Proton inelastic scattering reveals deformation in ^{8}He

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Current:

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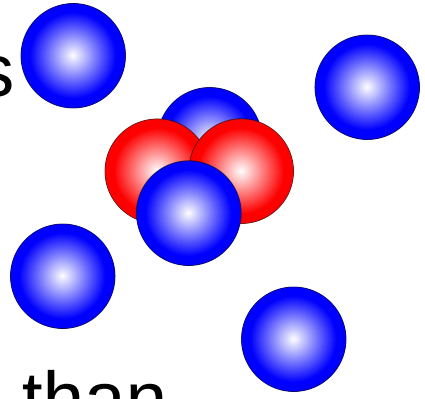
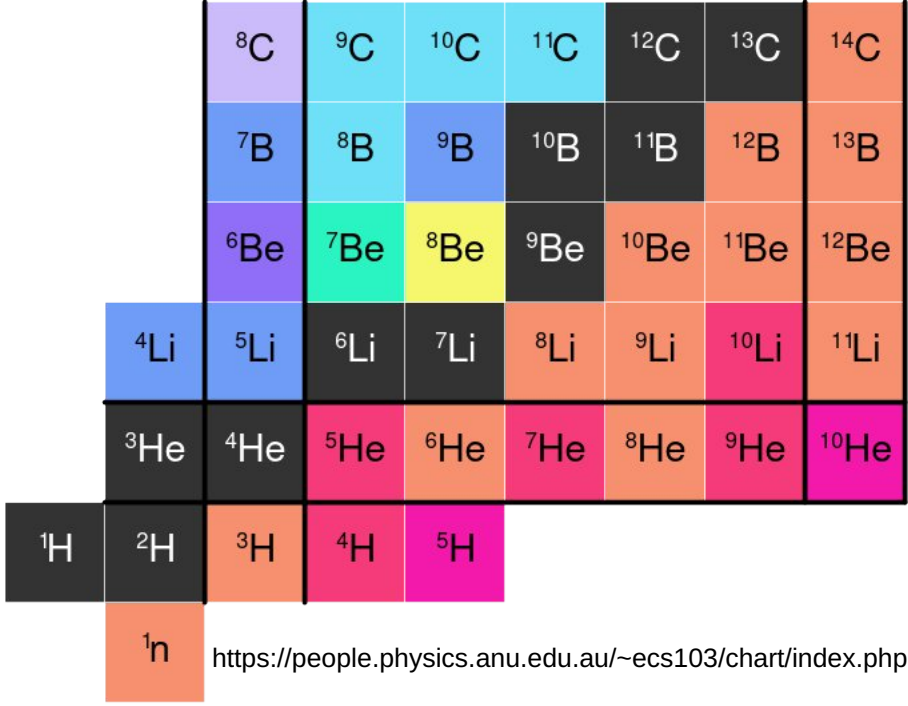
Outline

- Introduction: Properties of ^{8}He and previous measurements
- The IRIS setup at ISAC-II at TRIUMF
- Experimental results
- Comparison to theory
- Summary

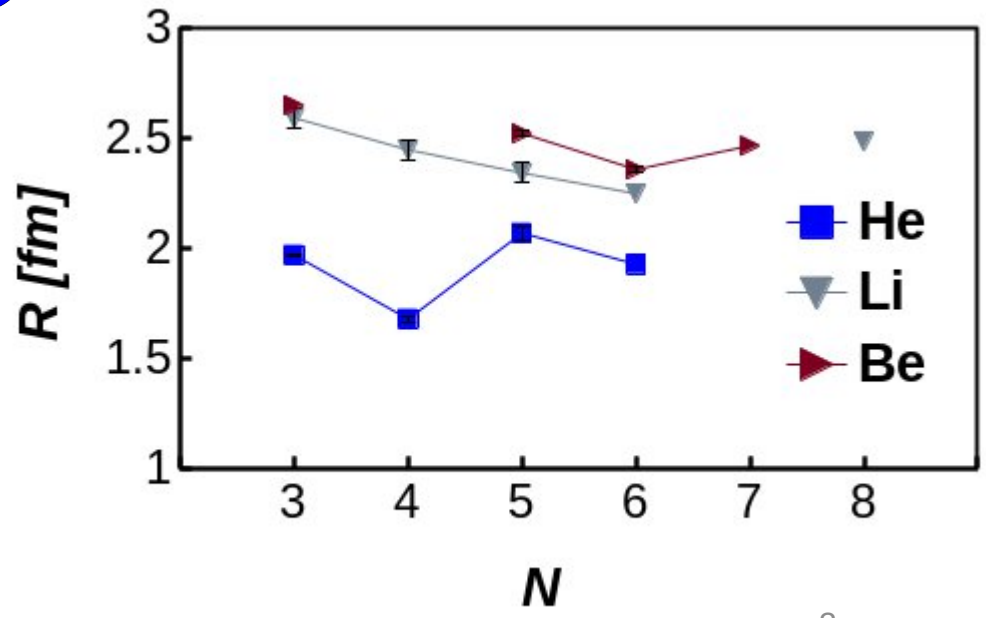
Introduction: ^{8}He

- Most neutron-rich bound nucleus
  - *N/Z=3*
- Structure ^{4}He + 4n
- Larger S_{2n}/smaller charge radius than ^{6}He
  - Indication of closed sub-shell?
- Precise knowledge of low-lying states required!

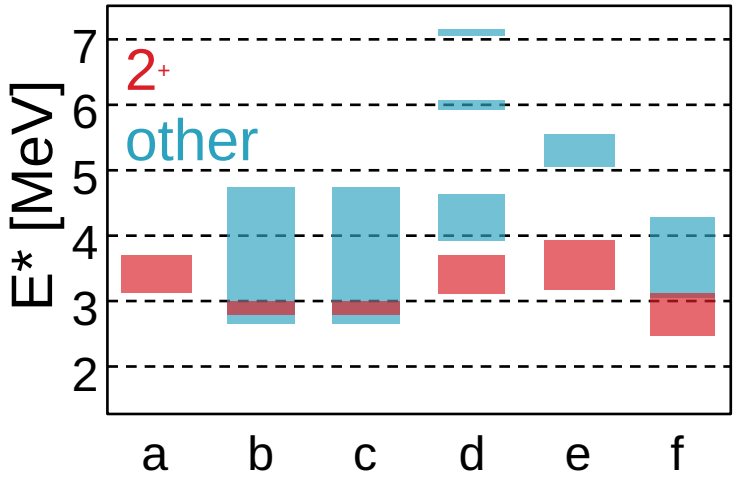




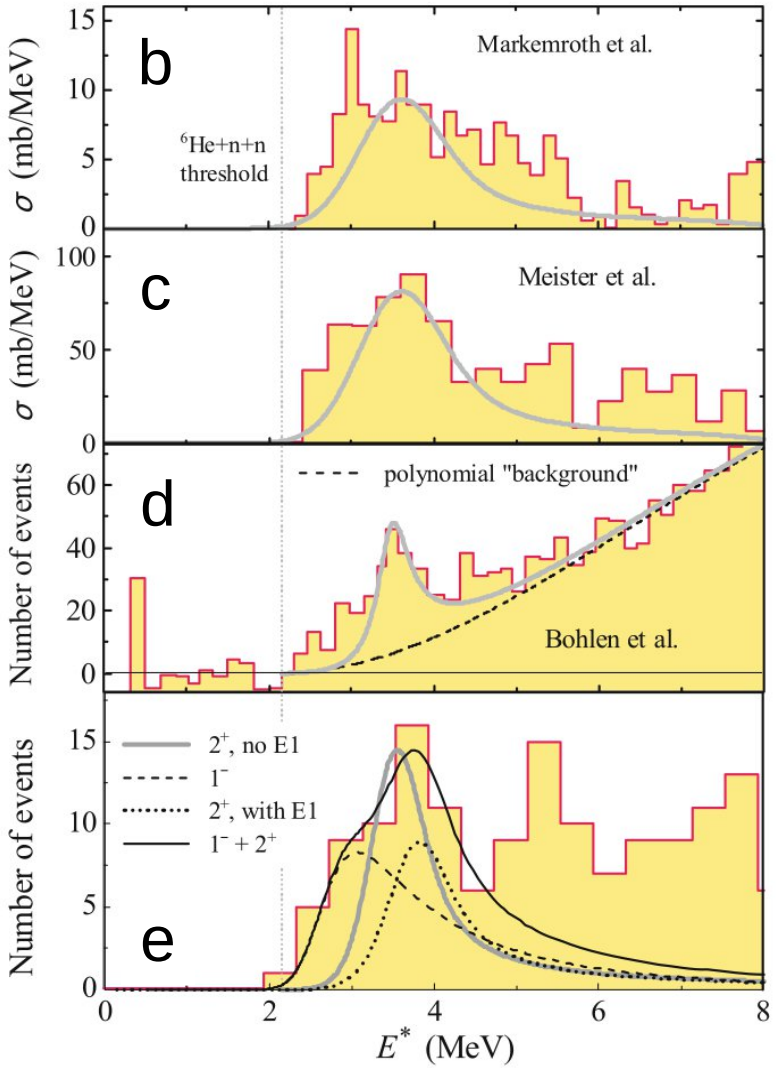
https://people.physics.anu.edu.au/~ecs103/chart/index.php

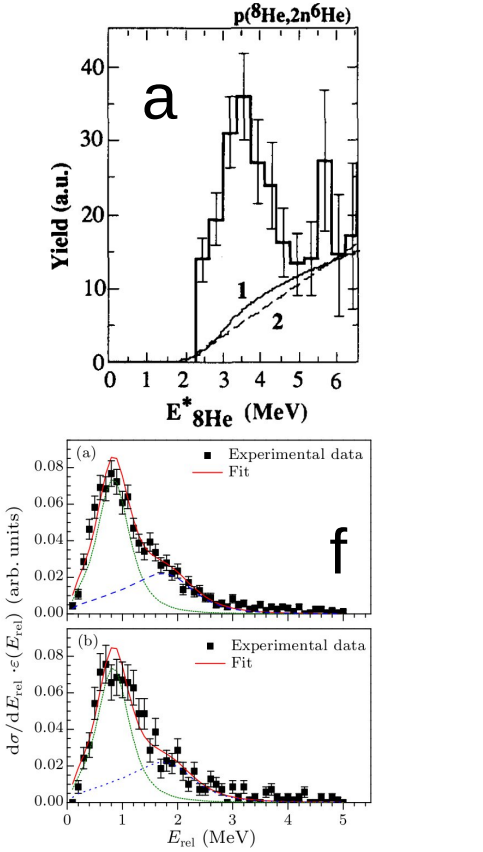


Previous Measurements



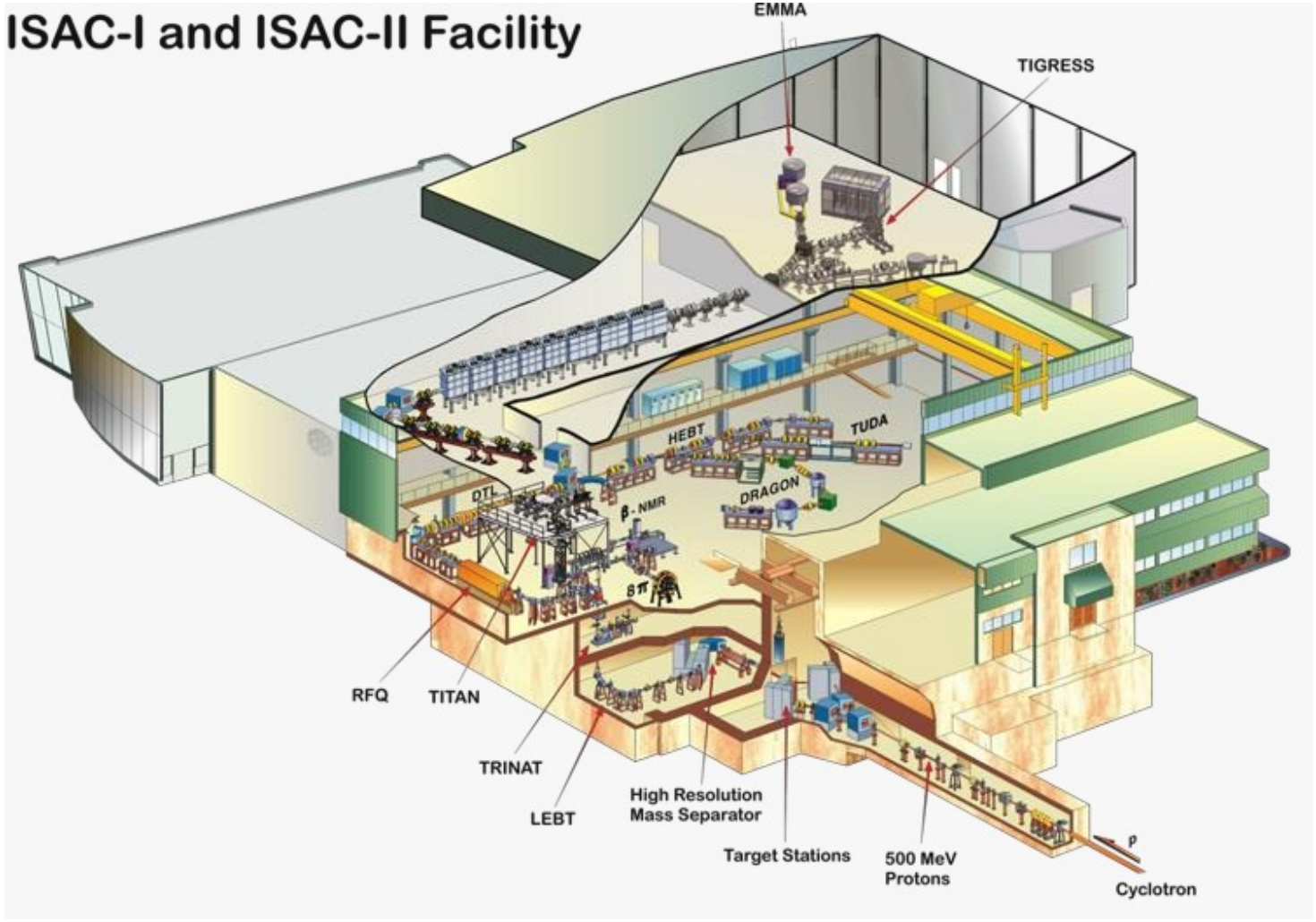
	Lab	Reaction Type	E [*A*MeV]
a	RIKEN	(p,p')	72
b	GSI	Coul. Ex.	227
c	GSI	Fragmentation	227
d	JINR	^{10}Be(^{15}N,^{17}F)^{8}He	16
e	JINR	^{6}He(t,p)^{8}He	25
f	RIKEN	Breakup	82





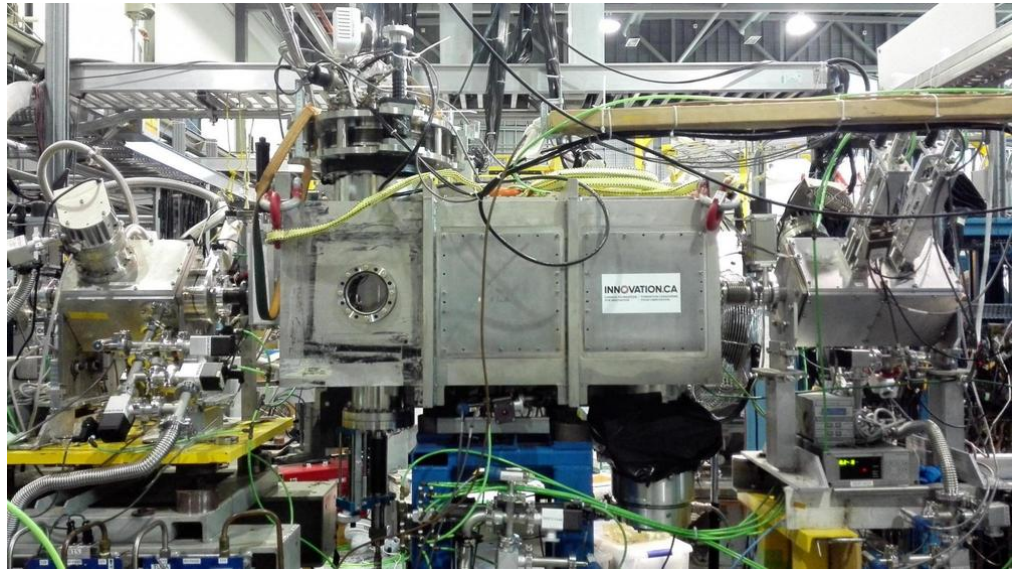
a: Korsheninnikov et al., Phys- Lett. B 316 (1993) 38
b: Markenroth et al. Nucl. Phys. A679 (2001) 462
c: Meister et al. Nucl. Phys. A 700 (2002) 3
d: Bohlen et al., Prog. Part. Nucl. Phys. 42 (1999) 17
e: Fornichev et al., Eur. Phys. J. A 42 465 (2009)
Golovkov et al., Phys. Lett. B 672 (2009) 22
f: Xiao et al., Chin. Phys. Lett. 29 8 (2012) 082501

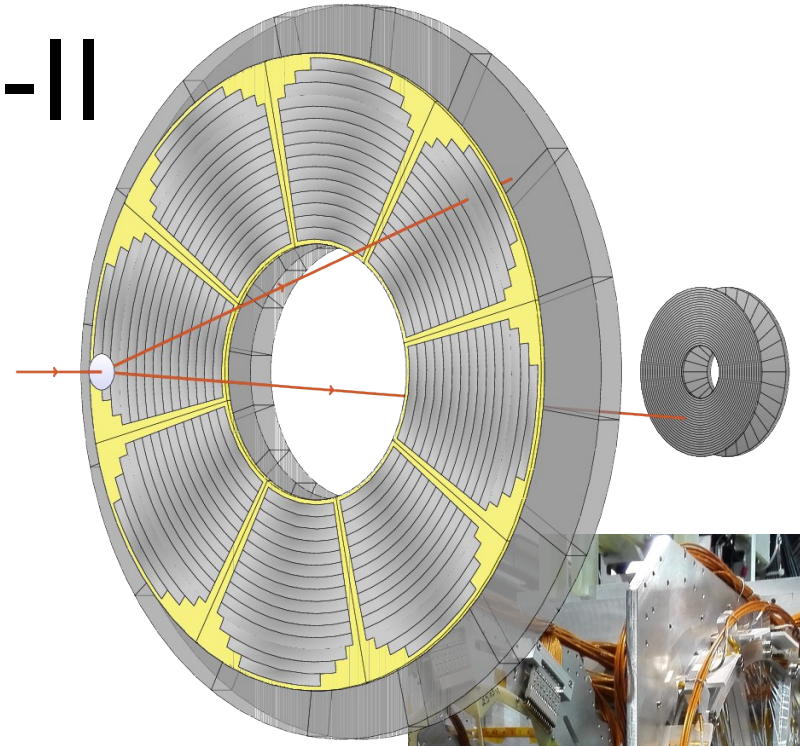
ISAC-II

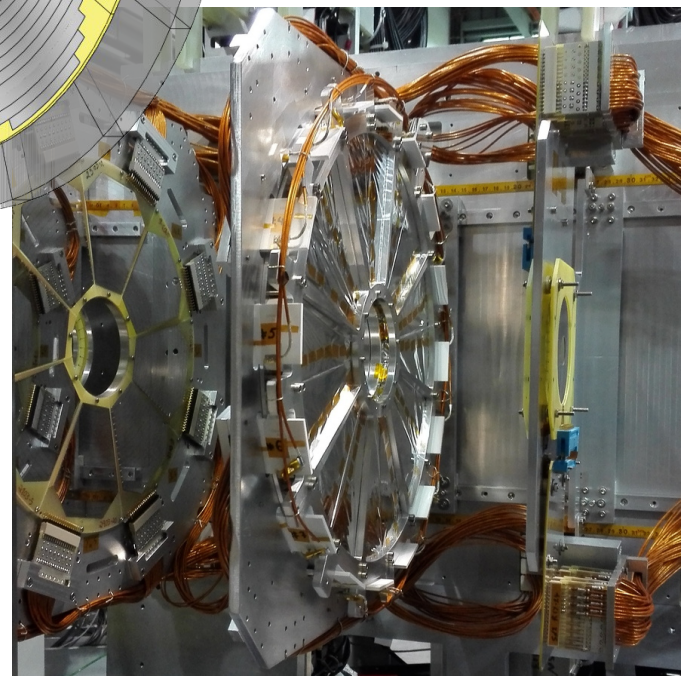


- ^{8}He produced from SiC target
- Accelerated to 8.25*A* MeV
- Delivered to IRIS@ISAC-II
- ~10^{4} particles per second
- ~90 % purity

The IRIS Setup @ ISAC-II

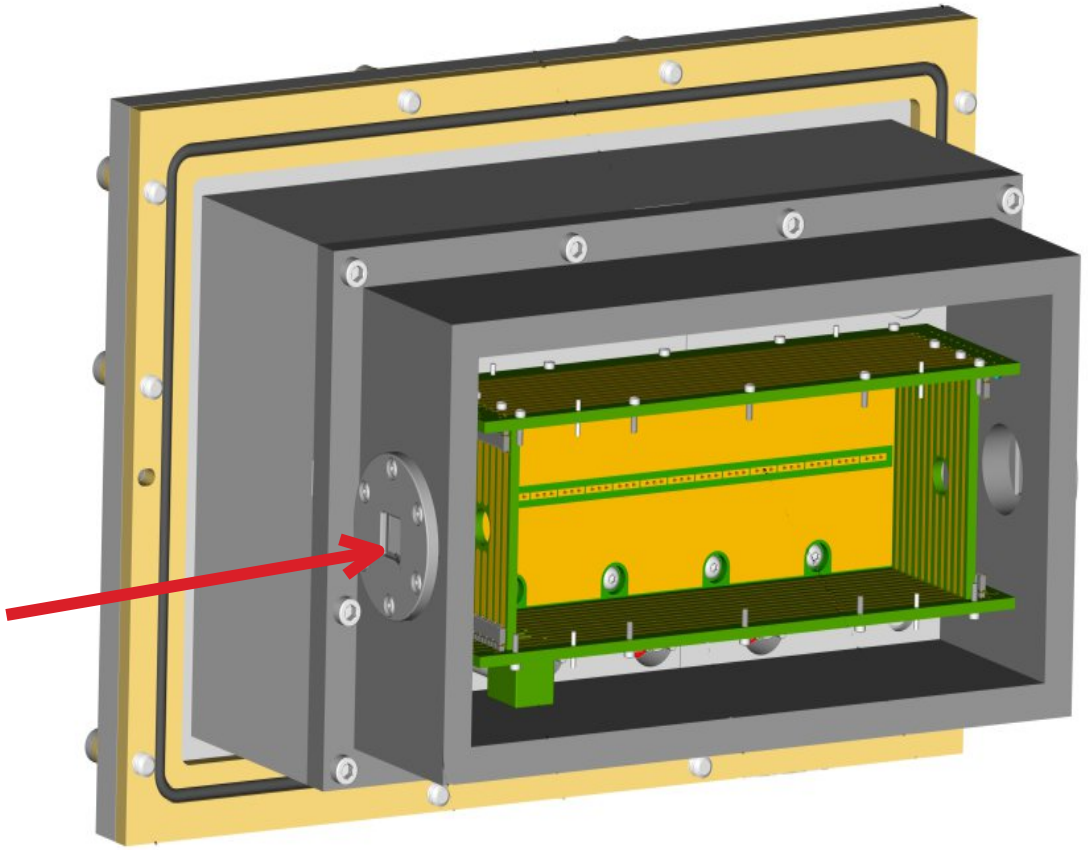




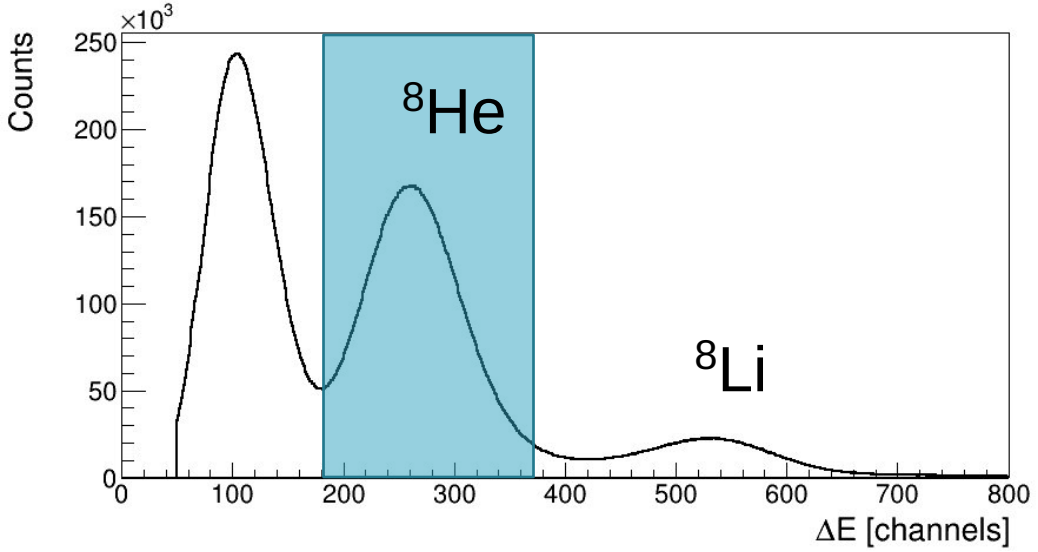


- Allows studies of direct reactions with low intensity beams
- Particle identification using 2 ΔE-E telescopes
  - Light particles: 100 μm Si detector + 1.2 cm CsI(Tl) array
    - covering 21°-46°
  - “Heavy” particles: 60 μm + 1 mm Si detectors
    - covering ~3°-10°

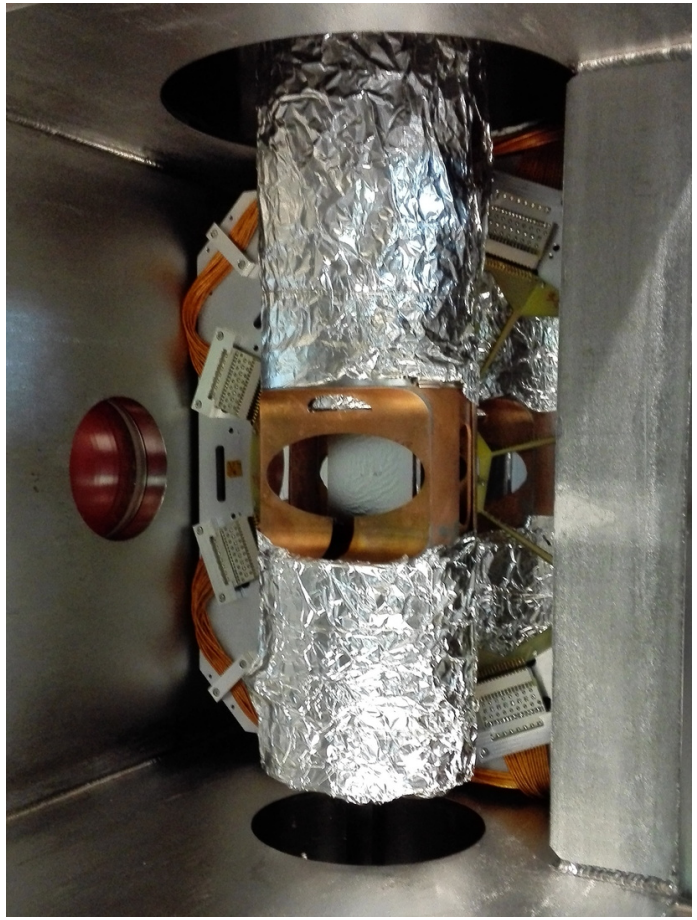
Low Pressure Ionization Chamber



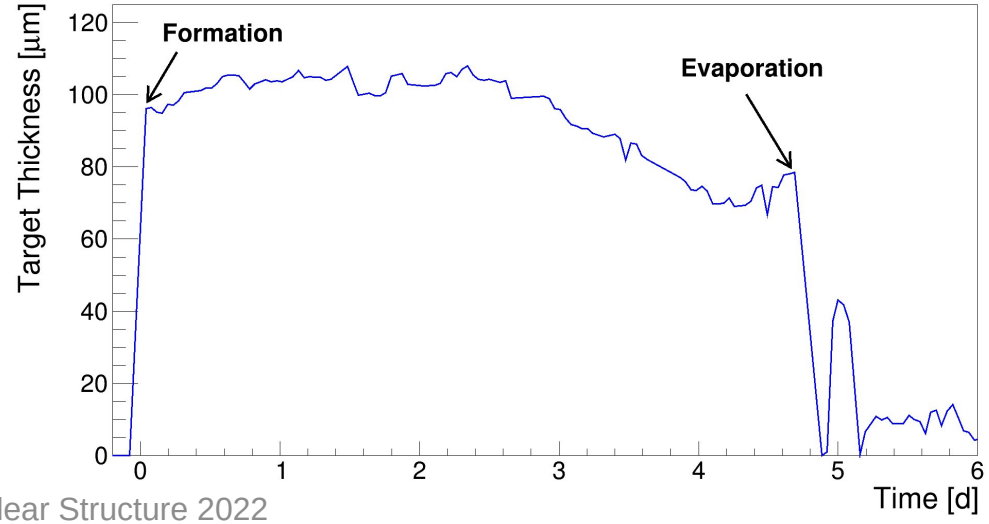
- Used to identify beam contaminants with minimal energy loss
- 19.5 Torr isobutane



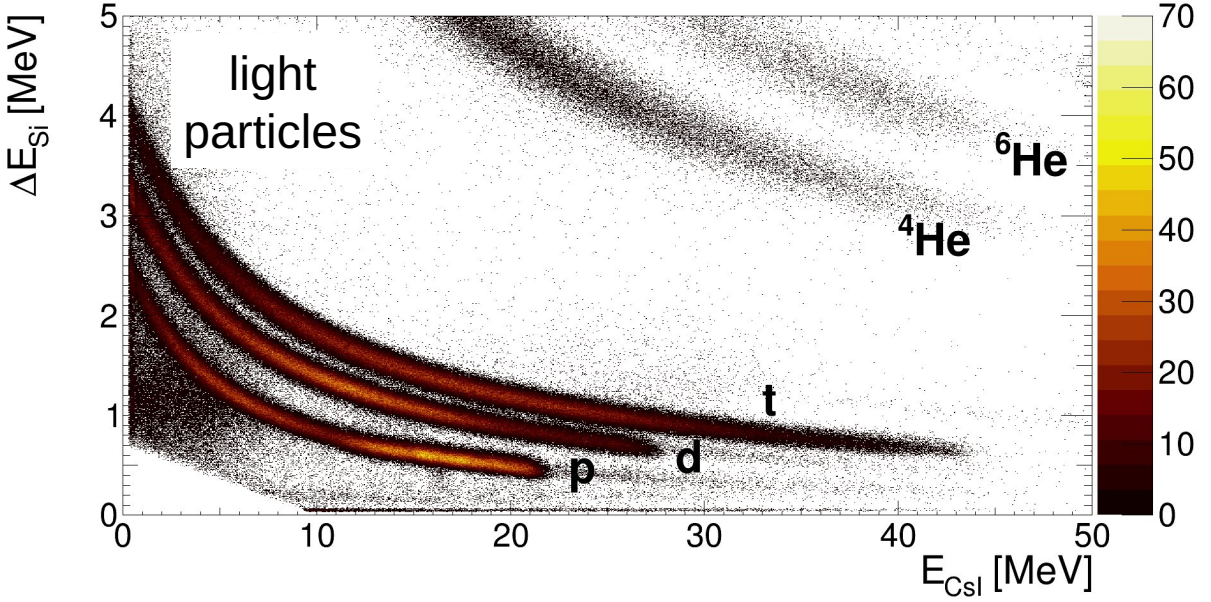
Solid Hydrogen Target

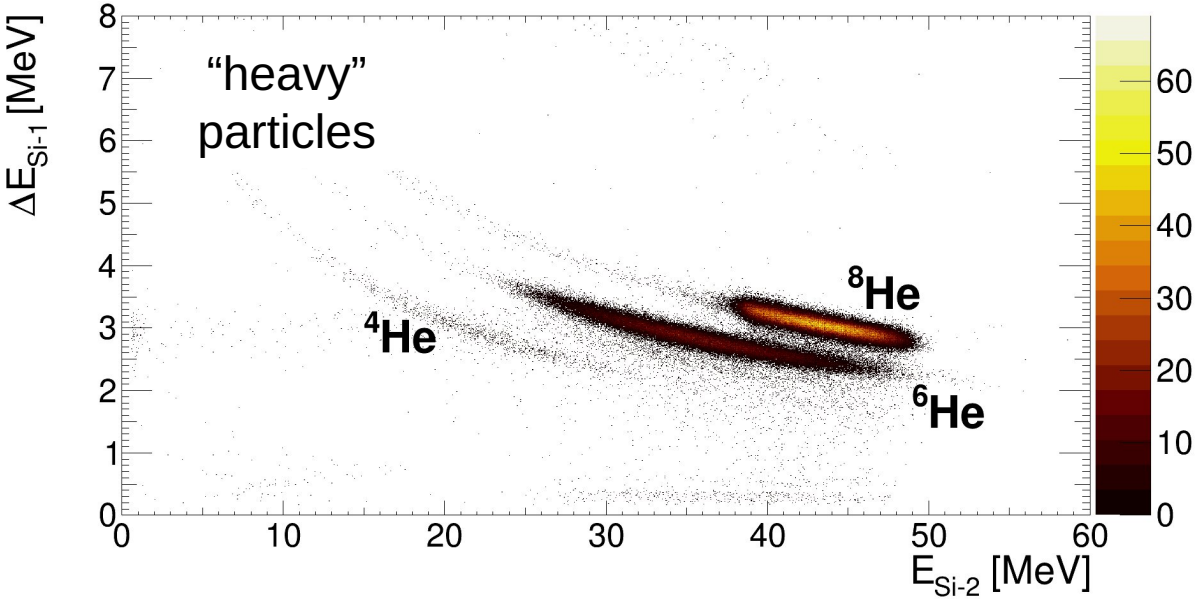


- 100 μm solid H_2 target
- Formation: H_2 gas sprayed onto a 4.5 μm silver foil at T<4 K
- Energy difference of nuclei scattered elastically off the silver foil with and without H_2 used to continuously measure thickness

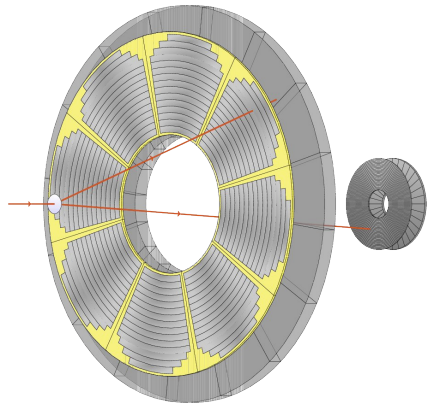


Particle ID

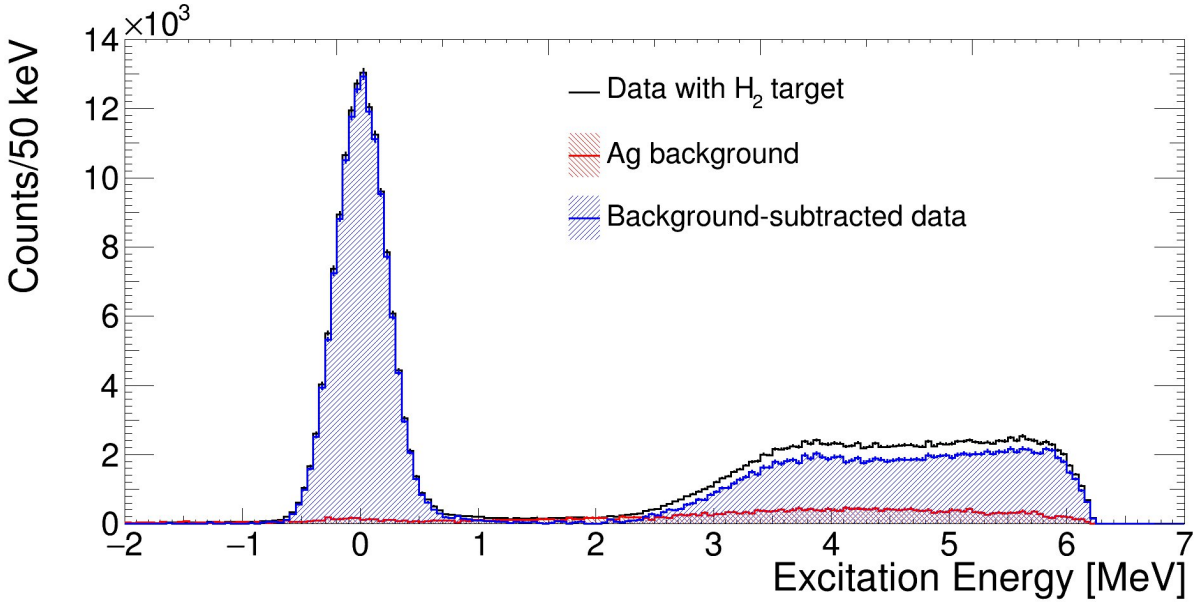


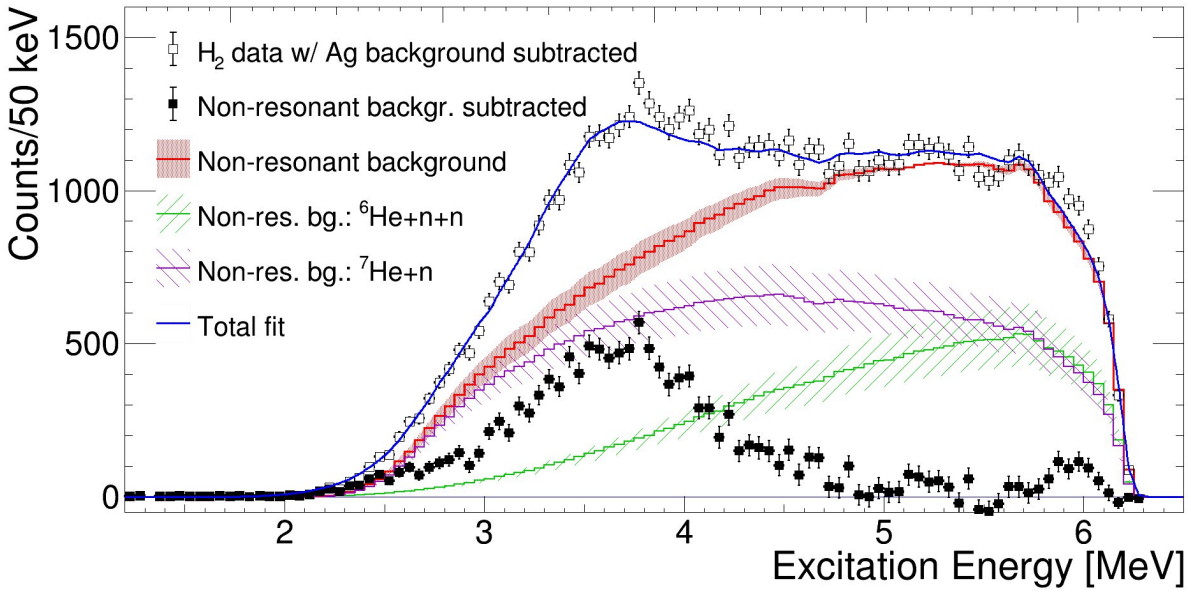


- Light and heavy reaction products identified using ΔE-E telescopes



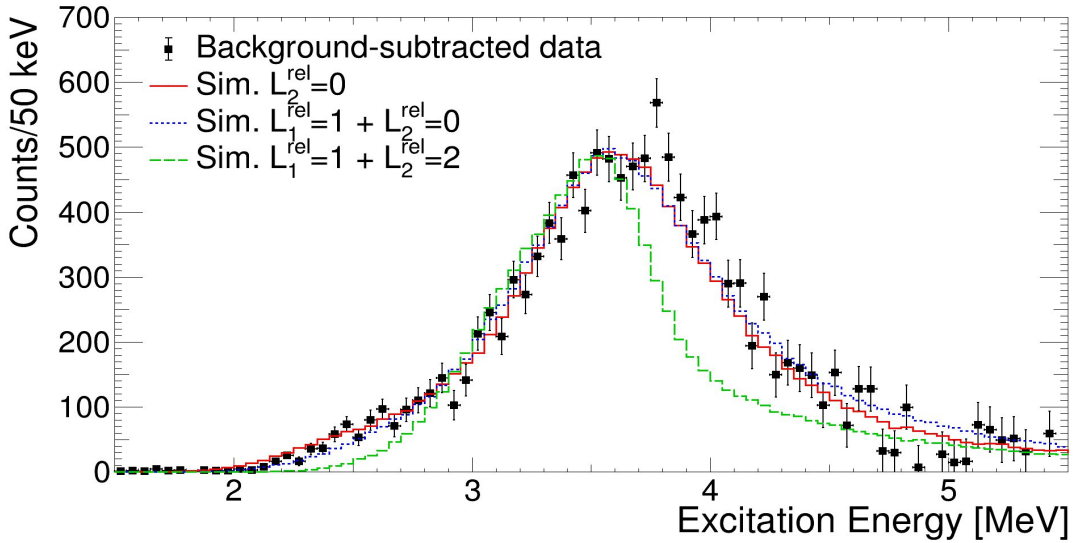
Excitation Energy Spectrum

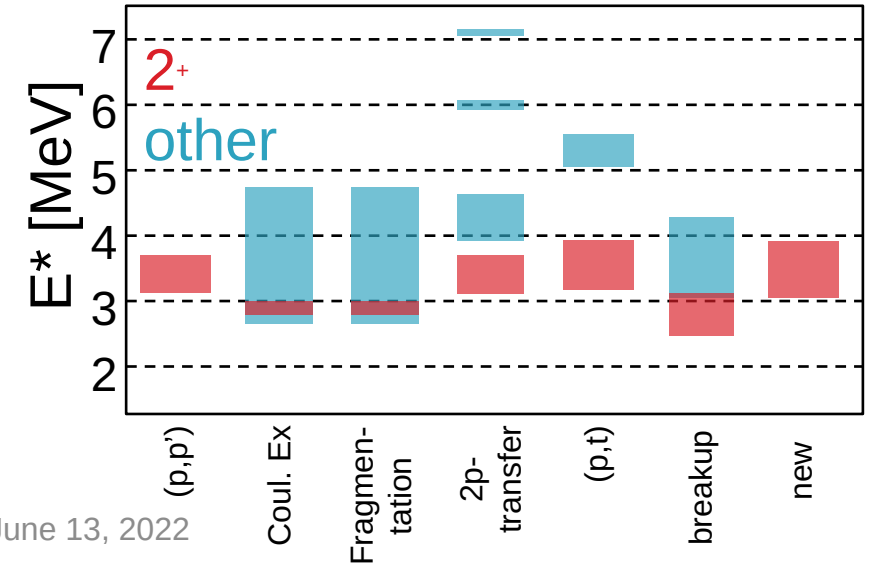




- Background from silver foil subtracted
- Elastic scattering analyzed by gating on ground state
- Inelastic scattering:
  - Excitation spectrum above neutron threshold dominated by non-resonant reactions
  - Data fit by simulated detector response of resonance(s) + non-resonant background

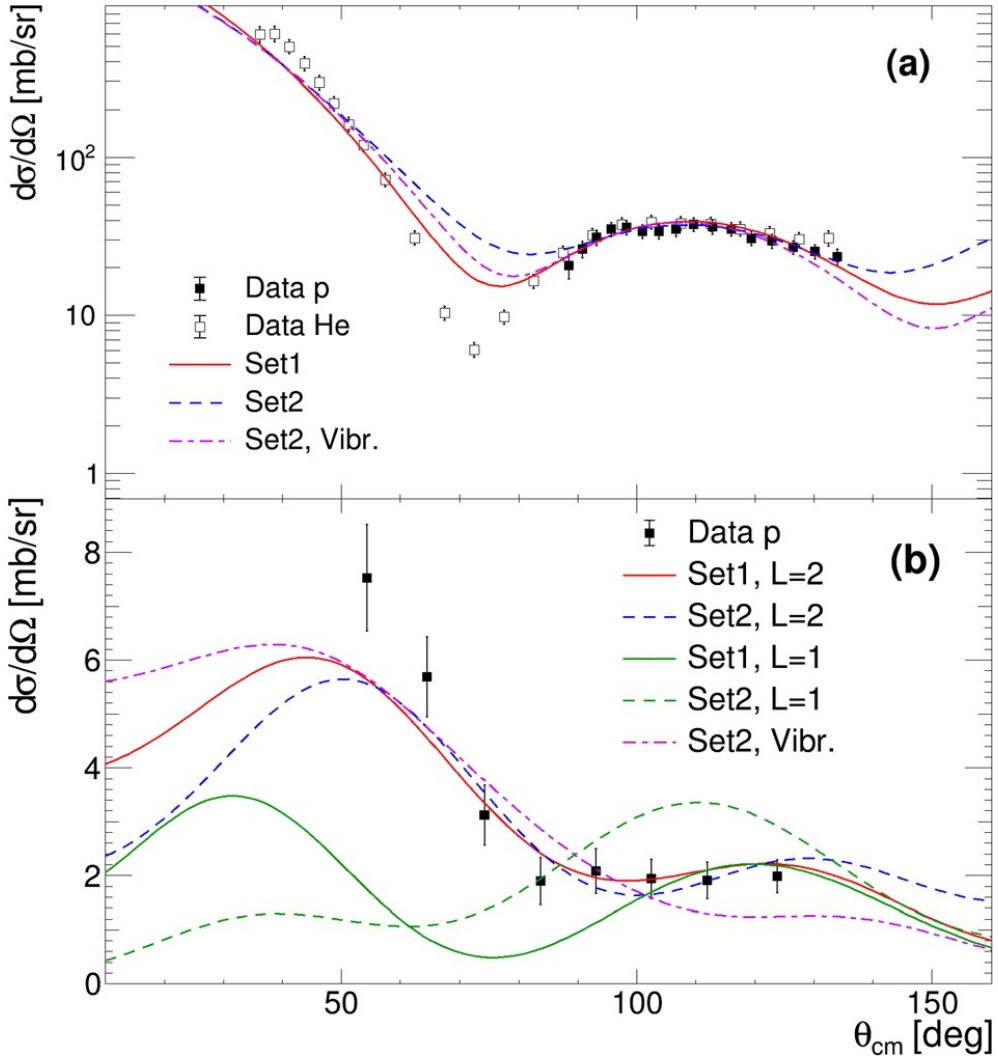
Low-lying resonance in ^{8}He





- Possible decays of resonance:
  - Direct: ^{8}He(2^{+})→^{6}He(0^{+})+2n
    - $S_{2n} = 2.1$ MeV, $L_2^{rel} = 0,2$
  - Sequential: ^{8}He(2^{+})→^{7}He+n→^{6}He+n+n:
    - $S_n = 2.5$ MeV, $L_1^{rel} = 1$
- Impossible to distinguish between pure direct and mixed decay
- Including additional resonances does not improve the description of the data
  - No sign of dipole excitation
- Resonance: $E^* = 3.54(6)$ MeV, $\Gamma = 0.89(11)$ MeV
  - In agreement with previous measurements from (p,p') and transfer

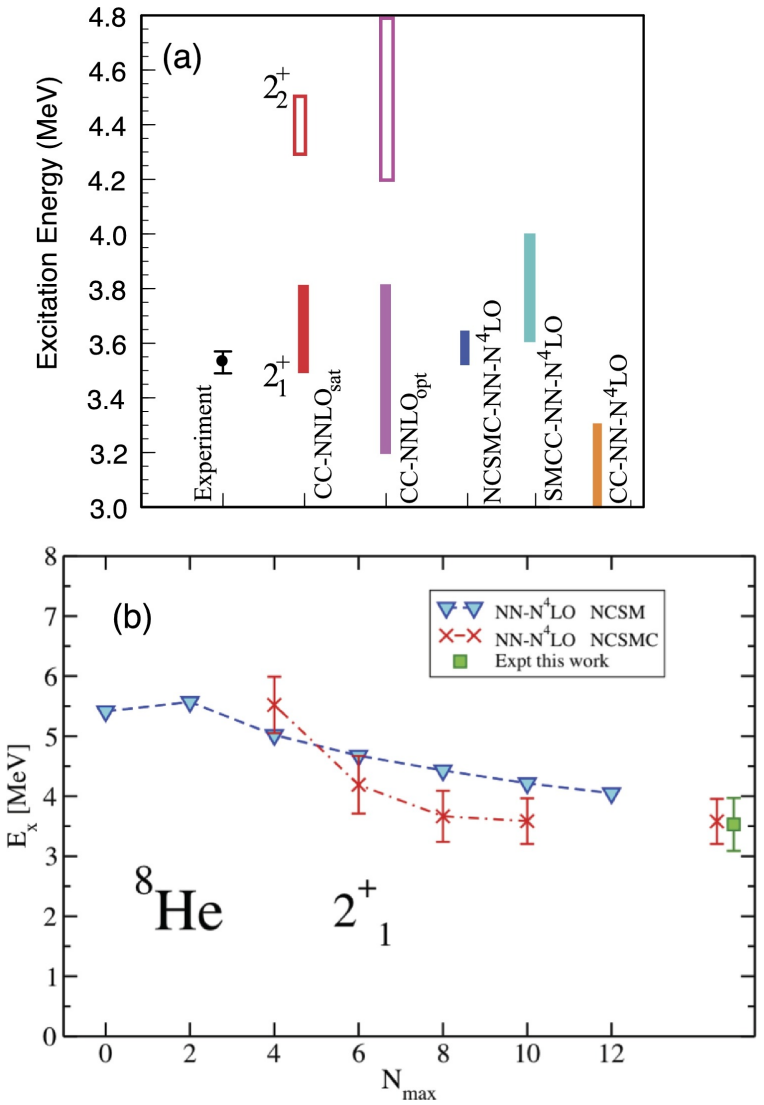
Differential Cross Sections



- p+^{8}He optical potential determined using SFRESCO
- Elastic and inelastic scattering analyzed simultaneously
- Using DWBA (Set 1) and coupled-channel (Set 2)
- State at $E^* = 3.5\ \mathrm{MeV}$ explained by $L = 2$
- All sets require large deformation lengths $\delta_2^{ex} = 1.24 - 1.40\ \mathrm{fm}$
- $\rightarrow \beta_2 = 0.40(3)$, ^{8}He has a deformed sub-shell gap

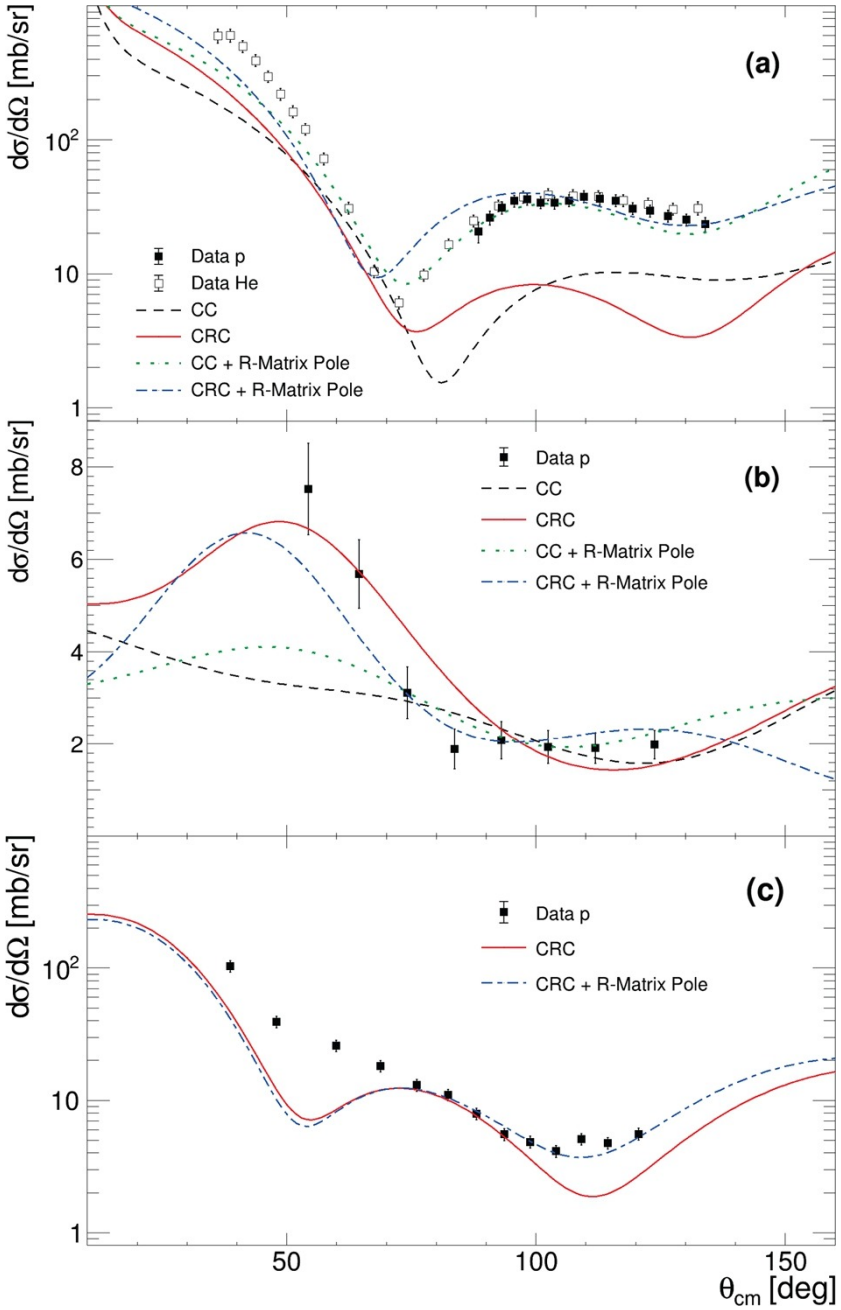
Comparison to *ab initio* calculations

- Two many-body approaches:
  - coupled-cluster theory (CC)
  - no-core shell model + continuum (NCSMC)
  - Several chiral interactions
- Resonance energy well reproduced by both approaches
- NCSMC:
  - good agreement for width ($\Gamma = 0.75$ MeV)
  - Quadrupole moment suggests sizable neutron deformation
  - No evidence of 1^--state below 6 MeV



CRC Calculations

- Coupled-channel (CC) and coupled-reaction-channels (CRC) calculations
  - Using NCSM inputs
- Good agreement with data for elastic and inelastic scattering, as well as ^{8}He(p,d)
  - Elastic scattering requires inclusion of resonance in compound ^{8}Li
- $\delta_2 = 1.39$ fm



Summary

- Measurement of proton inelastic scattering of ^{8}He at 8.25*A* MeV
- Confirmed first excited state of ^{8}He as unbound 2^{+} state
  - $E^{*} = 3.54(6)\ \mathrm{MeV}, \Gamma = 0.89(11)\ \mathrm{MeV}$
- Excitation energies from *ab initio* calculations in a coupled cluster framework and NCSMC in good agreement with the data
  - Γ From NCSMC also consistent with data
- DWBA/CC analysis of angular distribution yields a quadrupole deformation parameter $\beta_2 = 0.40(3)$ ($\delta_2^{ex} = 1.32(8)\ \mathrm{fm}$)
  - Consistent with quadrupole moment from NCSMC calculations
  - Microscopic CRC calculations with NCSM densities explain the inelastic scattering and yield $\delta_2 = 1.39\ \mathrm{fm}$

M. Holl [a,b], R. Kanungo [a,b,*], Z.H. Sun [c,d], G. Hagen [c,d], J.A. Lay [e,f], A.M. Moro [e,f], P. Navrátil [b], T. Papenbrock [c,d], M. Alcorta [b], D. Connolly [b], B. Davids [b], A. Diaz Varela [g], M. Gennari [b], G. Hackman [b], J. Henderson [b], S. Ishimoto [h], A.I. Kilic [g], R. Krücken [b], A. Lennarz [b,i], J. Liang [i], J. Measures [j], W. Mittig [k,l], O. Paetkau [b], A. Psaltis [i], S. Quaglioni [m], J.S. Randhawa [a], J. Smallcombe [b], I.J. Thompson [m], M. Vorabbi [b,n], M. Williams [b,o]

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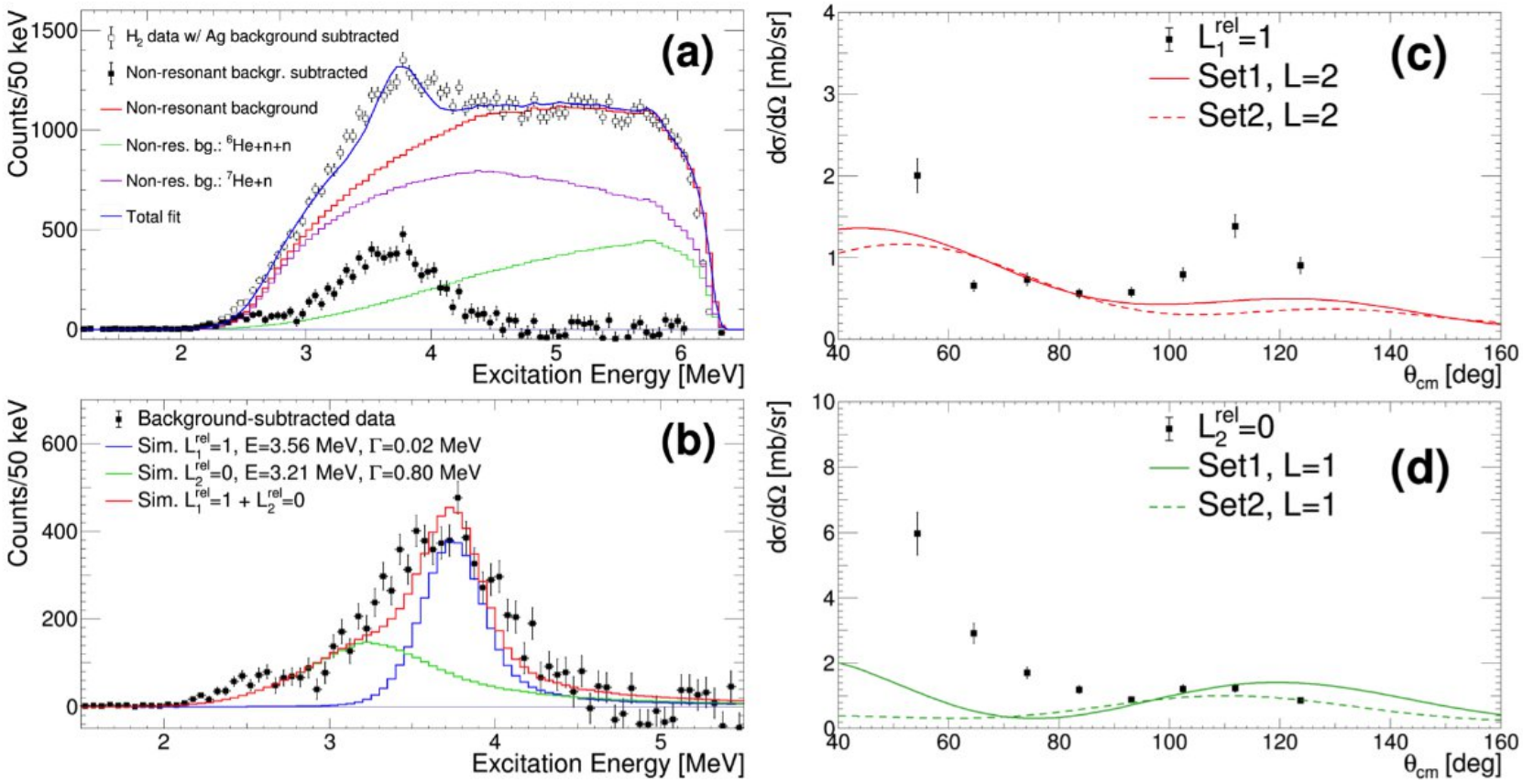
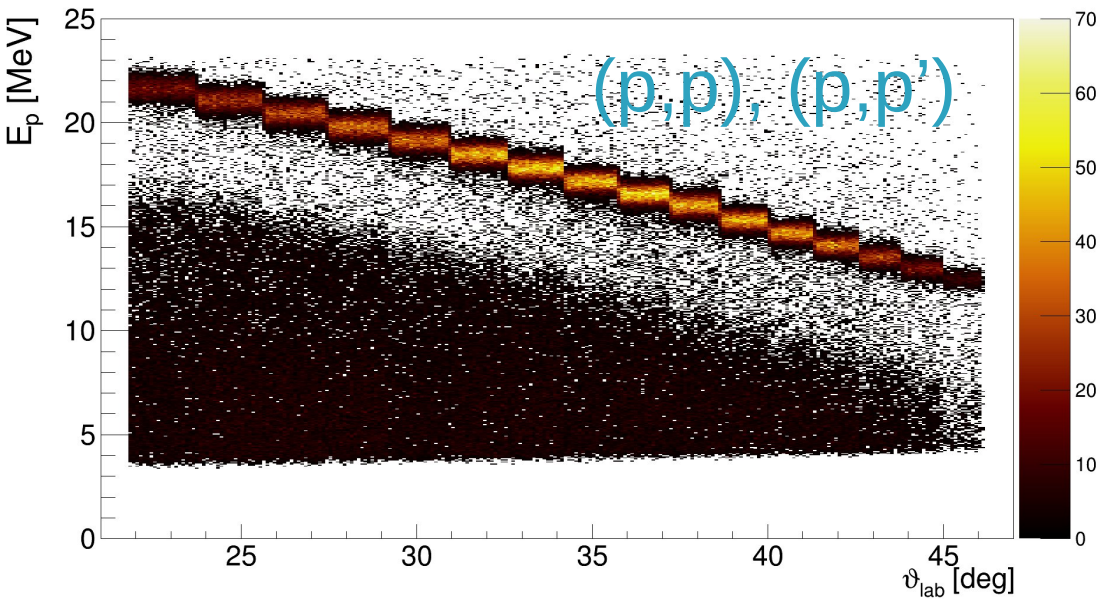
[k] *National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI 48824-1321, USA*
[l] *Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824-1321, USA*
[m] *Lawrence Livermore National Laboratory, P.O. Box 808, L-414, Livermore, CA 94551, USA*
[n] *National Nuclear Data Center, Bldg. 817, Brookhaven National Laboratory, Upton, NY 11973-5000, USA*
[o] *Department of Physics, University of York, York YO10 5DD, United Kingdom*

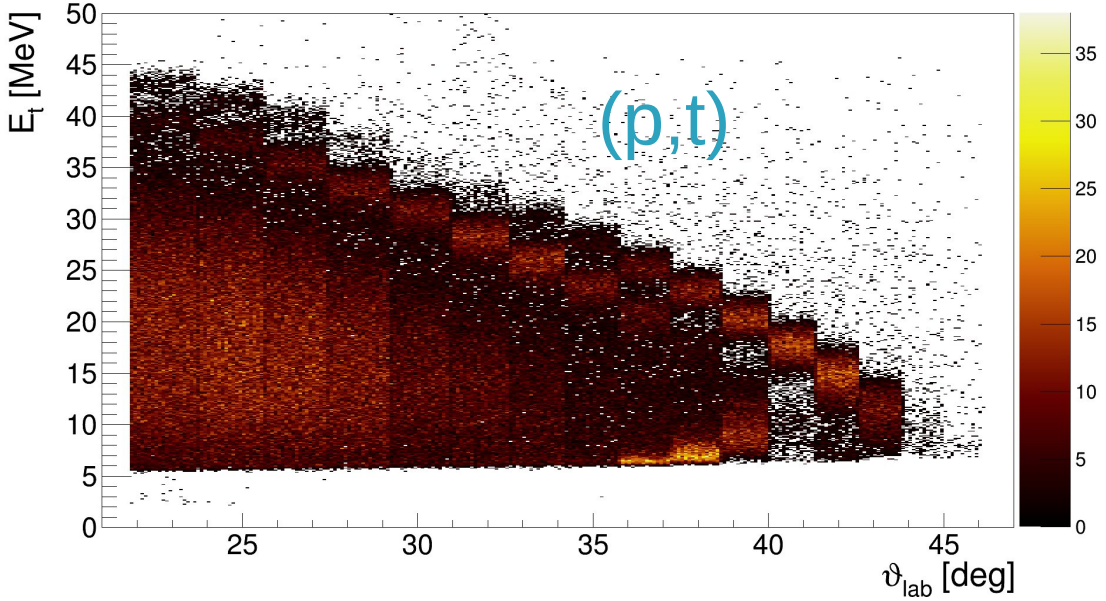
Thank you for your attention!

Fit with two resonances



Kinematics





- Excitation energy spectra reconstructed from light particle energies and angles