A New Study of ^{5}H

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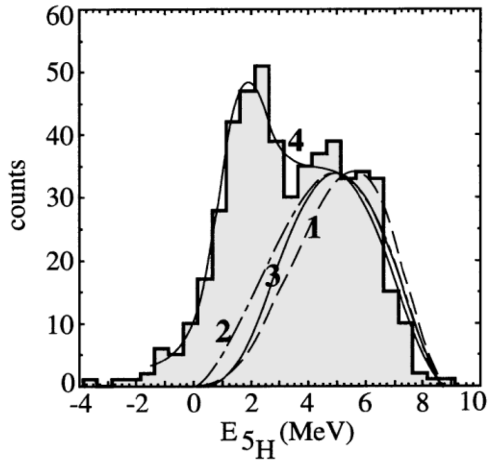
Motivation:

- "Super-heavy" hydrogen is the most neutron rich system we can observe
- Close to tetra-neutron
- ^{5}H has been studied for 50 years with inconclusive results
- Wide variety of energies and widths for the ground state resonance of ^{5}H from theory and experiment

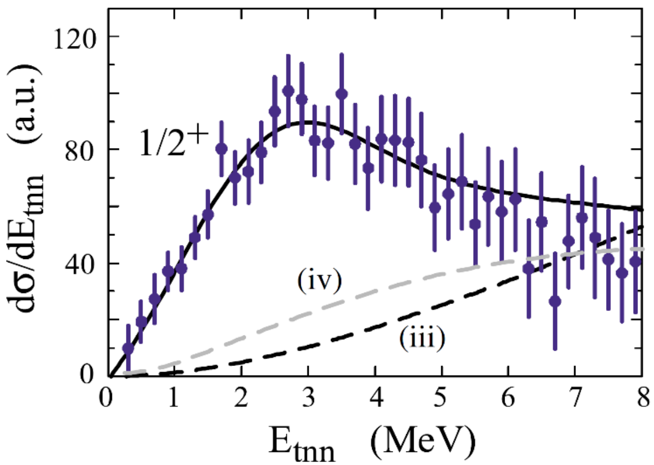
Previous Studies of ^5H

$^6He(p,pp)^5H$



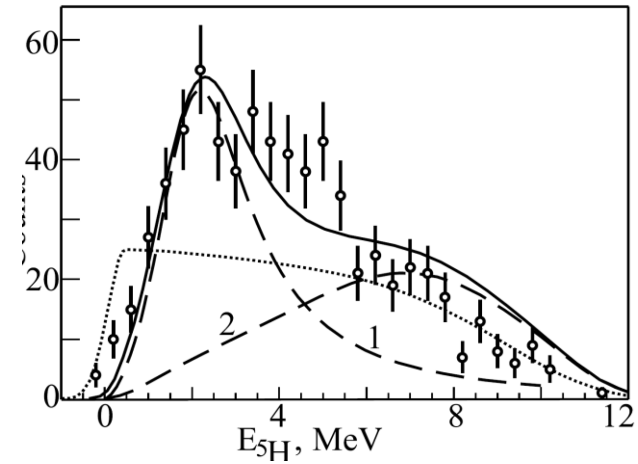
A.A. Korsheninnikov, Phys.Rev.Lett. 87, 092501 (2001)

$^{12}C(^6He,X)^5H$



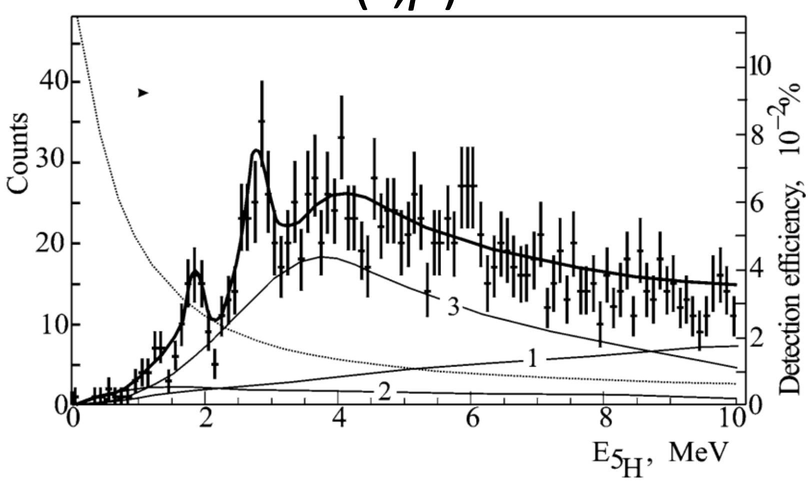
M. Meister, Phys.Rev.Lett. 91, 162504 (2003)

$^6He(d,^3He)^5H$



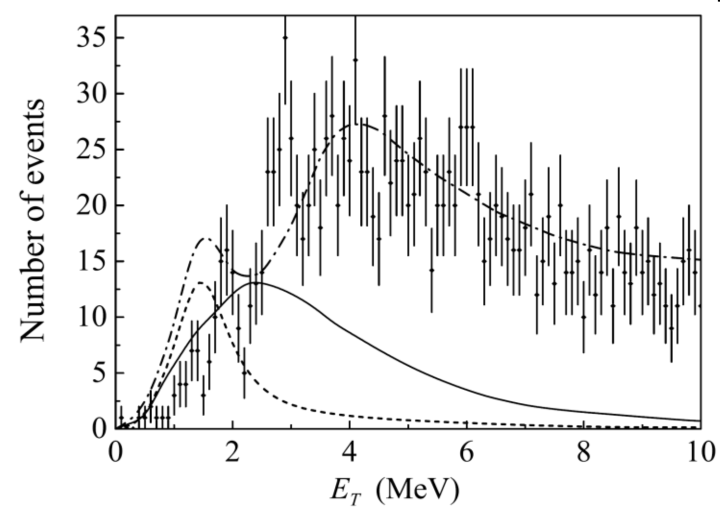
G.M. Ter-Akopian, Eur.Phys.J. A 25, Supplement 1, 315 (2005)

$^3H(t,p)^5H$



M.S. Golokov Phys.Lett. B 566, 70 (2003)

Same data as left, but different analysis

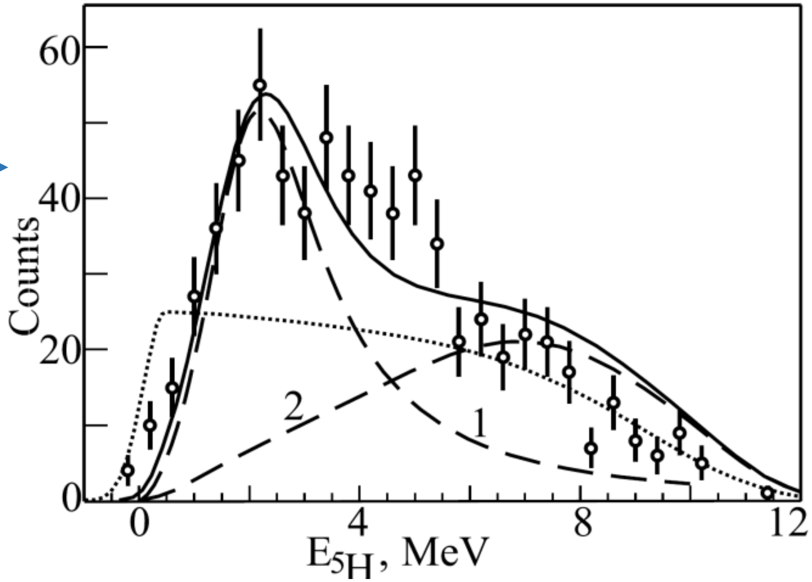


L.V. Grigorenko Eur.Phys.J. A 20, 419 (2004)

The $^{6}He(d,^{3}He)^{5}H$ reaction is our choice for studying ^{5}H

- $^{6}He(d,^{3}He)^{5}H$

Revisit this reaction! →



Spectroscopic factors

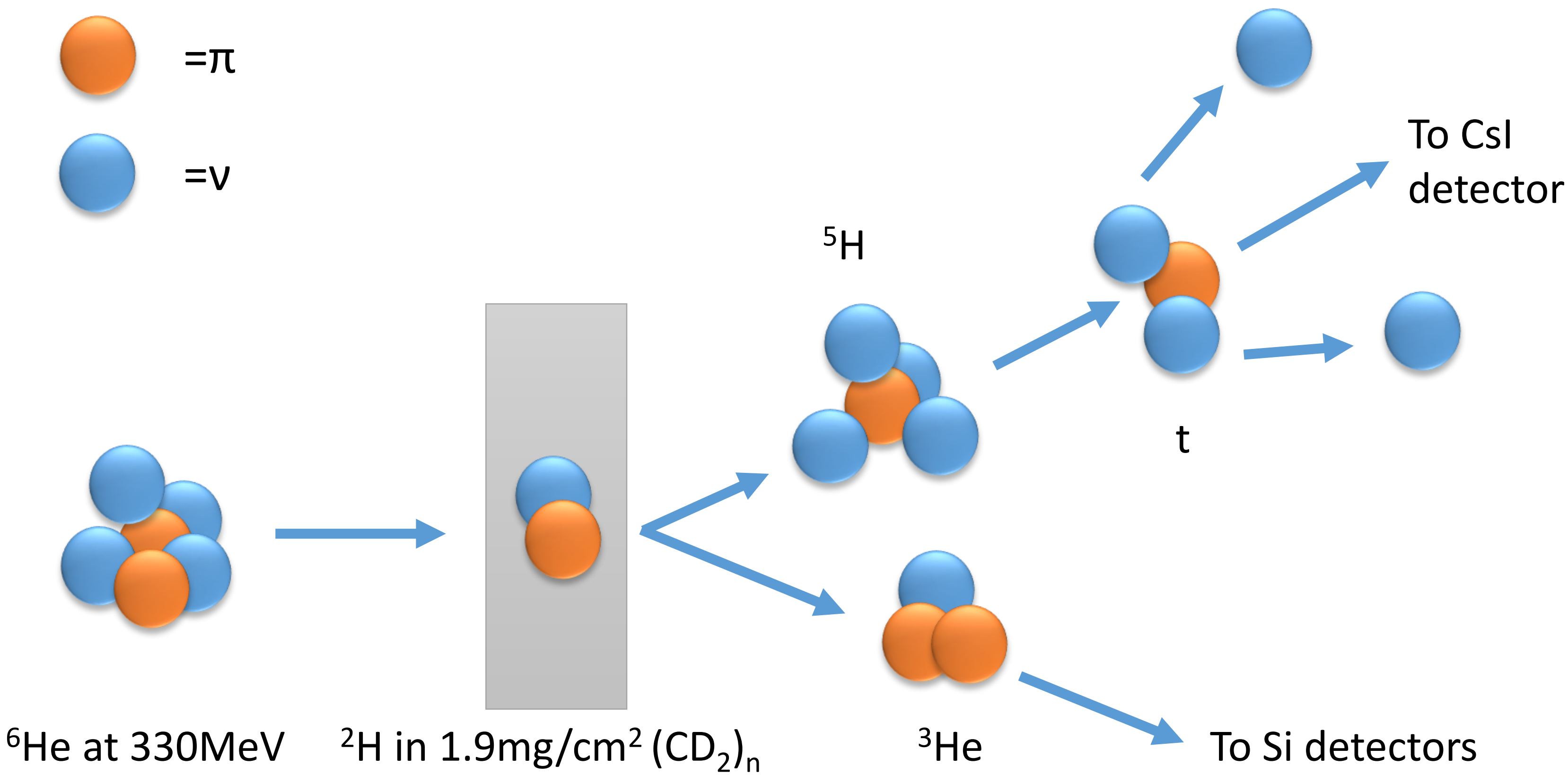
Method	$S(1/2^+)$	$S(3/2^+)$	$S(5/2^+)$
VMC/GFMC	1.18	0.0226	0.0172
Shell Model	1.992	≈ 0	≈ 0

Only the ground state should be populated in this reaction.

E_{res}=2.2 ±0.3MeV, Γ≈2.5MeV

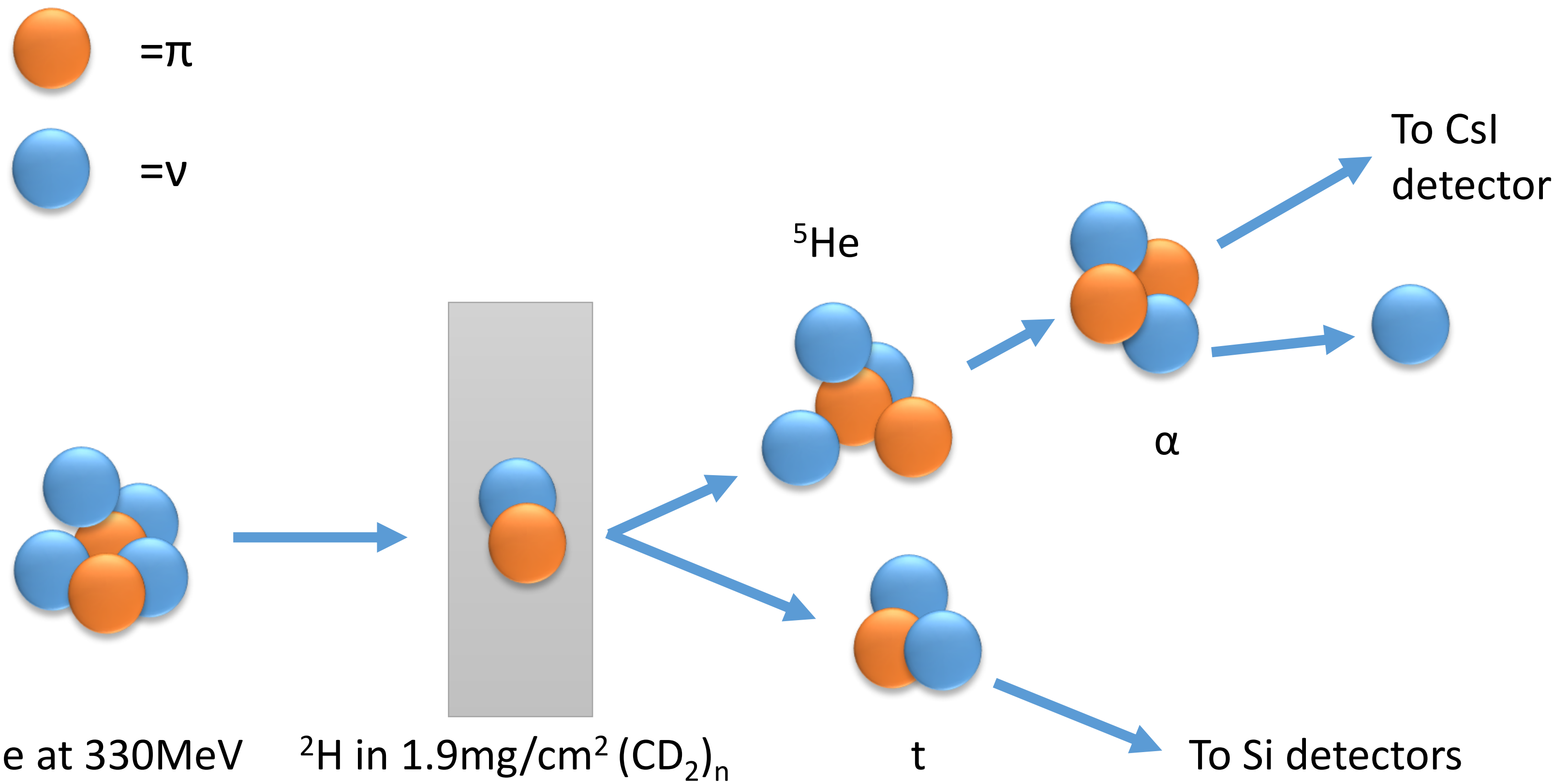
[Ref.] G.M. Ter-Akopian, Eur.Phys.J. A 25, Supplement 1, 315 (2005)

Particle energy range in the $^6He(d,^3He)^5H$ reaction



There is a large dynamic range of energies of the particles in inverse kinematics: ^3He particles are 10-12MeV, while ^5H decay products are 140-300MeV

The complementary $^{6}He(d,t)^{5}He$ reaction

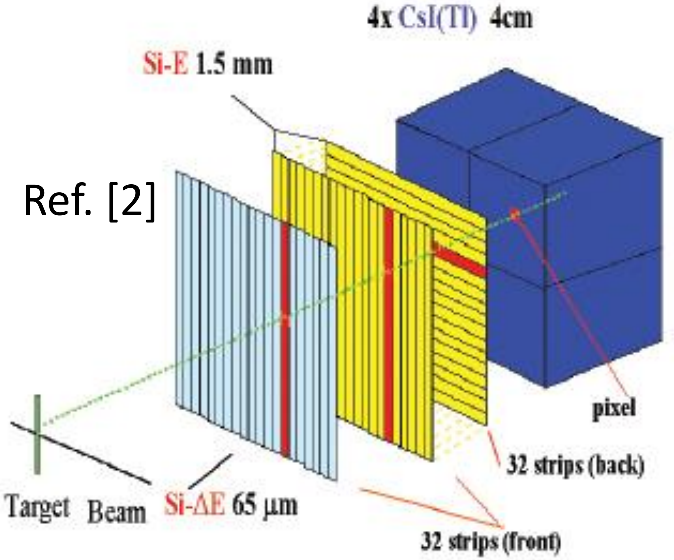


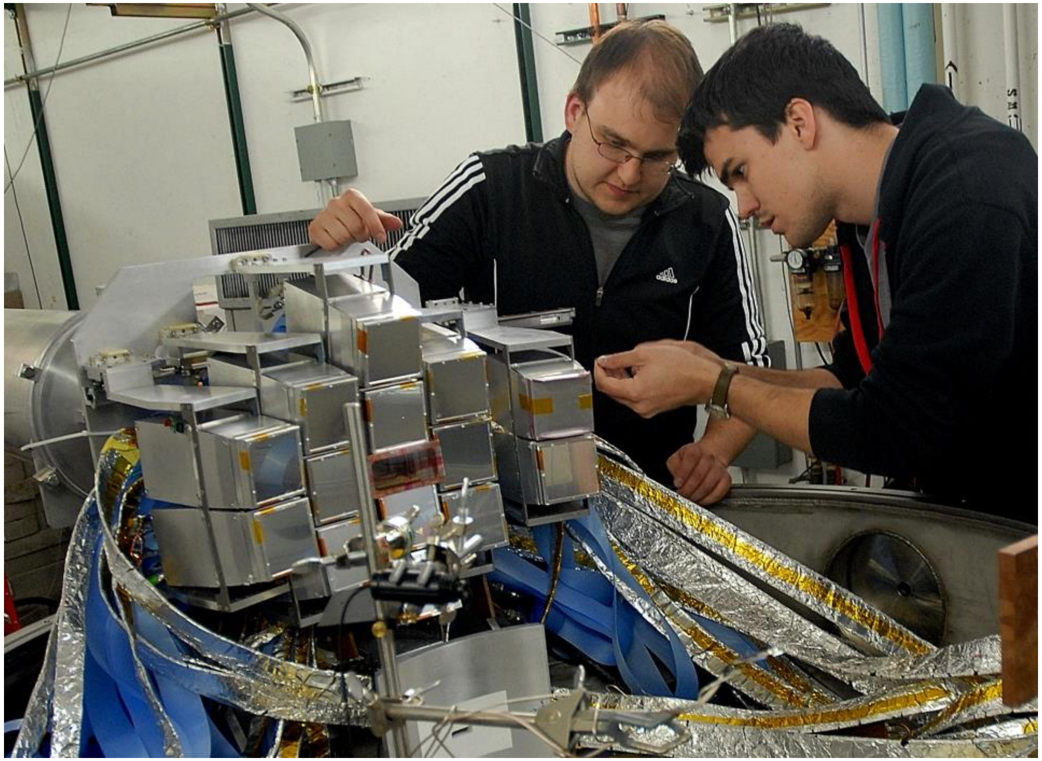
^{5}He is well understood from studies of $^{4}He(d,p)^{5}He$, making this a good comparison for the ^{5}H results

Position and Energy detection is provided by the HiRA[1] array

- 2 layers of Si detectors
- 4 CsI detectors

Ref. [2]



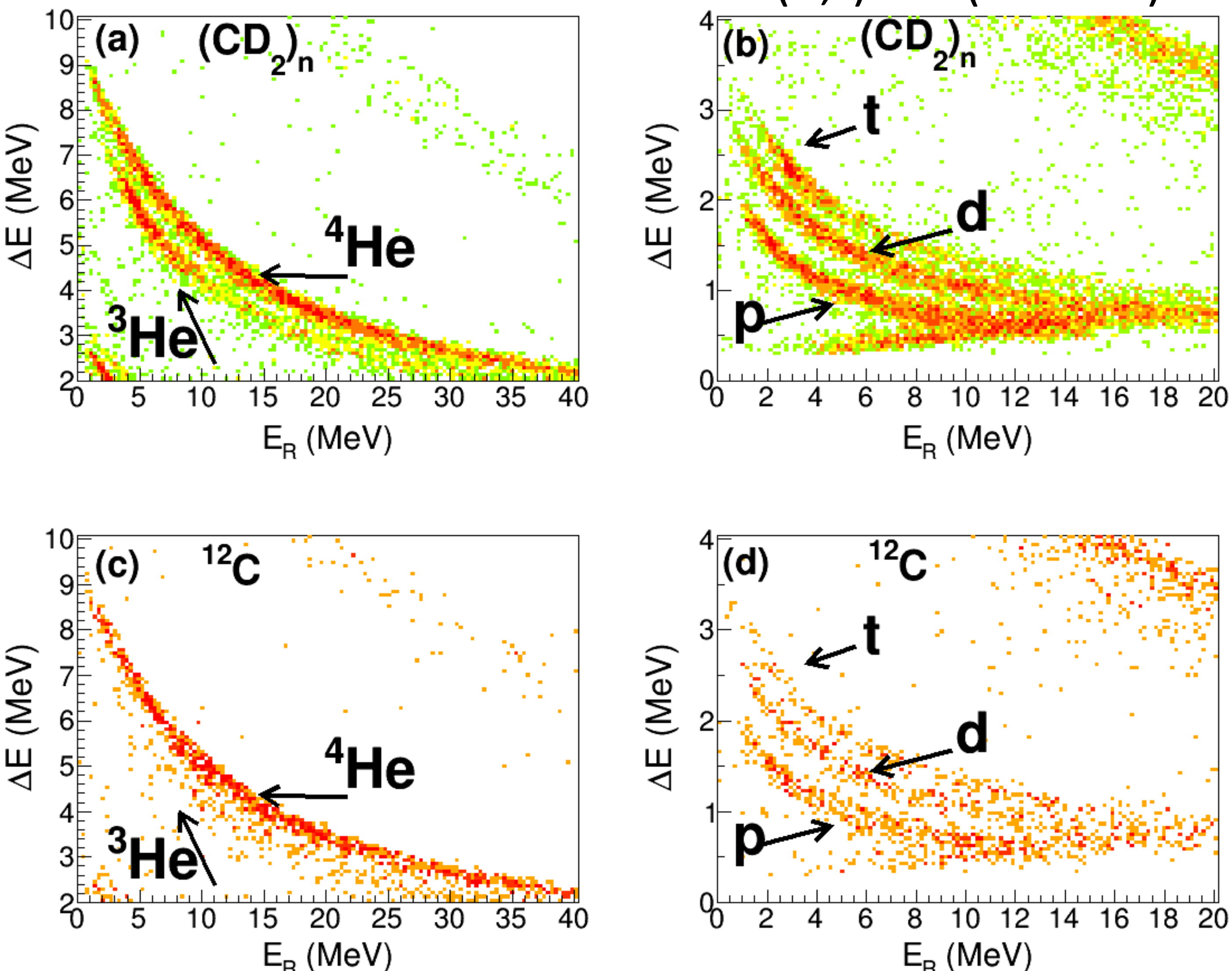


- Si layer one: 65µm, 32 strips
- Si layer two: 1500µm, double sided strip detector
- DSSD pixels subtend 0.13 degrees in laboratory

Ref. [1] M. S. Wallace et al., Nucl. Instrum. and Meth. A 583, 302 (2007)
Ref. [2] https://groups.nscl.msu.edu/hira/pdf/HIRA_final.pdf

Silicon detectors provide a clear ^{5}H signature

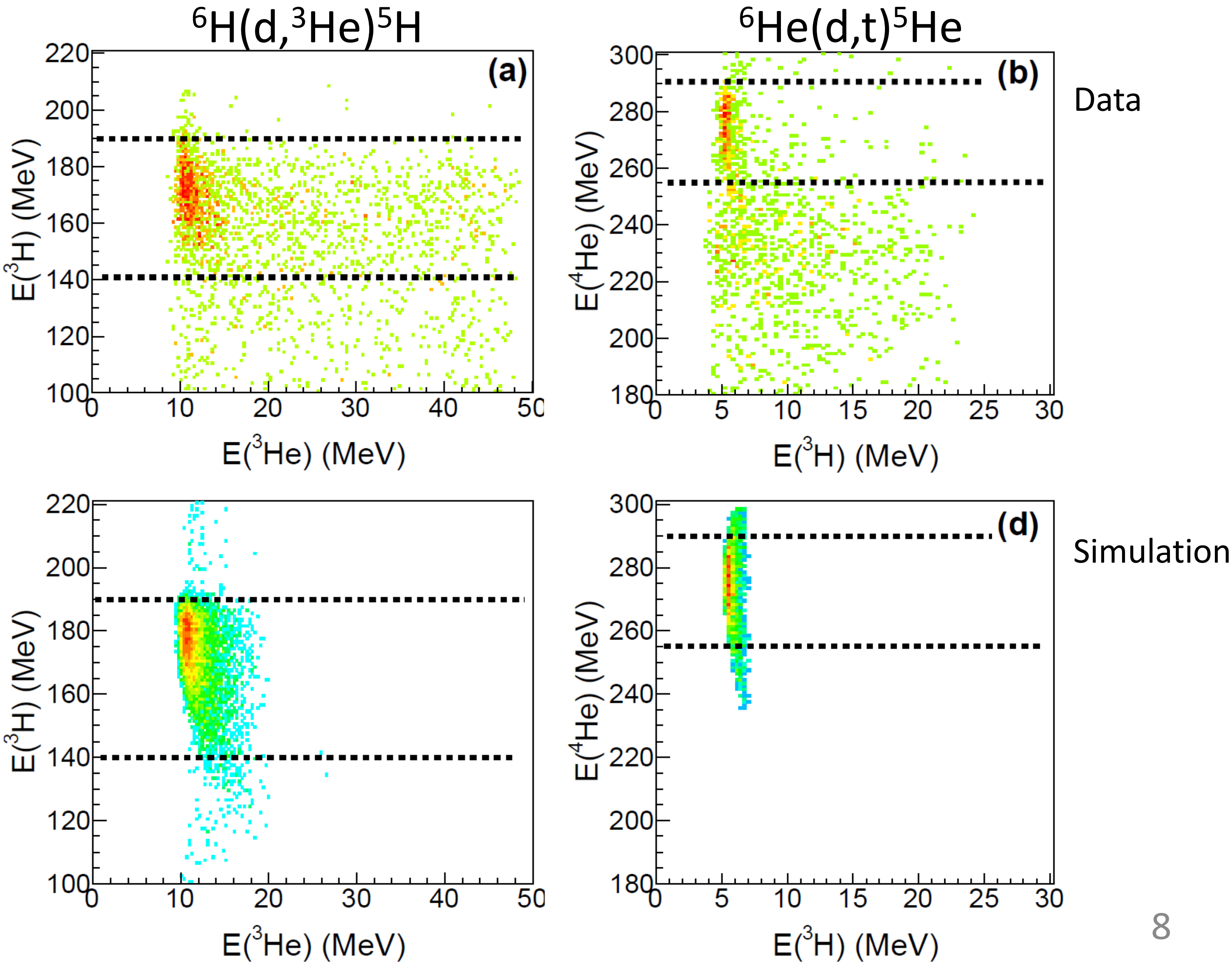
$^{6}H(d,{}^{3}He)^{5}H$ (^{3}H in CsI) $^{6}He(d,t)^{5}He$ (α in CsI)



ΔE

Residual Energy

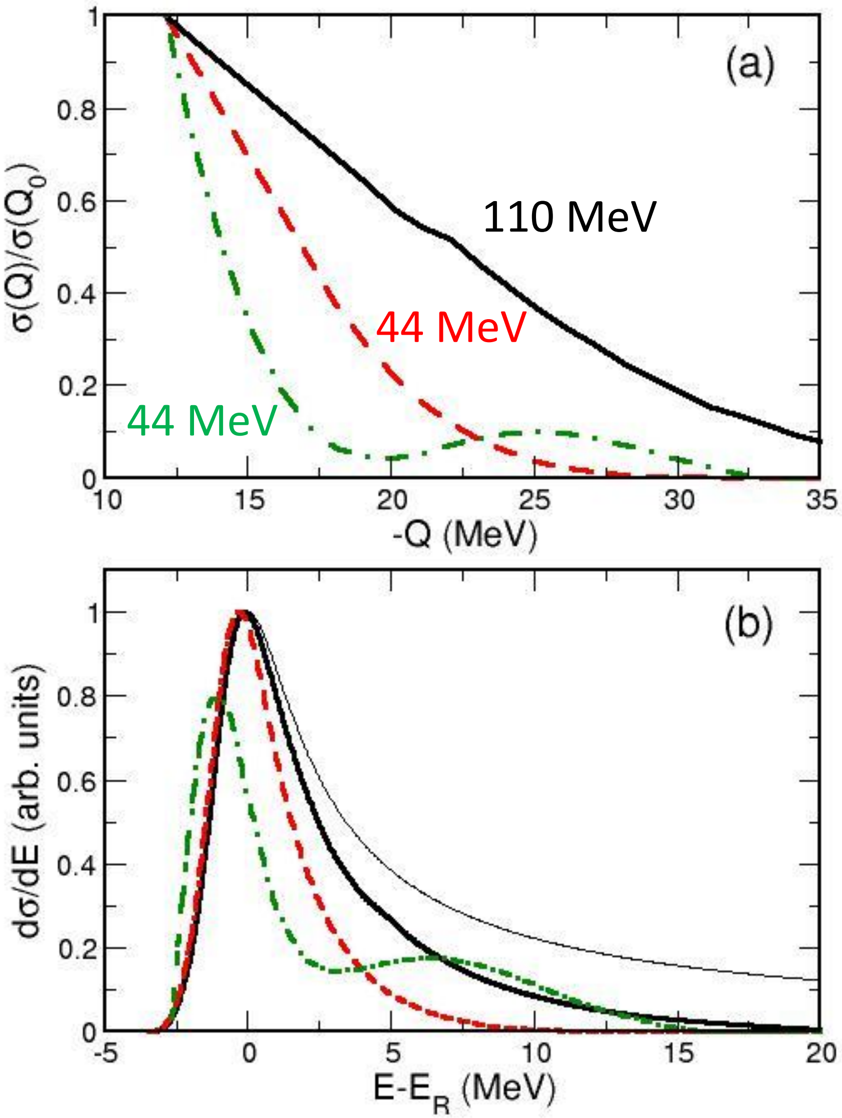
Simulations of recoil energy



Q-Value Dependence from DWBA

The figure (a) shows the yield Q-value dependence from DWBA calculations for
E_d=110 MeV, 0°-10° averaged,
E_d=44 MeV, 0°-10° averaged,
E_d=44 MeV, 20°-40° averaged

The figure (b) illustrates the effects of Q-value dependence on an intrinsic line shape for different deuteron energies

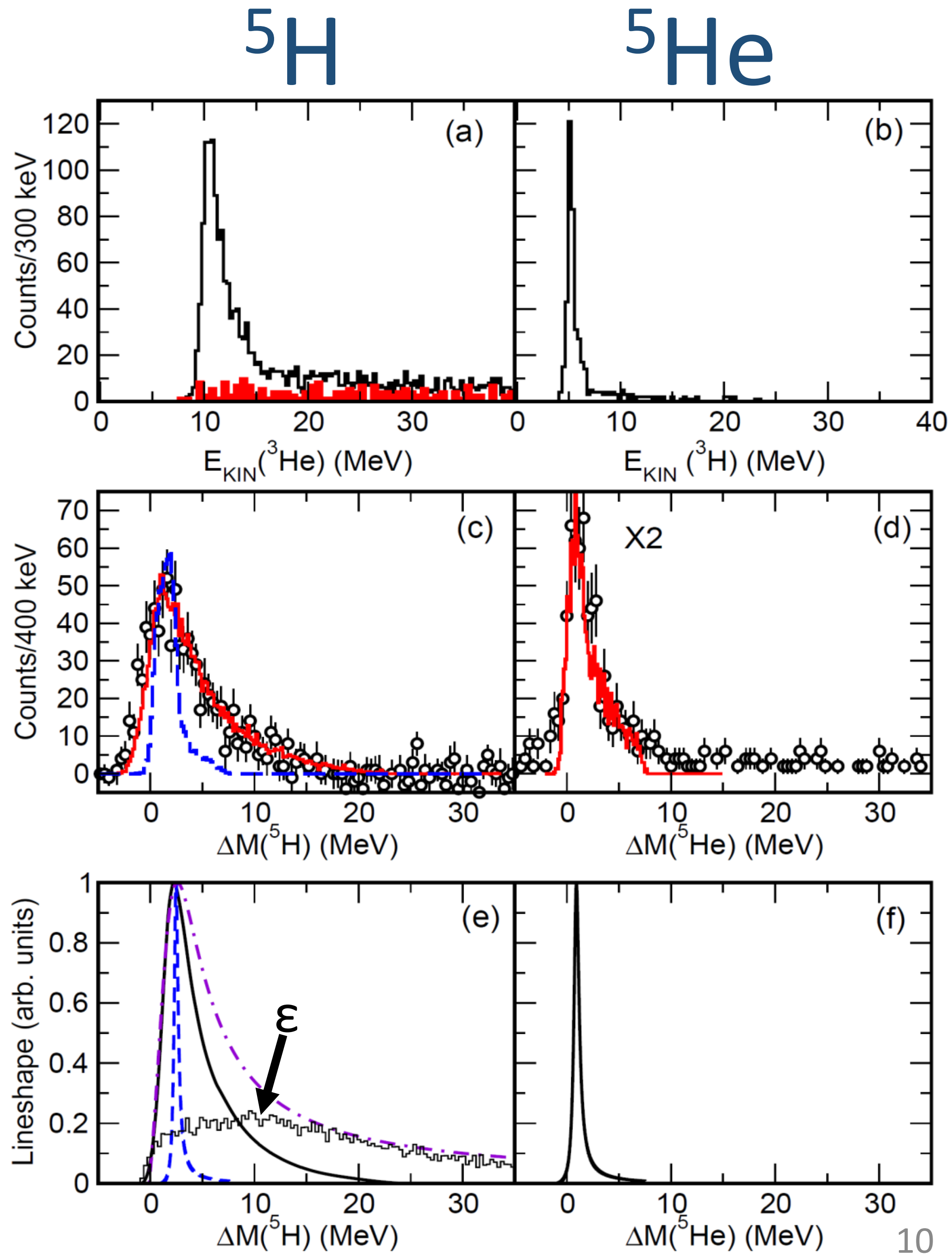


Results

Kinetic energy of the ejectile

Missing mass spectrum with our best fit profile results:
E_R=2.4±0.4MeV
Γ=4.8±0.4MeV

Line shapes used in red Monte Carlo histograms. The blue line shape is for a narrow ^5H peak, which is inconsistent with our data.



Conclusions

- A clear ^{5}H signature was observed
- The data are consistent with a broad resonance
- Comparison to ^{5}He results supports broad resonance
- Resonance and width consistent with some (not all) theoretical calculations and some experimental data

Acknowledgements

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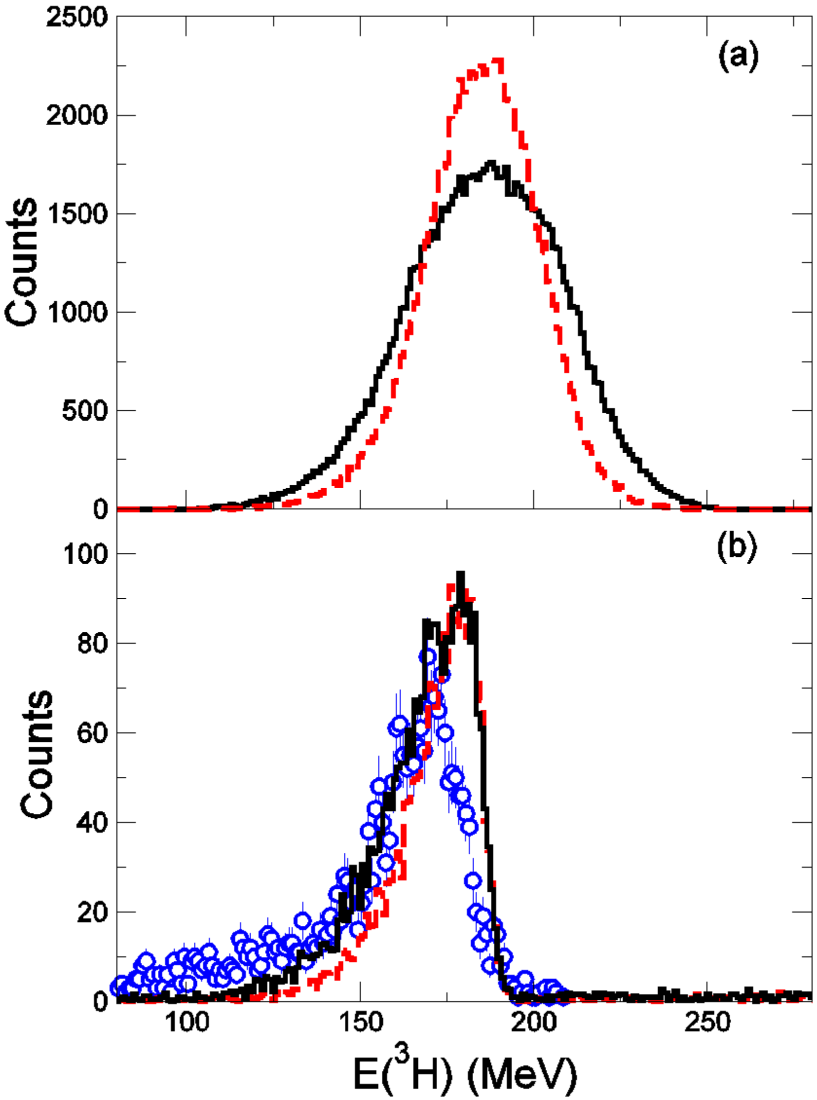
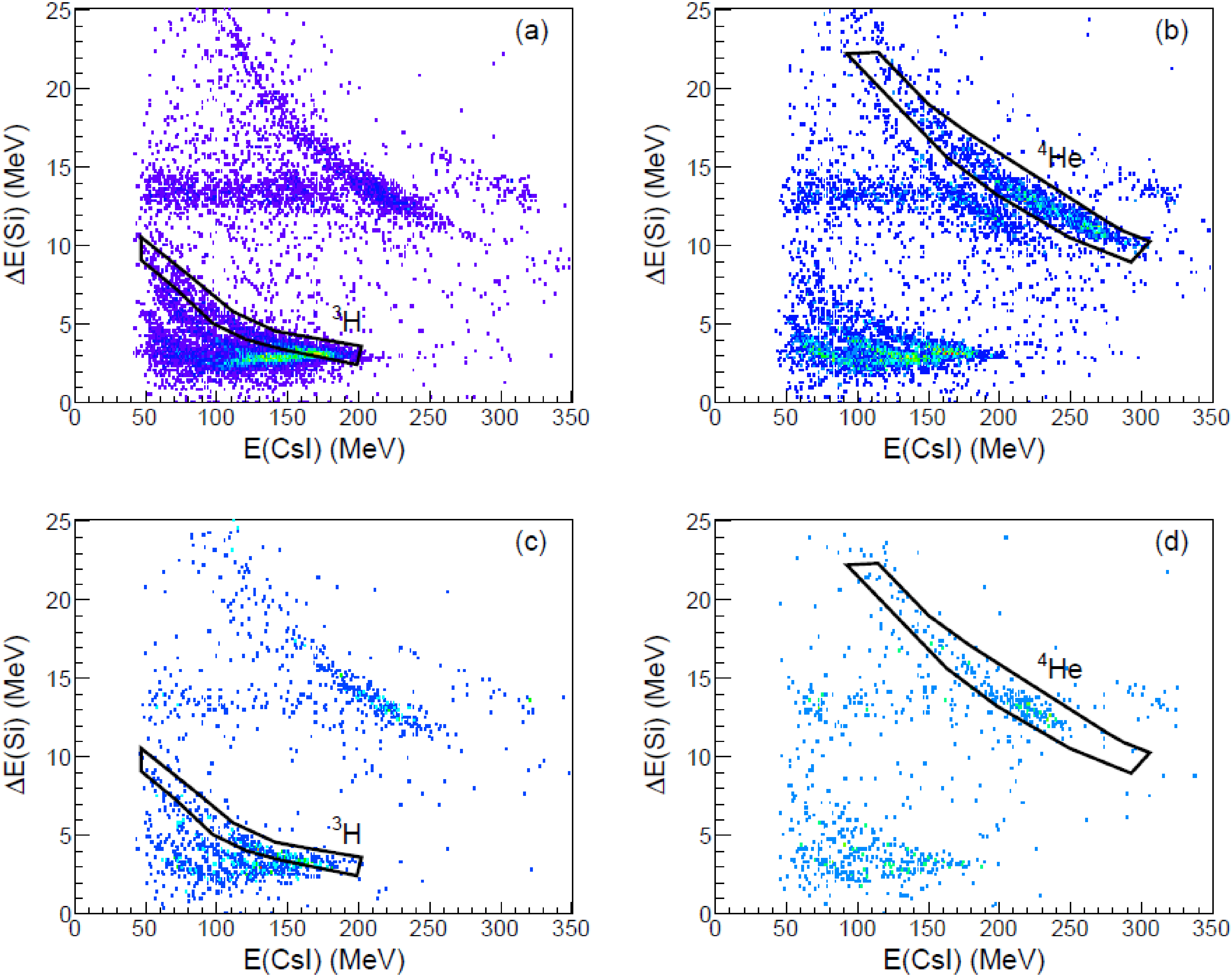
Di-Neutron vs. Sequential emission

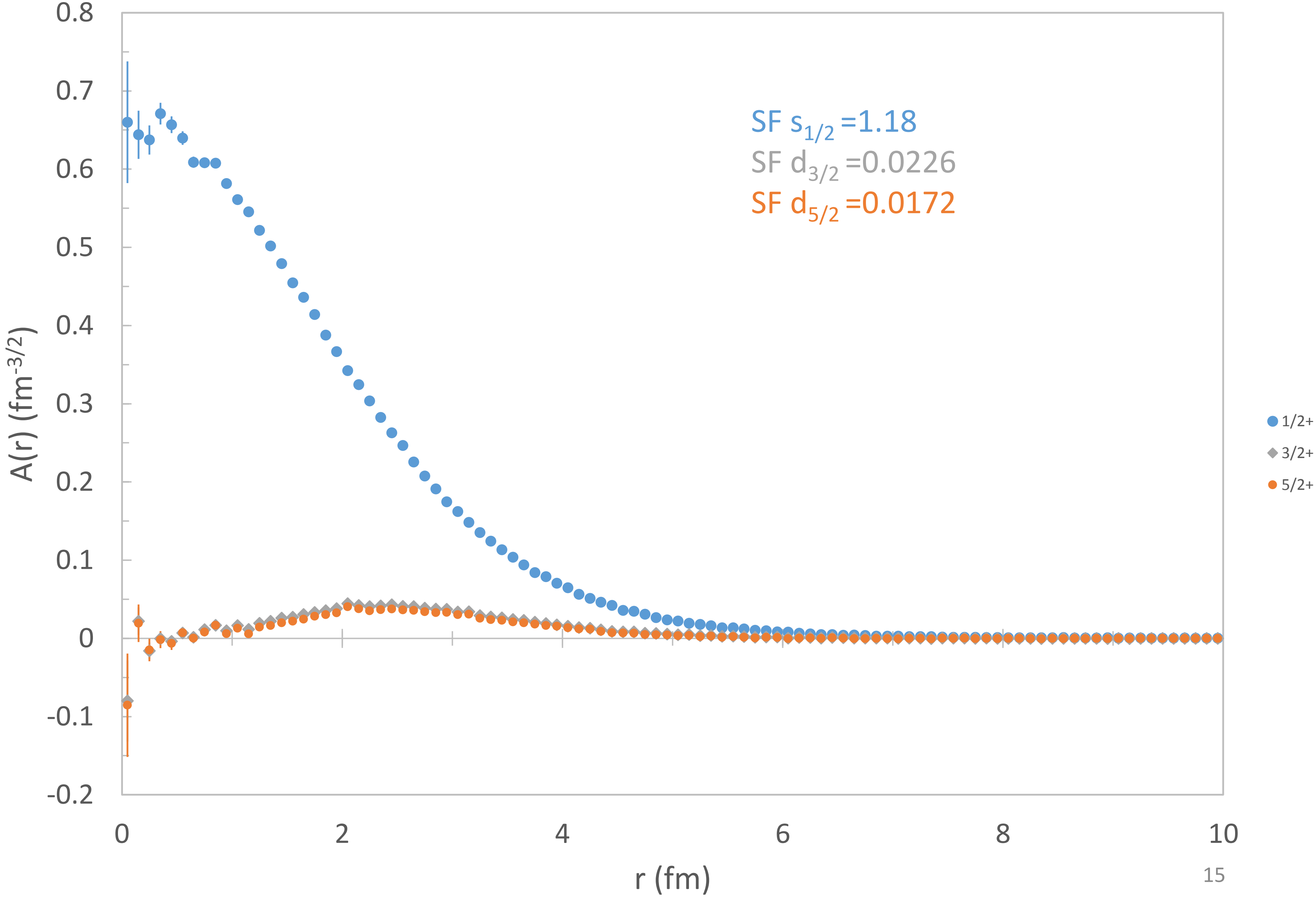
- The black curve shows simulated energy distribution of the triton for di-neutron emission
- The red curve shows simulated sequential emission through a broad ^4H state
- Monte Carlo simulations of the two extreme cases compared to data in blue





(a)
(b)
(c)
(d)
^{3}H
^{4}He
ΔE(Si) (MeV)
E(CsI) (MeV)
0
5
10
15
20
25
0
50
100
150
200
250
300
350

VMC Spectroscopic Overlaps for $^6He(0^+) \rightarrow ^5H + p$



Reference	Method	E_R (MeV)	Γ (MeV)
[30]	Cluster, GCM	$\approx$3	$\approx$1-4
[19]	3Body	2.5-3	3-4
[31]	Cluster complex scaling	1.59	2.48
[3]	Cluster MWS	2-3	4-6
[32]	Cluster, ACCC	1.9±0.2	0.6±0.2
[29]	cluster 3body adiabatic expansion	1.57	1.53
[26, 27]	Cluster Jmatrix RGM	1.39	1.60

Calculations of ^{5}H from various theories

Table 1. States in ^{5}H relative to the $t + n + n$ threshold (energies and widths of the states are given in MeV).

Method	$1/2^+$		$3/2^+$		$5/2^+$	
	E	Γ	E	Γ	E	Γ
Shell model [10]	5.5					
Shell model [11]			10.5		7.4	
HH, 5-body [12]					6	~ 6
RGM [13]	~ 6	> 4				
HH, $3 \to 3$ [8]	~ 2.7	~ 3	~ 6.6	~ 8	~ 4.8	~ 5
GCM [14]	~ 3	1–4				
HH, 5-body [9]	~ 2					

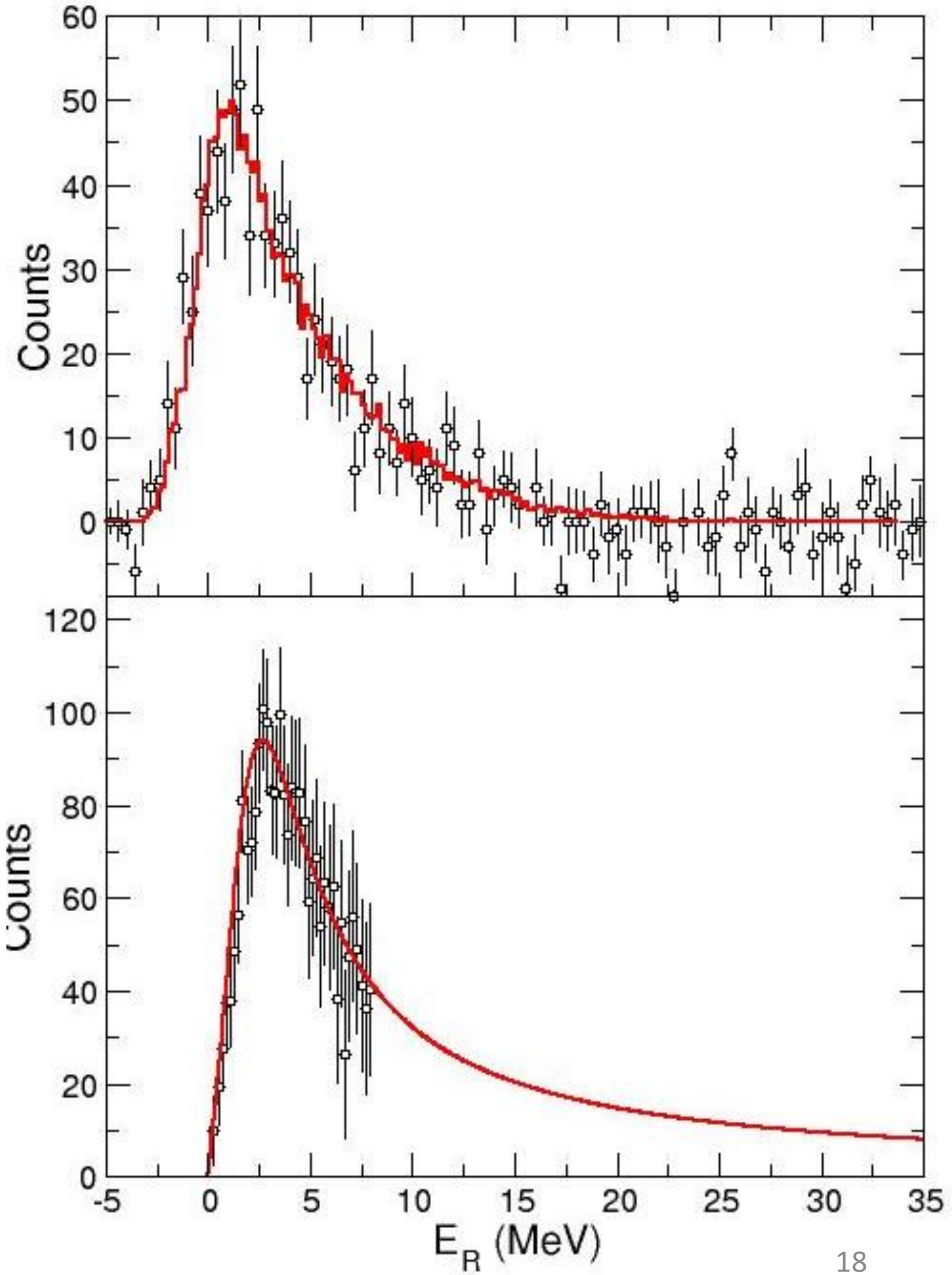
L.V. Grigorenko[1,2,a], N.K. Timofeyuk[3], and M.V. Zhukov[4]

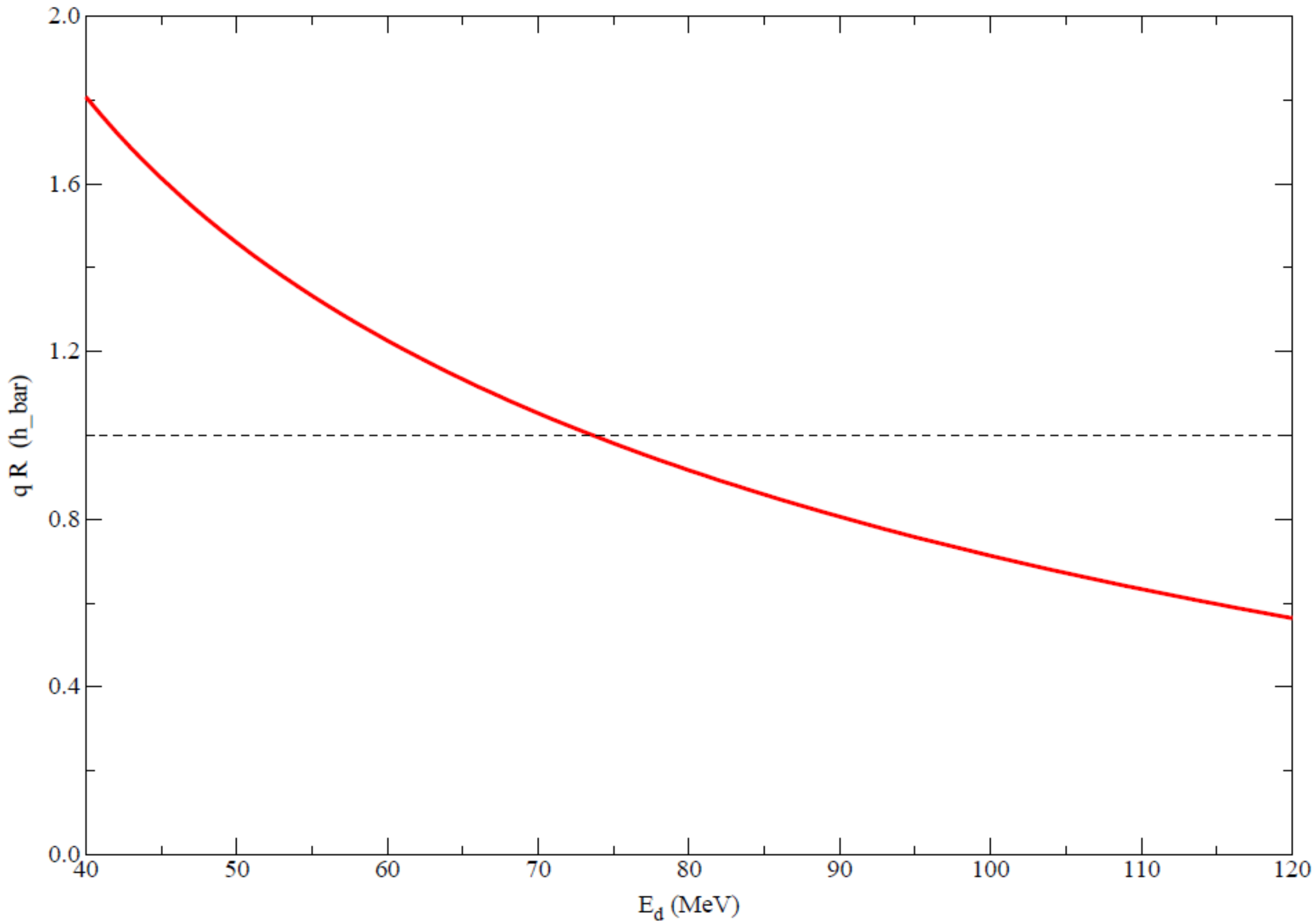
Eur. Phys. J. A **19**, 187–201 (2004)

Comparison to $^{6}He+^{12}C$

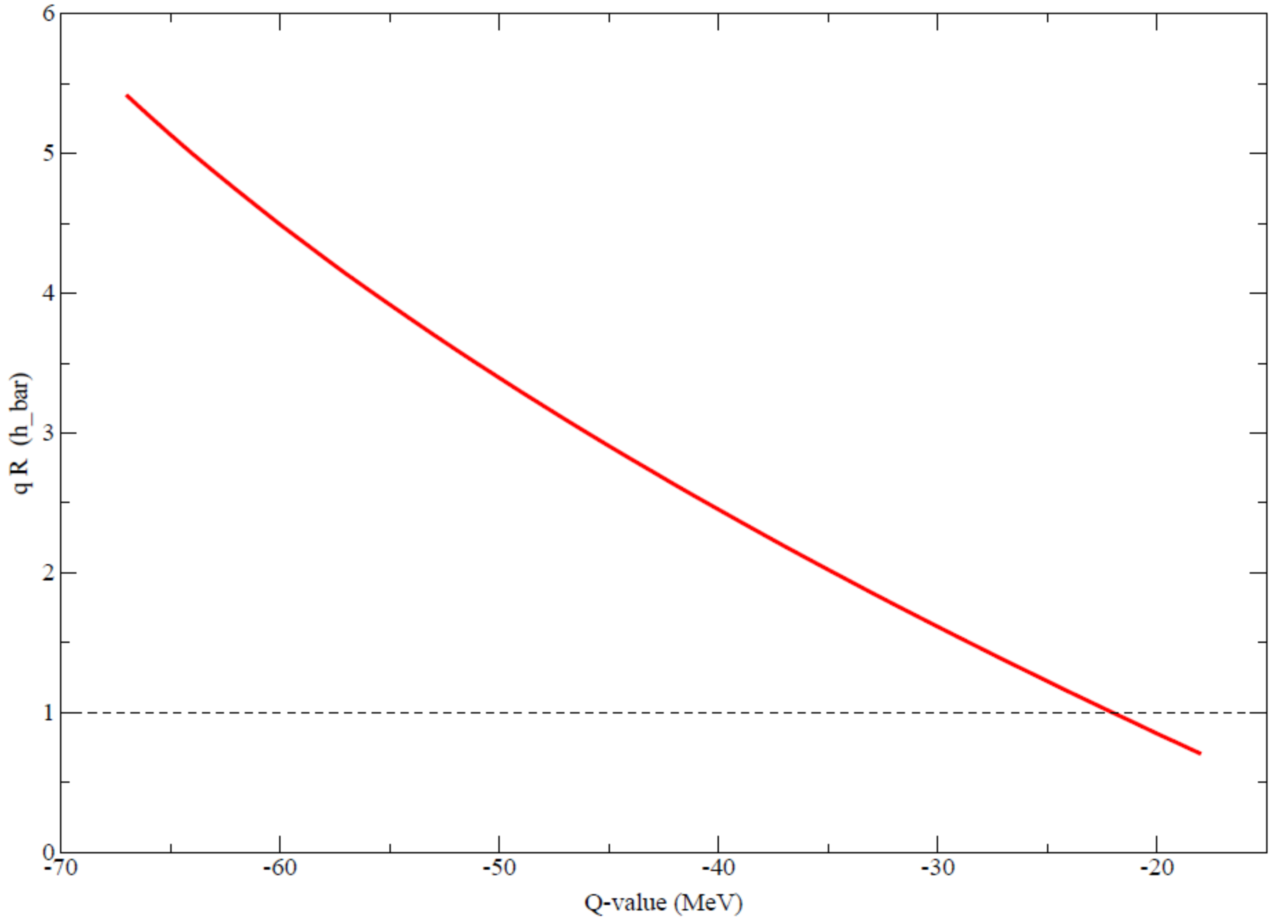
This Experiment

$^{6}He+^{12}C$ with our intrinsic lineshape





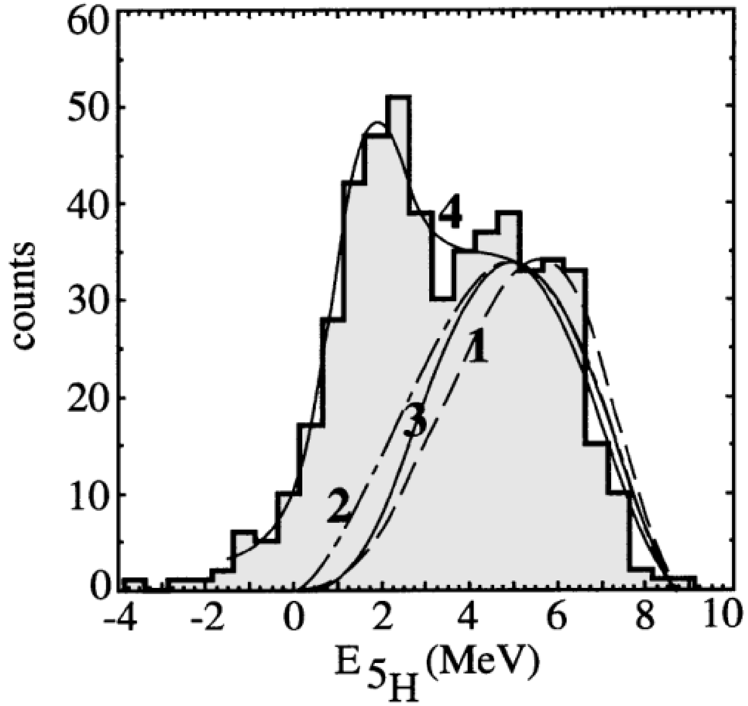
2.0
1.6
1.2
0.8
0.4
0.0
q R (h_bar)
40
50
60
70
80
90
100
110
120
E_d (MeV)



6
5
4
3
2
1
0
q R (h_bar)
-70
-60
-50
-40
-30
-20
Q-value (MeV)

Previous experimental results

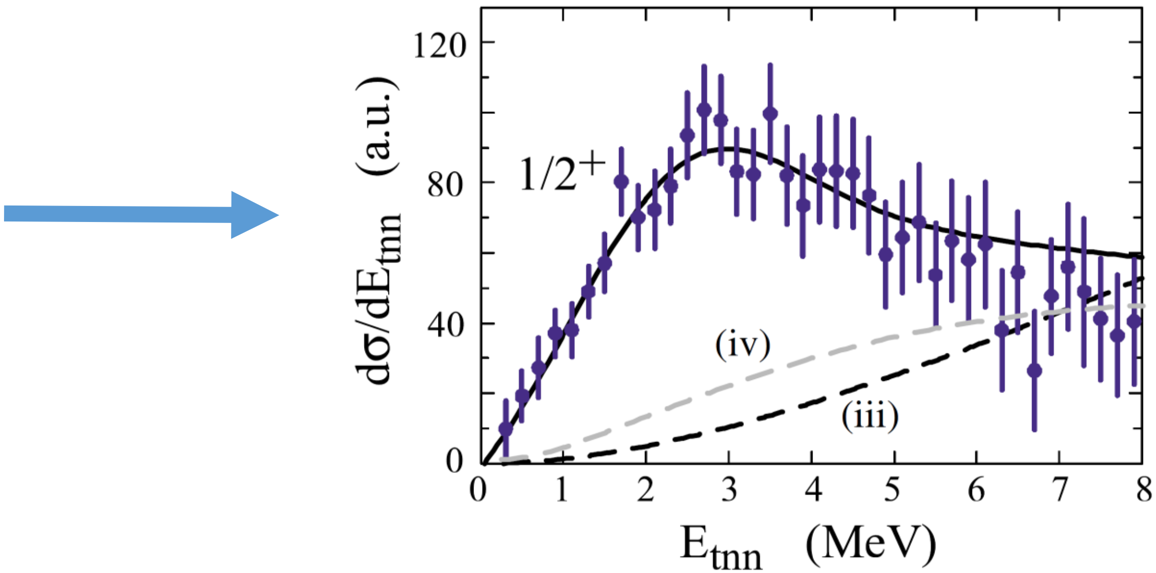
- $^{6}He(p,pp)^{5}H$
- $^{12}C(^{6}He,X)^{5}H$
- $^{3}H(t,p)^{5}H$
- $^{6}He(d,^{3}He)^{5}H$



E=1.7 ± 0.3MeV Γ=1.9 ± 0.5MeV[ref A.A. Korsheninnikov 2001 PRL 87 number 9]

Previous experimental results

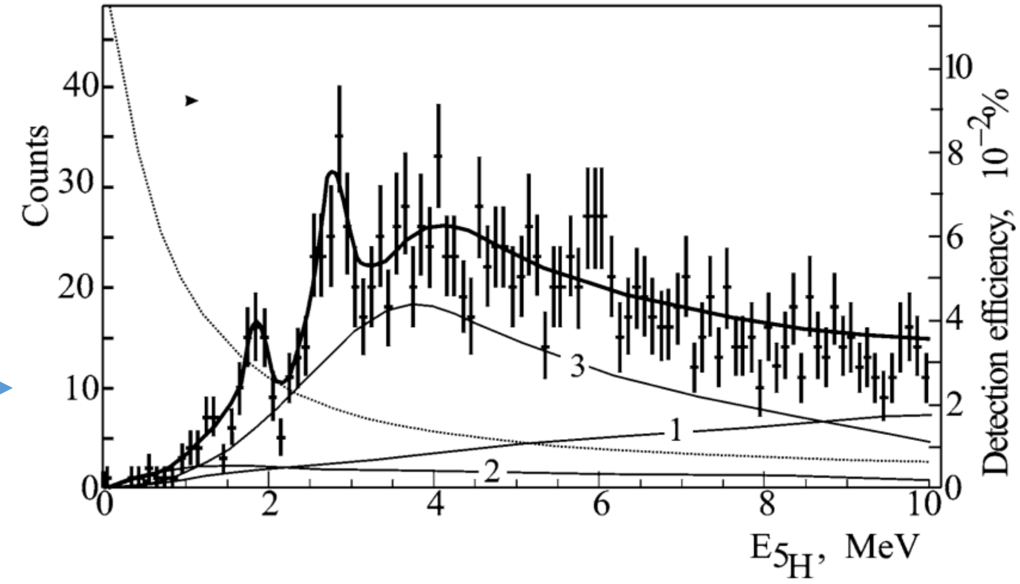
- $^{6}He(p,pp)^{5}H$
- $^{12}C(^{6}He,X)^{5}H$
- $^{3}H(t,p)^{5}H$
- $^{6}He(d,^{3}He)^{5}H$



E=2.5-3MeV, Γ=3-4MeV [ref M. Meister 2003 PRL 91 number 16]

Previous experimental results

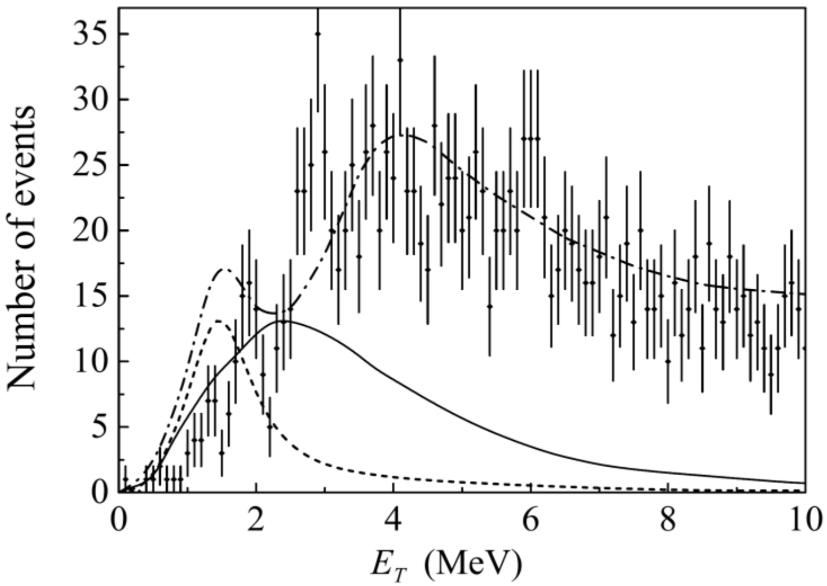
- $^{6}He(p,pp)^{5}H$
- $^{12}C(^{6}He,X)^{5}H$
- $^{3}H(t,p)^{5}H$
- $^{6}He(d,^{3}He)^{5}H$



E=1.8 ± 0.1MeV Γ≤0.5MeV [ref M.S. Golokov 2003 PLB 566 70-75]

Previous experimental results

- $^{6}He(p,pp)^{5}H$
- $^{12}C(^{6}He,X)^{5}H$
- $^{3}H(t,p)^{5}H$
- $^{6}He(d,^{3}He)^{5}H$



Same spectrum, different analysis [ref L.V. Grigorenko 2004 EPJA 20, 419-427]