarrow ^{140}\text{Ce}(\text{g.s.}, 0^+)$   $\beta$ -decay  $B(\text{GT}) = 0.245$

