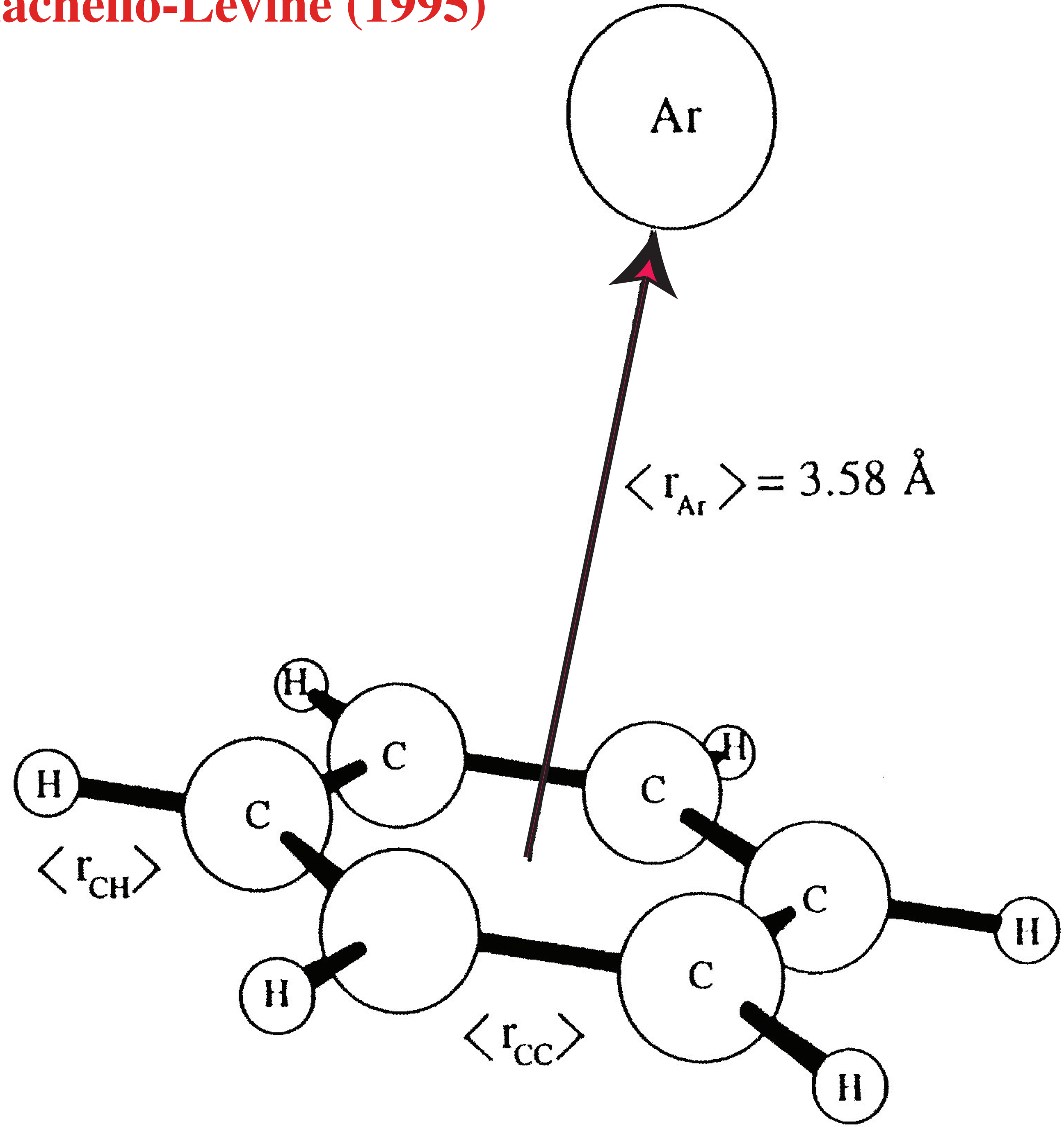
Tests of the Algebraic Cluster Model and Conjectured Hole States of the Cluster Shell Model

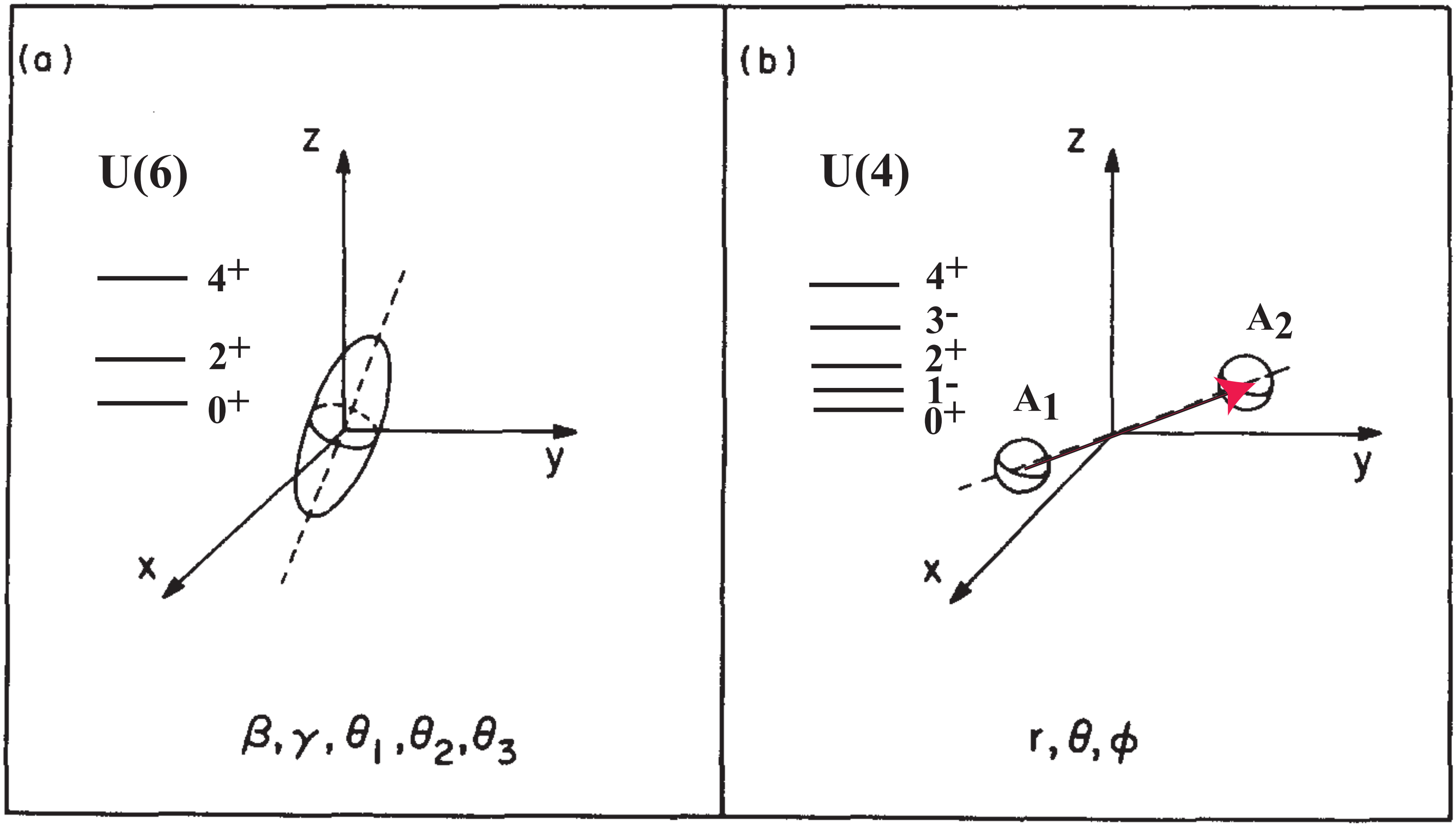
Moshe Gai
University of Connecticut
http://astro.uconn.edu, moshe.gai@uconn.edu

1. **Molecular Degrees of Freedom**
2. **The Algebraic Cluster Model (ACM): ^{12}C**
3. **The Cluster Shell Model (CSM): ^{9}Be**
4. **Conjectured Hole States of the CSM: ^{7}Be, ^{19}F**
5. **Conjectured P-H States: ^{8}Be**
6. **The HIγS and ISOLDE Projects**

The 7th Int. COMEX7, Catania, Italy from June 14, 2023

The Molecular Degree of Freedom
Iachello-Levine (1995)





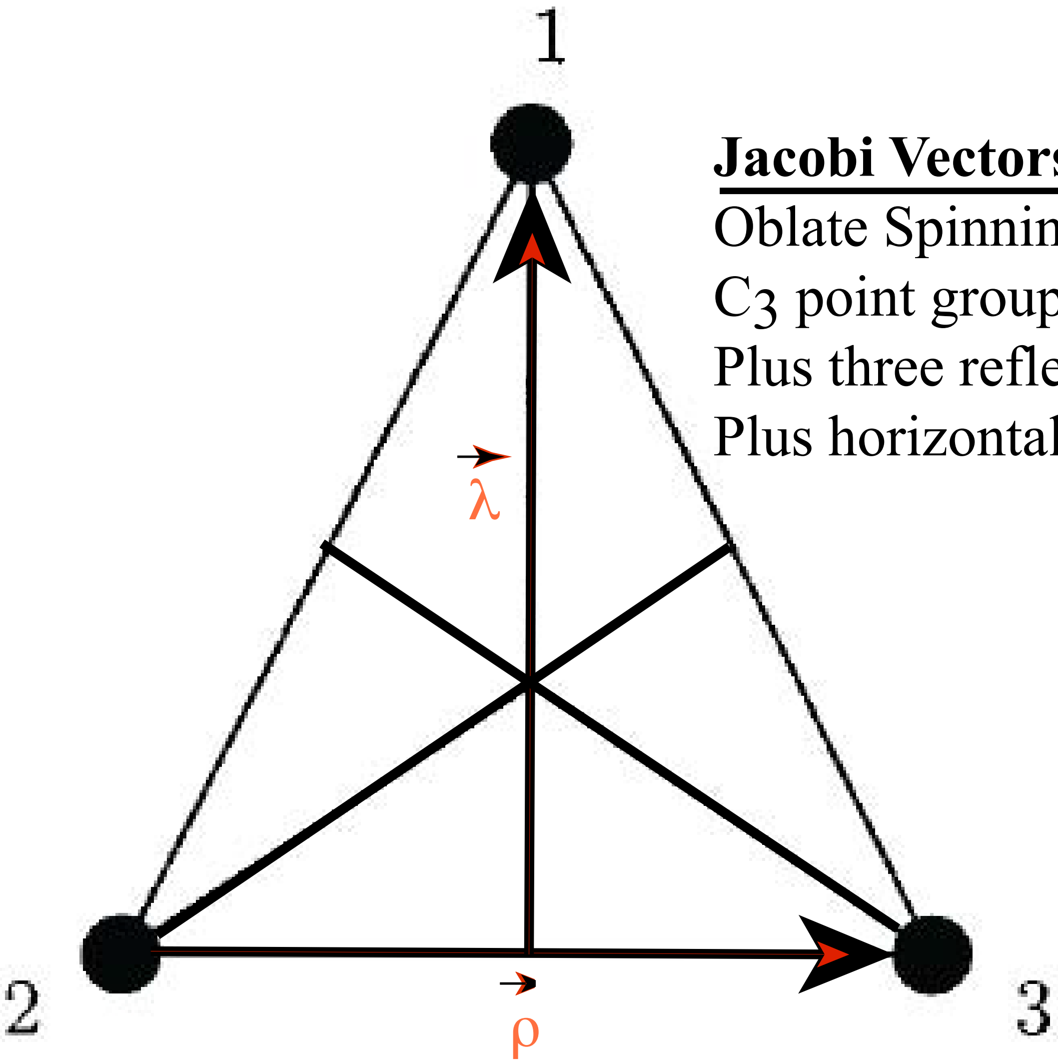
J. Chem. Phys., Vol. 77, No. 6, 15 September 1982

Spectrum of the (Symmetric) Triangular Spinning Top:

Molecular Physics: H_3^+ Molecule

Hadron Structure: Three Quark Model

Nuclear Structure: ^{12}C Three Alpha-Particles



Jacobi Vectors: $\vec{\rho}$, $\vec{\lambda}$

Oblate Spinning Top: U(6+1)

C_3 point group symmetry

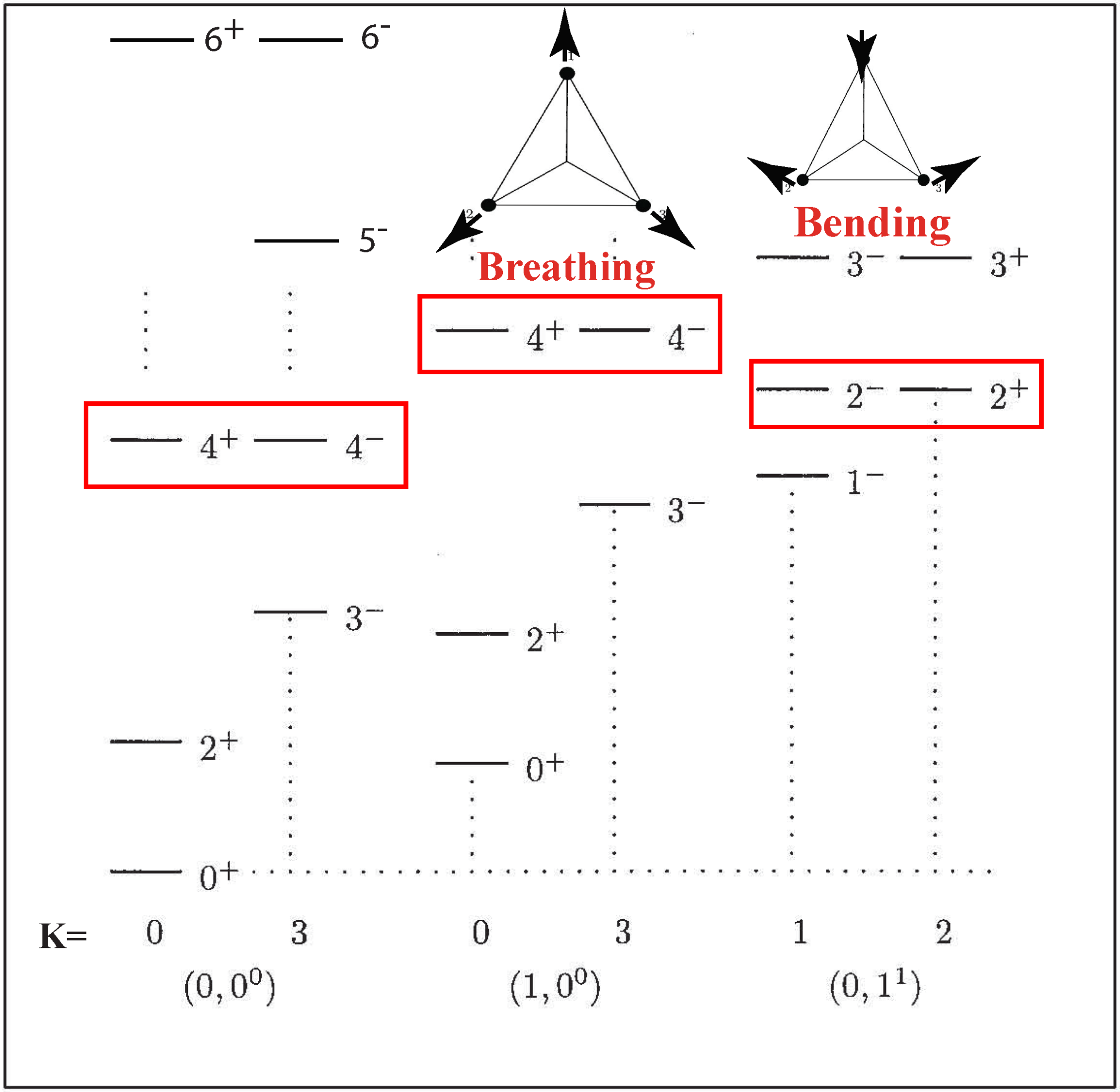
Plus three reflections

Plus horizontal: D_{3h} Symmetry

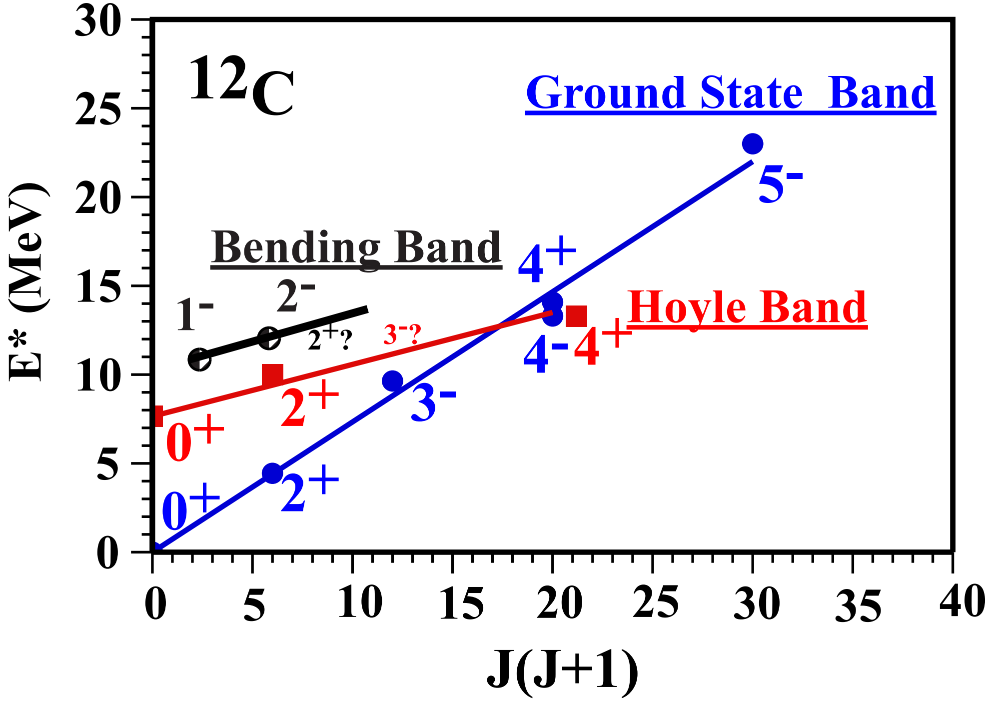
Rotation-Vibration Spectrum of the
Three Alpha Triangular Spinning Top

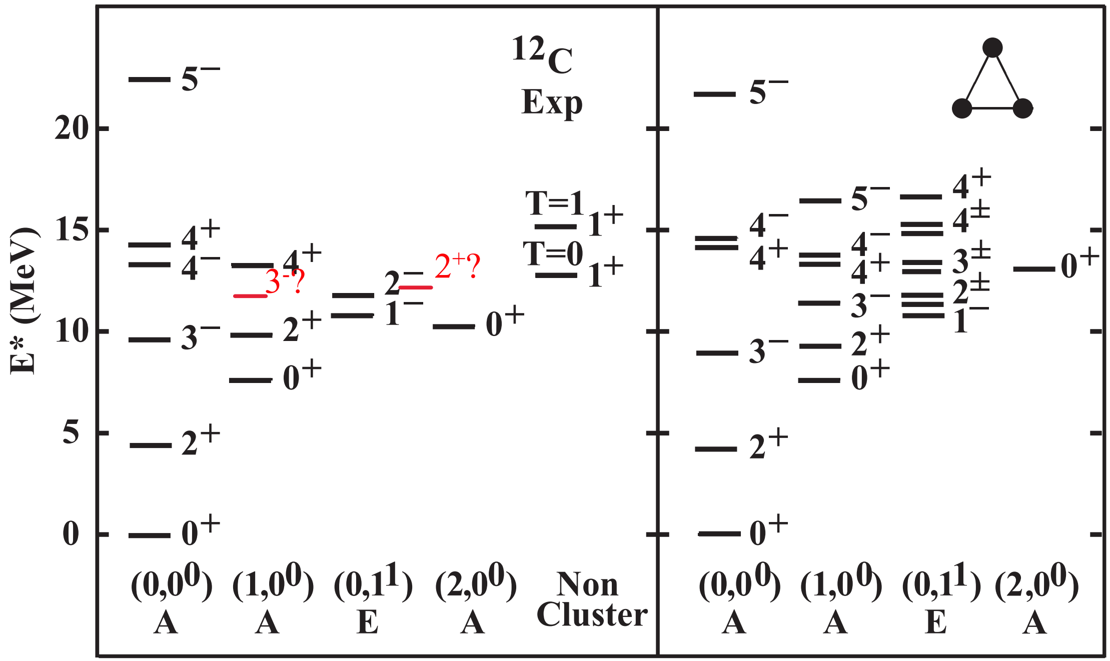
U(7) Model/ $\mathcal{D}_{3h}$ Symmetry

R. Bijker and F. Iachello; Ann. Phys. **298**(2002)334



D.J. Marin-Lambarri, R. Bijker, M. Freer, M. Gai, Tz. Kokalova, D.J. Parker, C. Wheldon, Phys. Rev. Lett. 113, 012502 (2014)





M. Freer *et al.* PHYSICAL REVIEW C **76**, 034320 (2007)

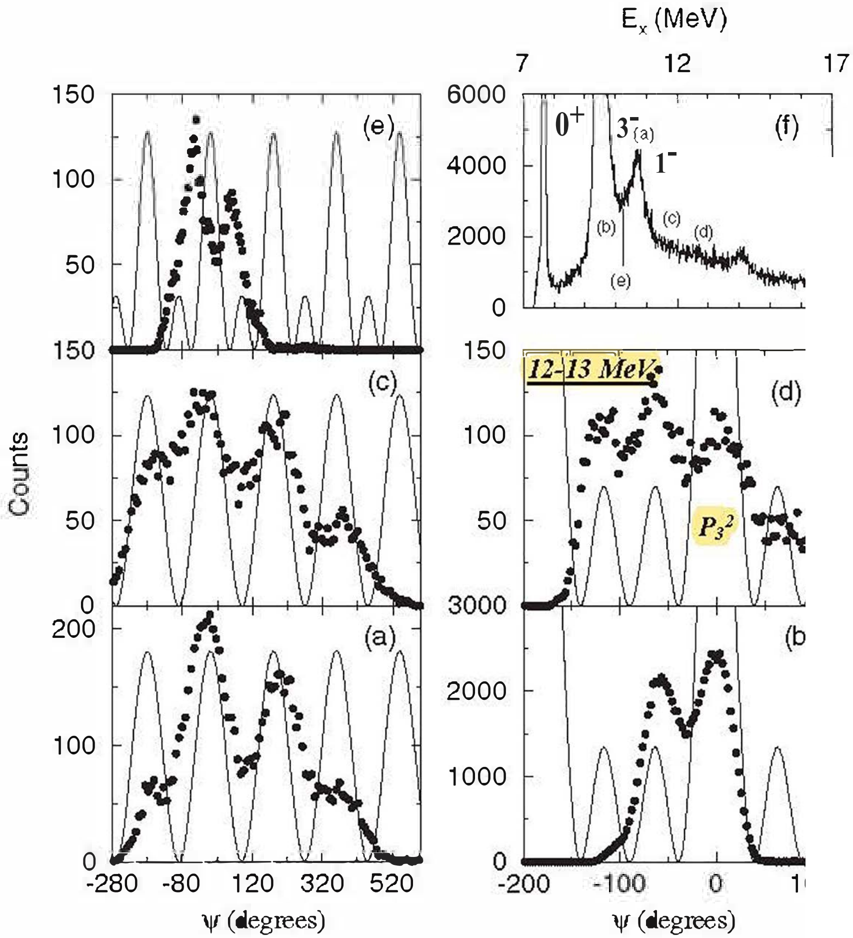
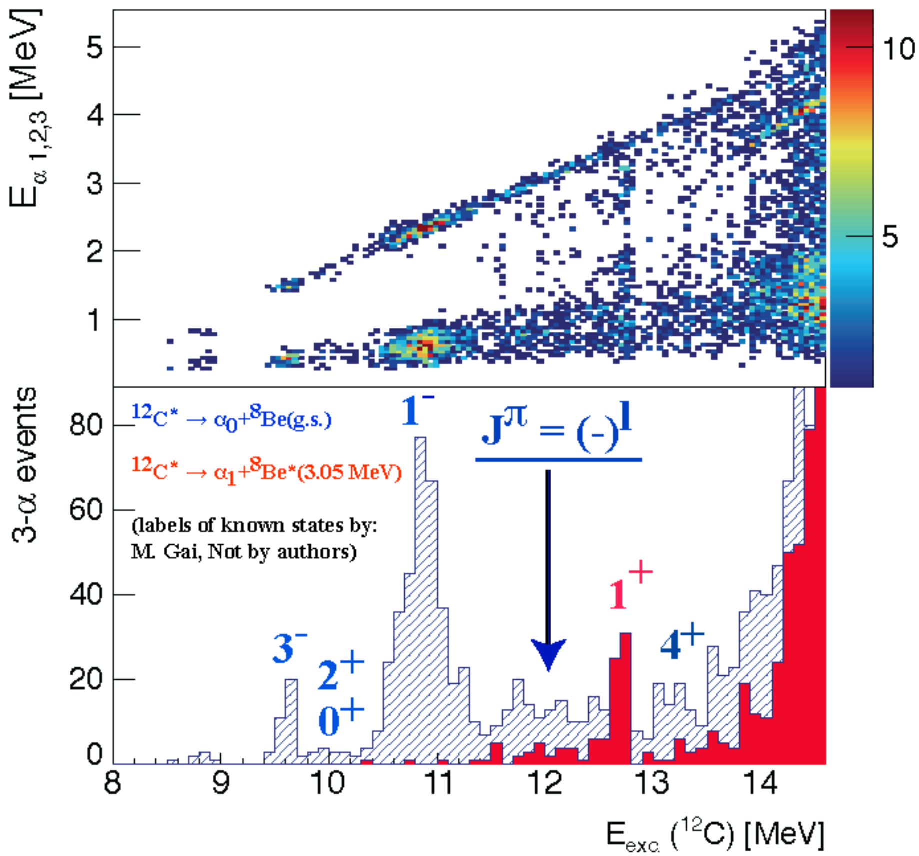
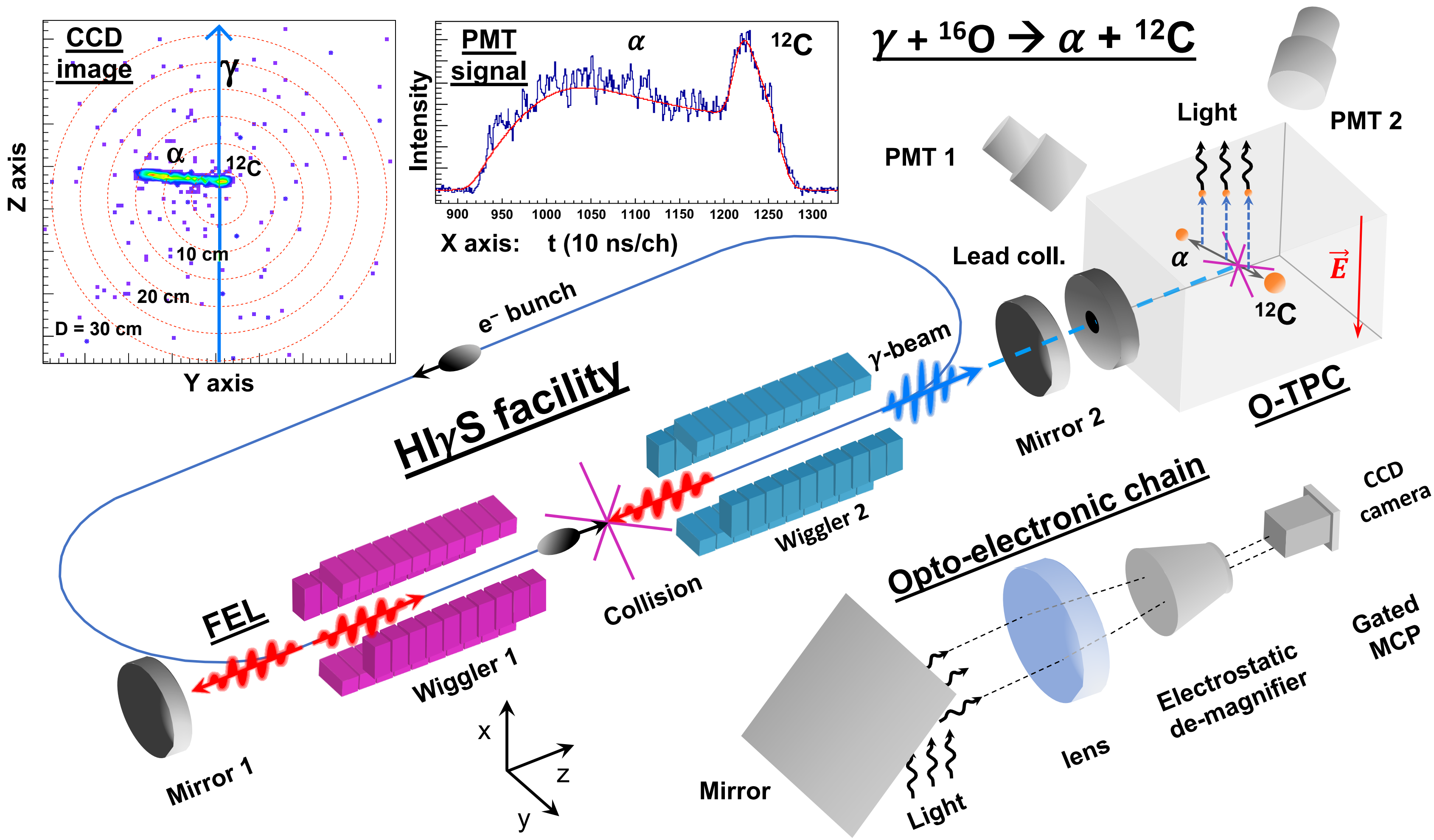


FIG. 5. Angular distributions (circles), panels (a) to (e), portions of the ^{12}C excitation energy spectrum shown in panel (f). ' periodicity of the angular distributions are compared with Leger polynomials (solid lines). (a) 1^- state at 10.84 MeV compared \ a $|P_1(\cos\psi)|^2$ polynomial, (b) data for the 3^-, 9.64 MeV, state a $|P_3(\cos\psi)|^2$ distribution, (c) and (d) E_x energy intervals 11 12 MeV and 12–13 MeV compared with the functions $|P_1(\cos\psi)|^2$ and $|P_3(\cos\psi)|^2$, respectively. (e) Excitation energy interval between the 9.64 and 10.84 MeV peaks. The data were projected onto the ψ axis at an angle that would correspond to a spin 2 state. The function shown is a corresponding $|P_2(\cos\psi)|^2$ Legendre polynomial.

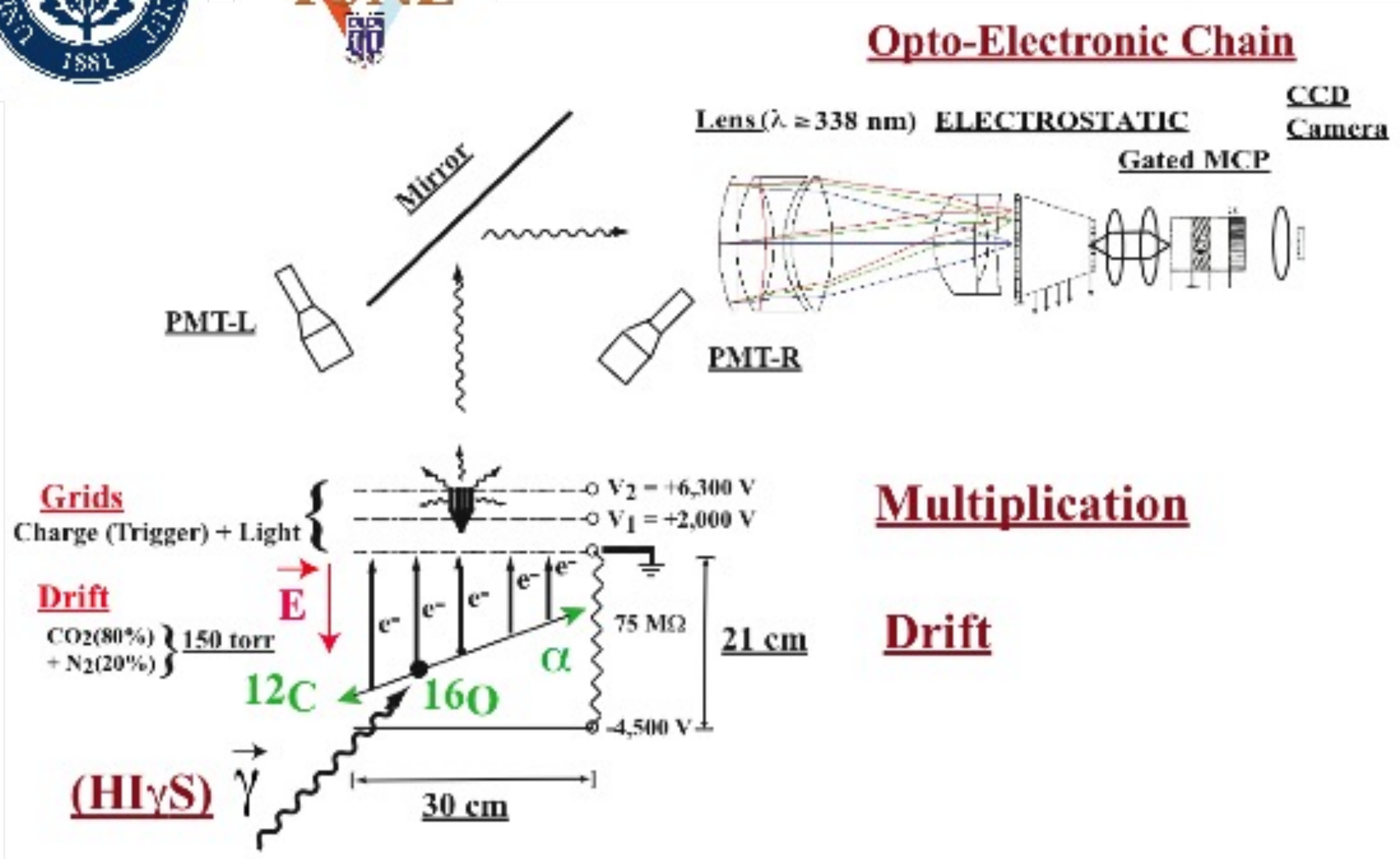
K. L. Laursen, H. O. U. Fynbo1, O. S. Kirsebom, K. S. Madsbøll, and K. Riisager Eur. Phys. J. A 52(2016)370.

^{11}B + p: ^{12}C*(16.11 MeV: 2^+, T=1), allowed E1/M1 and E2 - decays to T=0 (3α states)





R. Smith, M. Gai, D.K. Schweitzer, S.R. Stern and M.W. Ahmed, Nature Communications, 12, 5920 (2021). https://www.nature.com/articles/s41467-021-26179-x



M. Gai *et al.* JINST 5, 12004 (2010)12004
UConn-TUNL-Weizmann-PTB-UCL

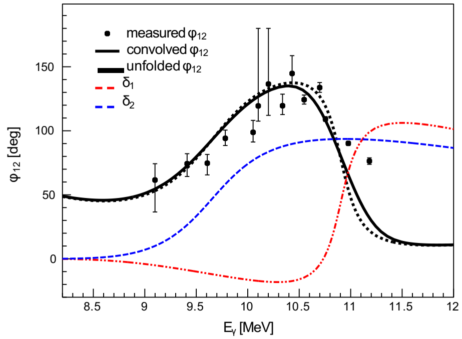
O-TPC at HIγS at TUNL/ Duke

Warsaw eTPC/ 1,000 GET channels

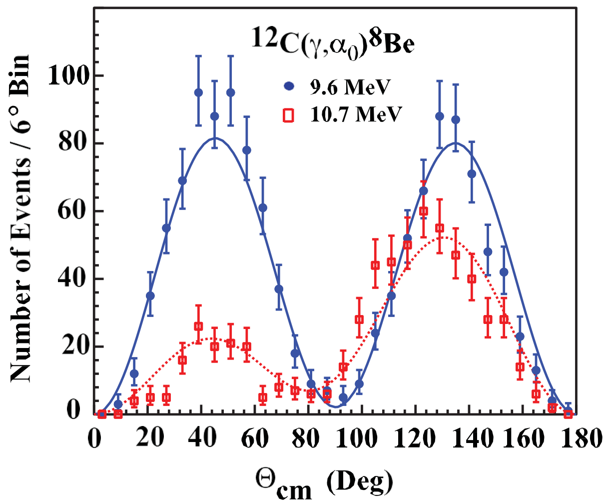
W.R. Zimmerman *et al.*; Phys. Rev. Lett. 110(2013)152502

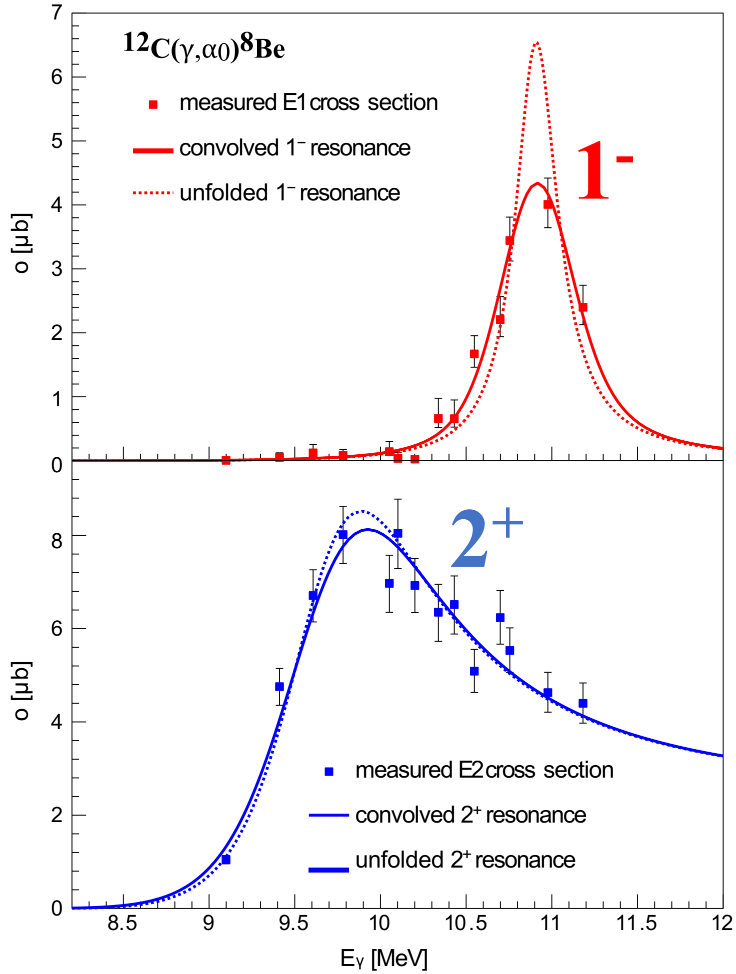
UConn-HIγS O-TPC

$$\varphi_{12} = \delta_2 - \delta_1 + \arctan(\eta/2)$$



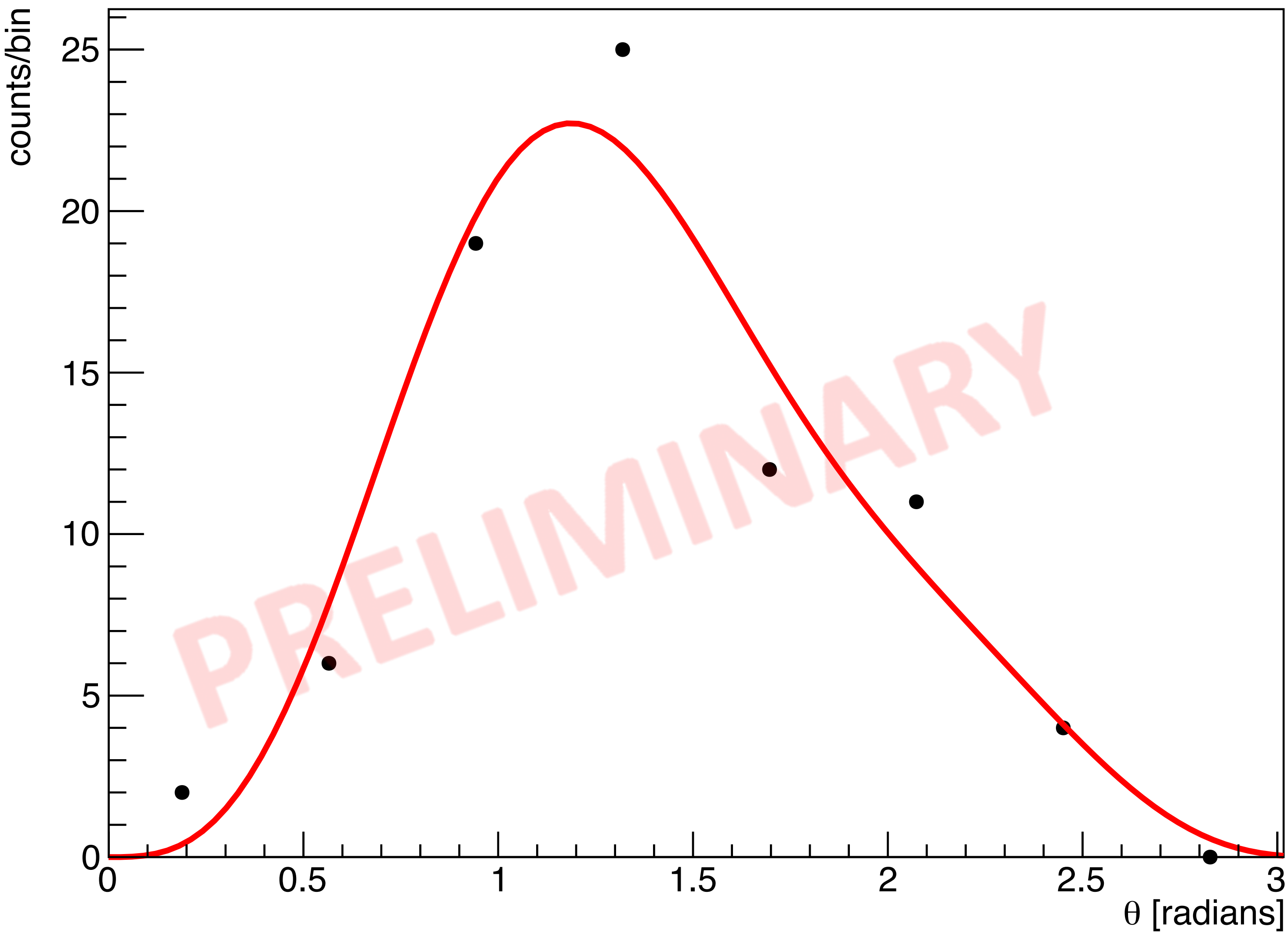
	9.6 MeV	10.7 MeV
E2/(E1+E2)	= 0.97 ± 0.02	0.71 ± 0.05
φ_{12}	= 80 ± 6°	132 ± 5°





$^{12}C(\gamma,\alpha_0)^8Be(g.s.)$ E1 + E2

E_γ = 13.1 [MeV]



V. Della Rocca, R. Bijker, F. Iachell0, Nucl. Phys. A 966(2017)156
V. Della Rocca, F. Iachello, Nucl. Phys. A 973(2018)1

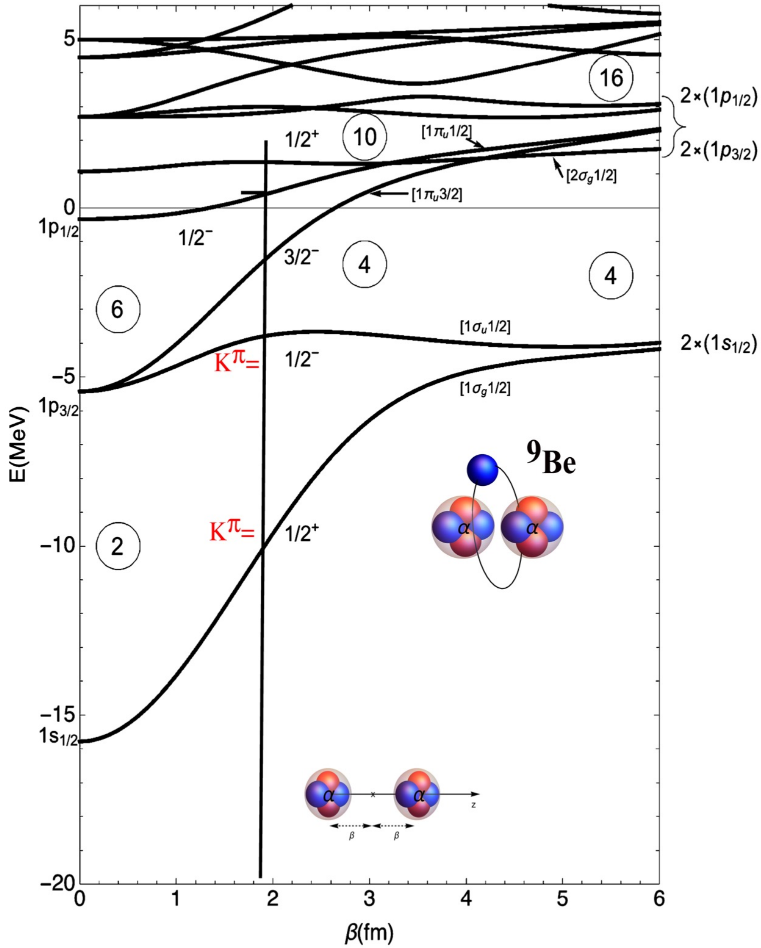
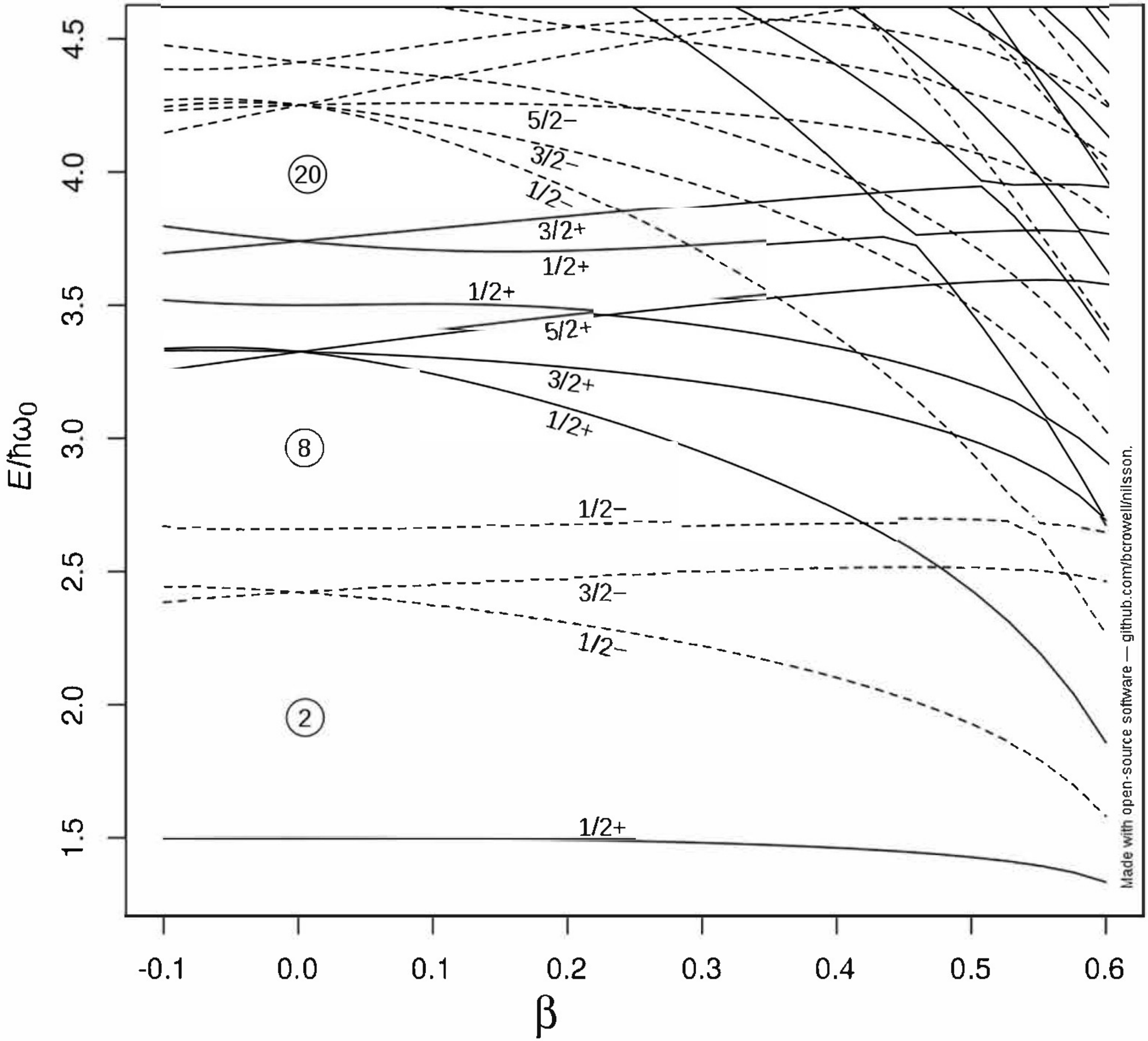


Fig. 5. Energy levels ϵ_Ω in a potential with $V_0 = 20$ MeV, $V_{so} = 22$ MeVfm^2 and $\alpha = 0.1115$ fm^{-2}, appropriate to ^{9}Be.

Table 5
Intrinsic energies in ^{9}Be at $\beta = 1.82$ fm.

State Ω K ^{P}	ϵ_Ω (MeV)
$3/2^-$	-1.78
$1/2^-$	$+0.32$
$1/2^+$	$+1.35$

The Nilsson Model



VOLUME 49, NUMBER 20 PHYSICAL REVIEW LETTERS 15 NOVEMBER 1982

Radiative Width of Molecular-Cluster States

Yoram Alhassid and Moshe Gai
A. W. Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut 06511

and

George F. Bertsch
Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48823

(Received 5 August 1982)

Molecular states are characterized by enhanced electromagnetic deexcitations of many different multipolarities. The expected enhancement of $E1$, $E2$, and $E3$ transitions is examined by deriving molecular sum rules for radiative deexcitation widths and via a dimensionality approach. The enhancement of the $E1$ transitions is the most striking.

PACS numbers: 21.60.Gx, 23.20.Ck, 25.40.Lw

"Molecular shape, when expanded in spherical harmonics, require substantial higher order terms": (Enhanced E1, E2, E3, E4...)

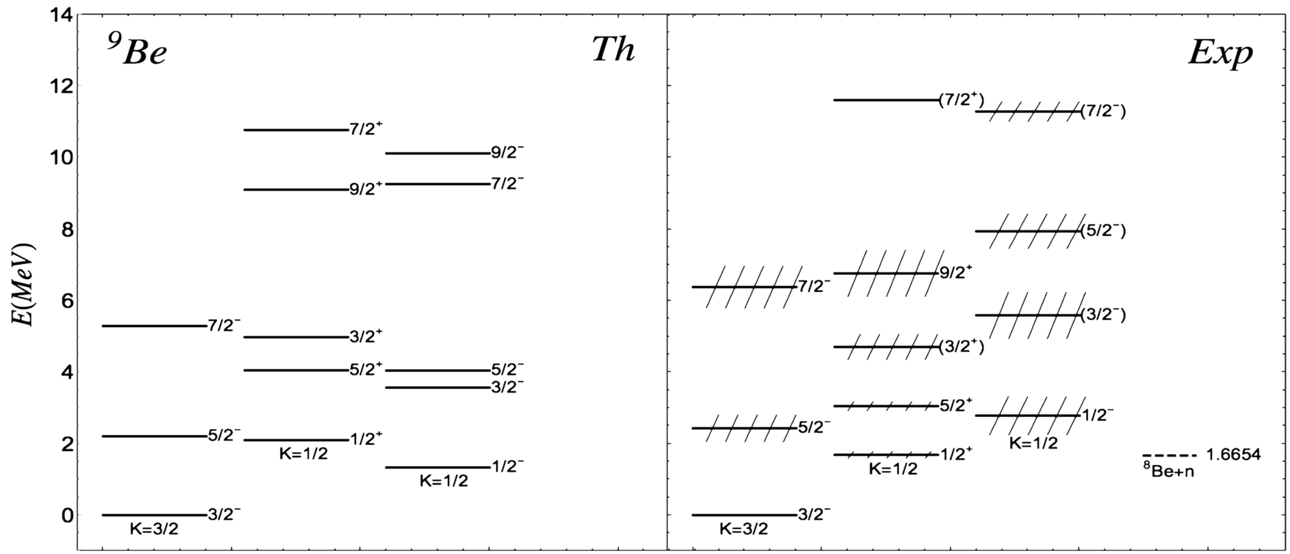


Fig. 7. Comparison between the cluster spectrum in CSM and the experimental spectrum of ^{9}Be [50]. The dashed region is given by the width of the states.

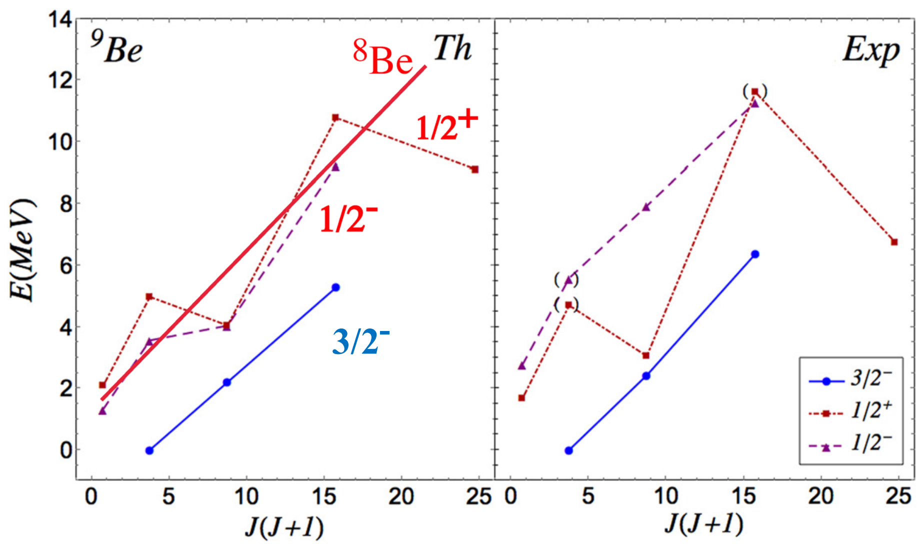
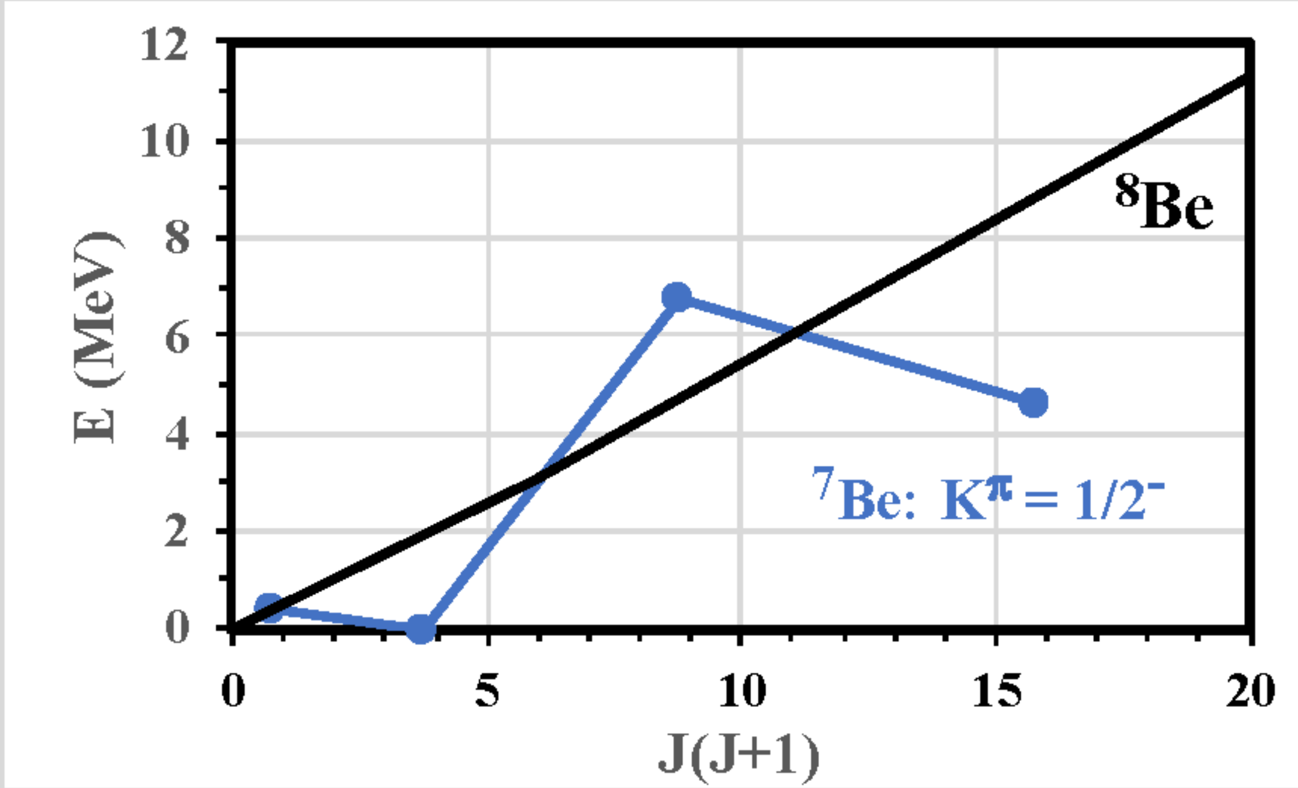


Fig. 8. Observed rotational bands in ^{9}Be.

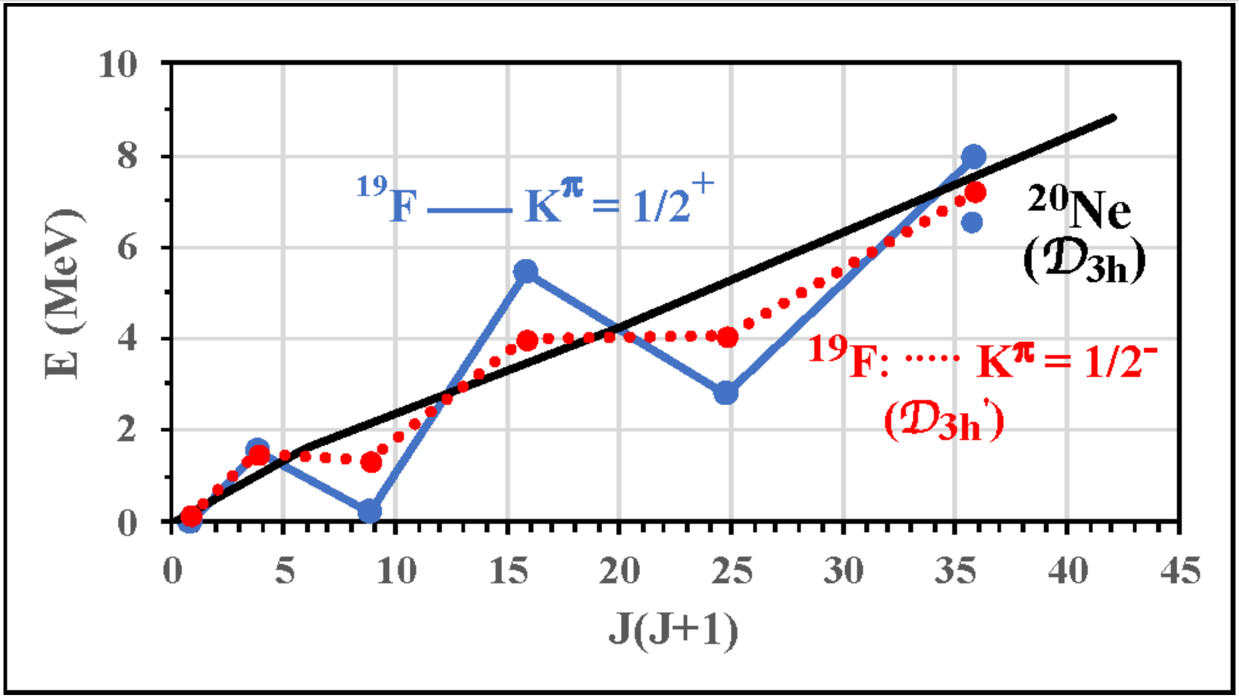


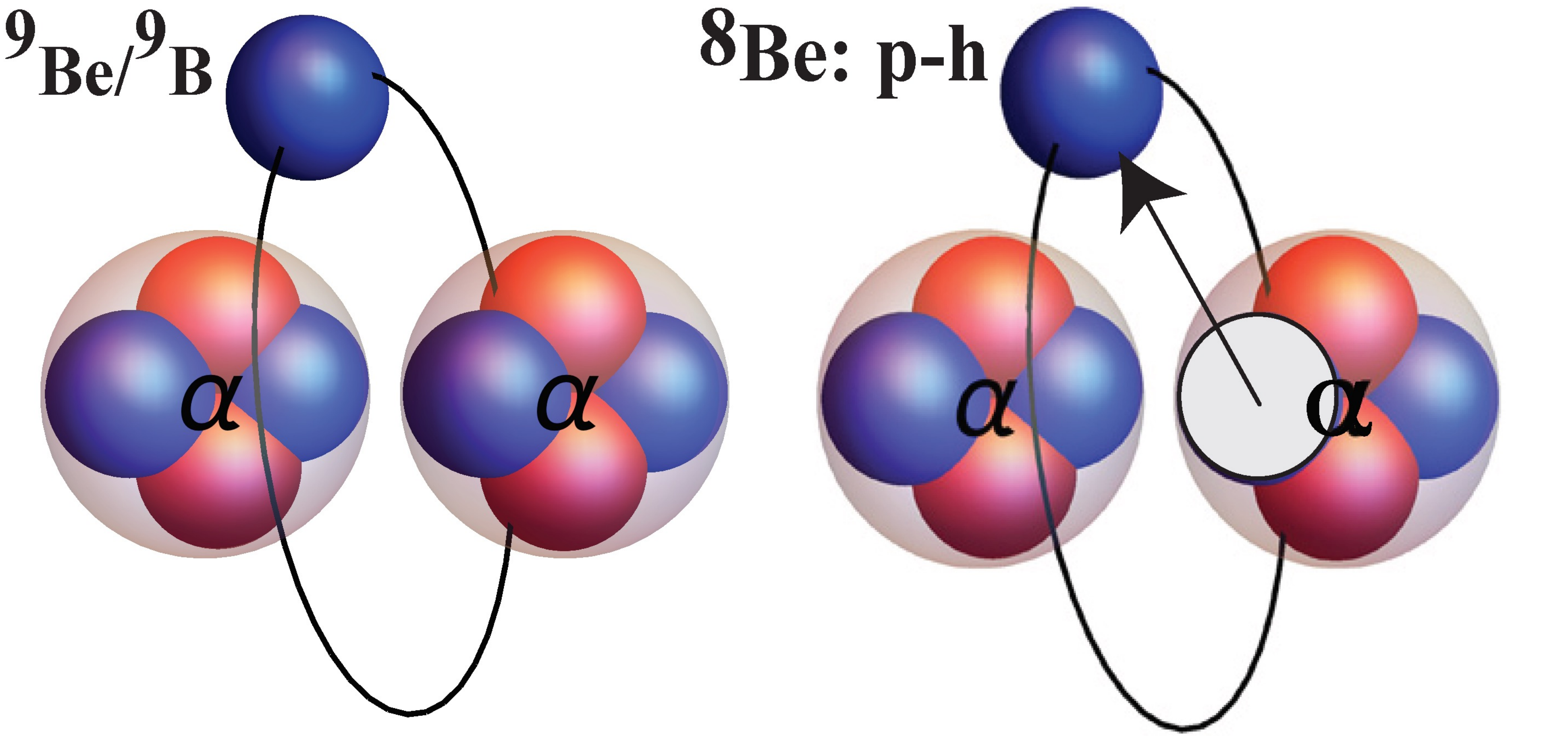
S.P. Pandya,
Phys. Rev. 103, 956 (1956)

Relationship between:
P-P and P-H m.e.
Valid in jj coupling scheme
^{38}Cl (Z=17) and ^{40}K (Z=19)

P-h Symmetry in CSM??

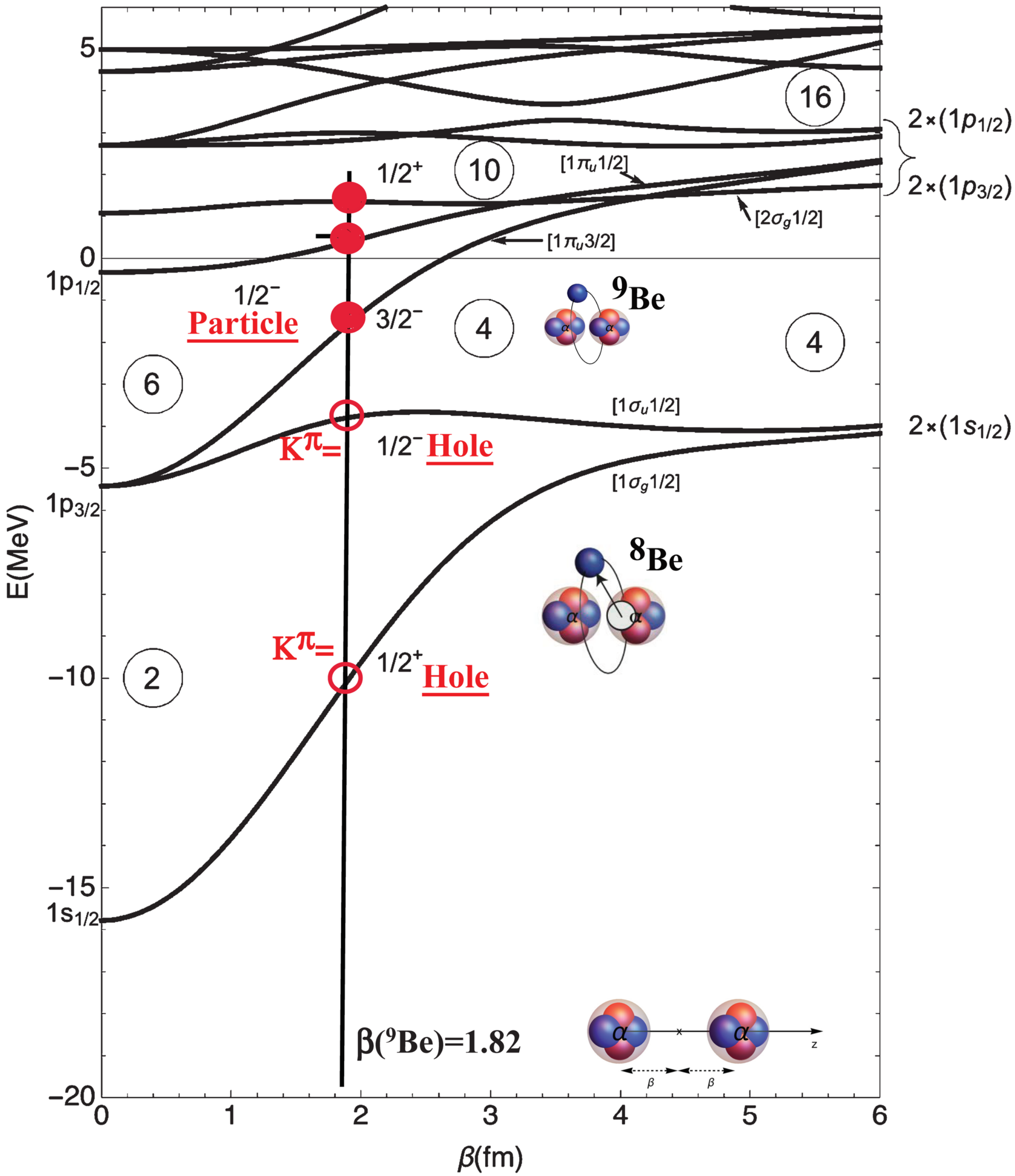
^{7}Be - ^{9}Be
^{19}F – ^{21}Na ($\mathcal{D}_{3h}$')

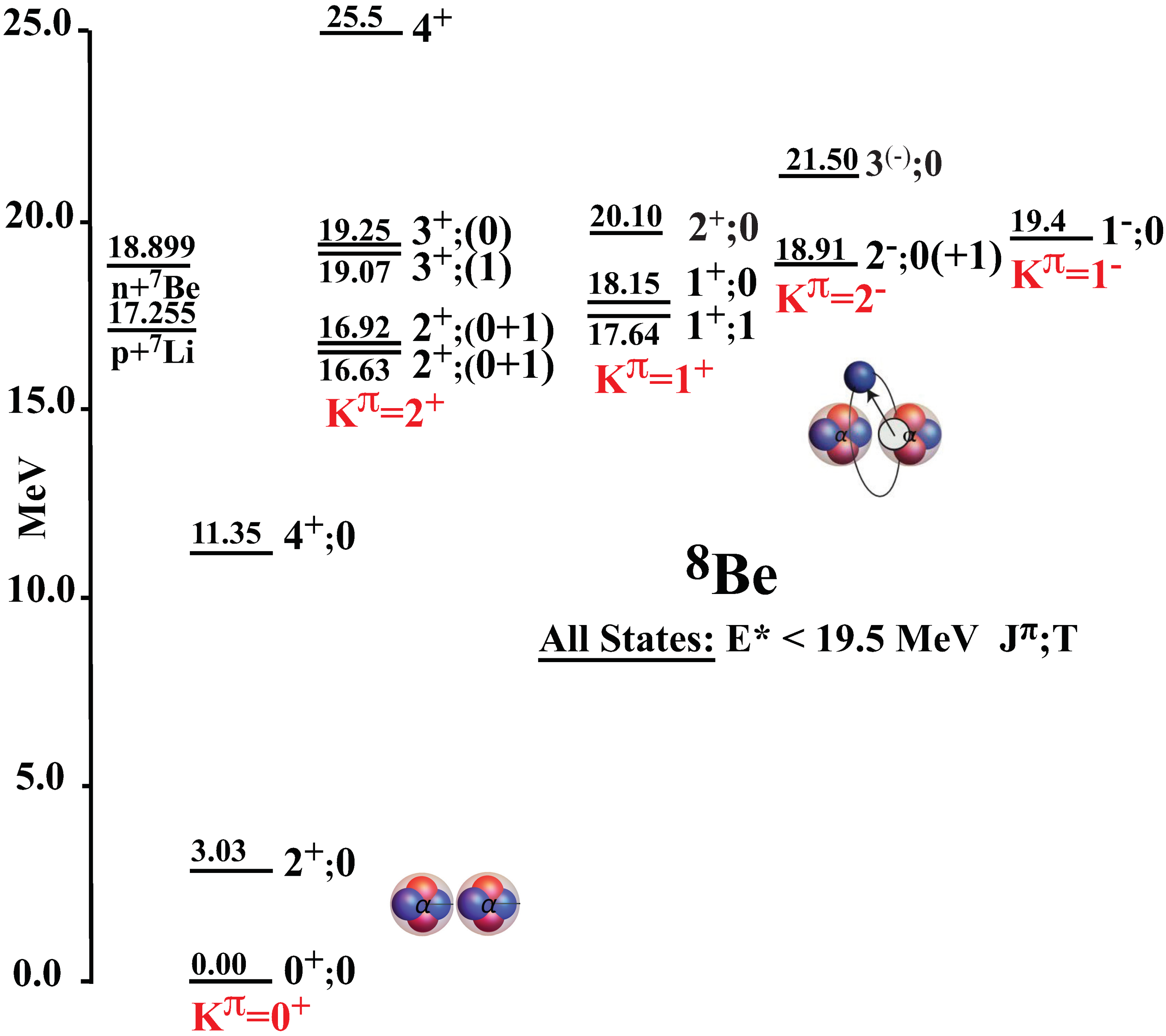




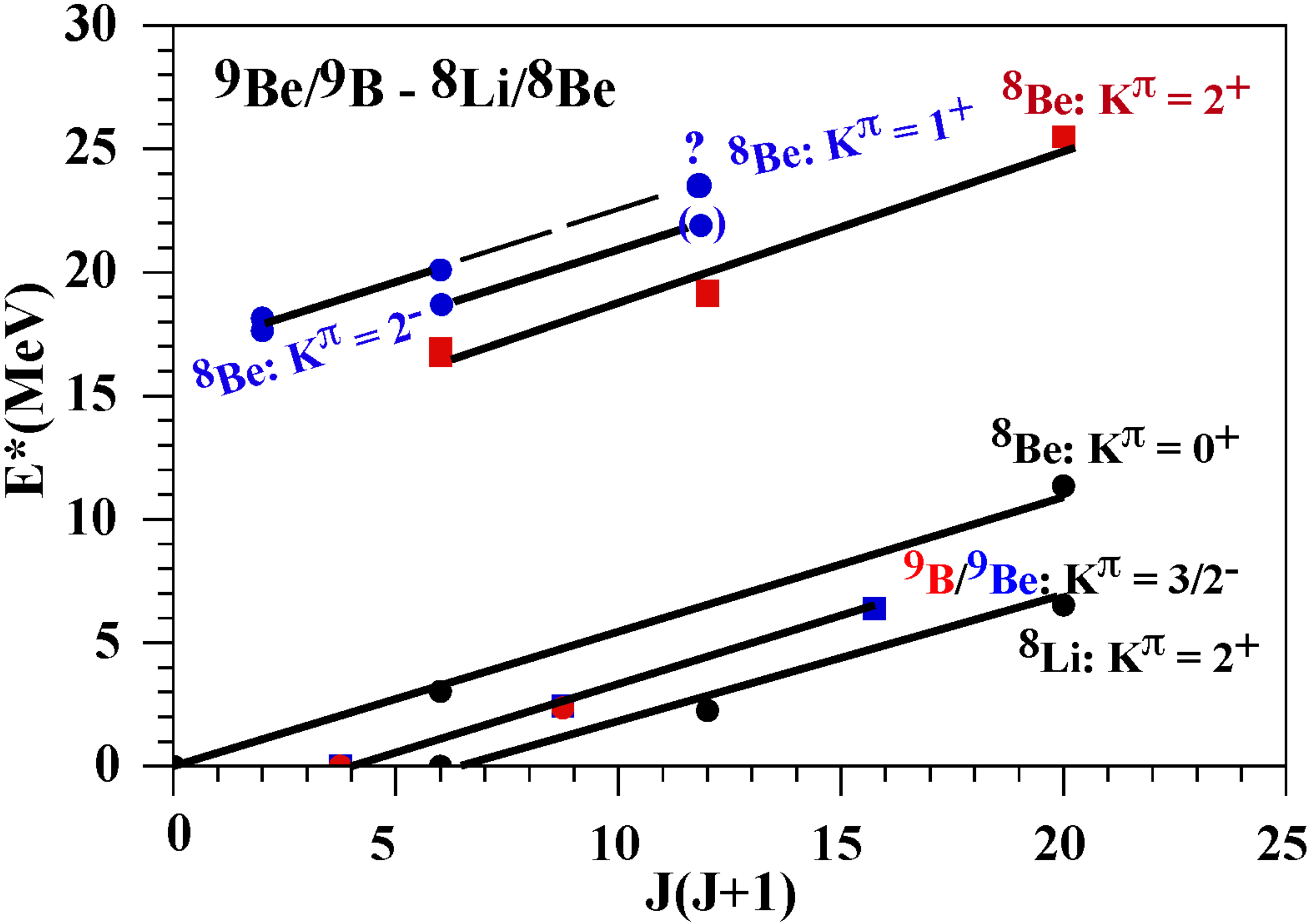
^{9}Be/^{9}B
α
α
^{8}Be: p-h
α
α

(The Cluster Shell Model)



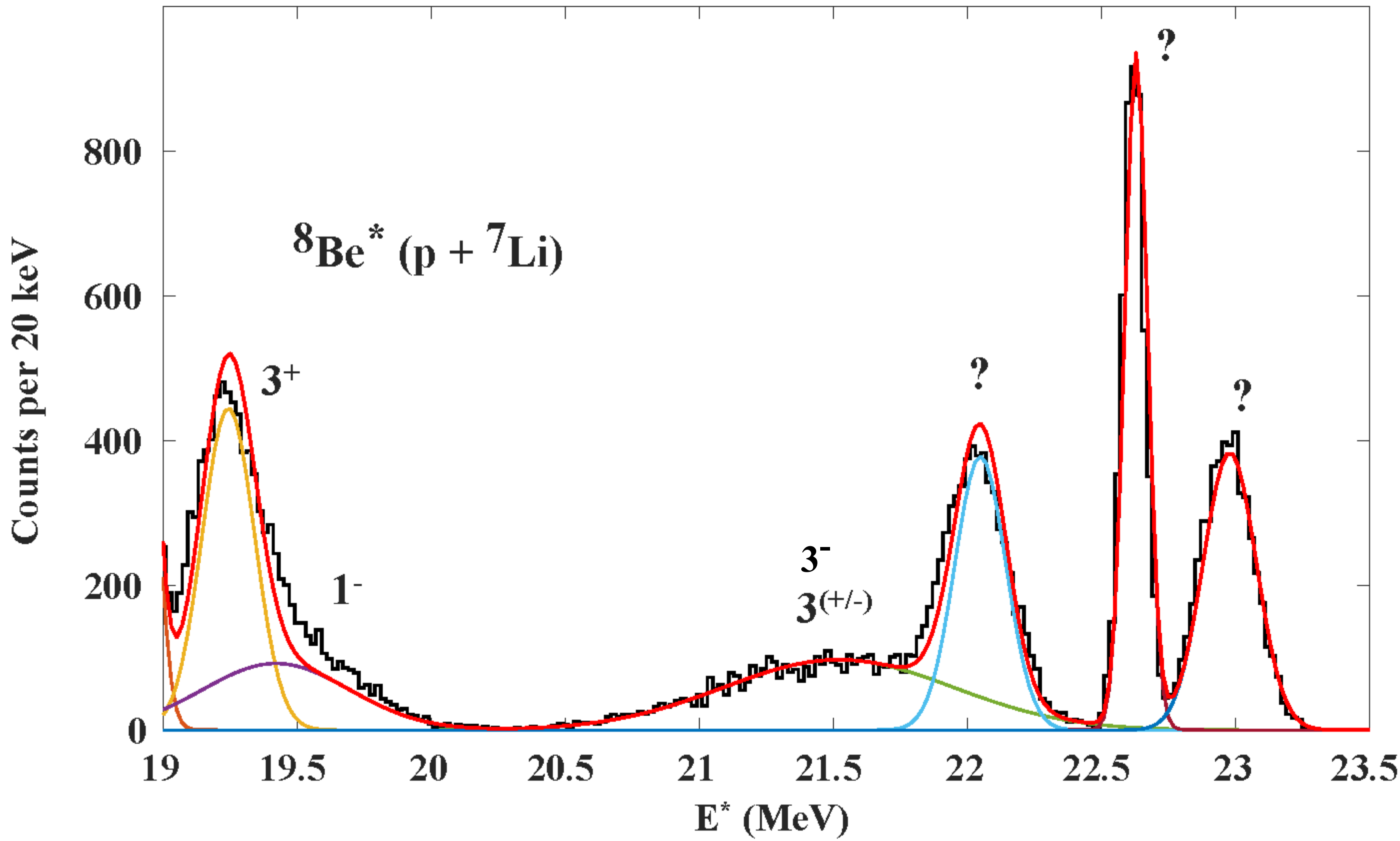


25.0
20.0
15.0
10.0
5.0
0.0
MeV
18.899
n+7Be
17.255
p+7Li
0.00 0+;0
Kπ=0+
3.03 2+;0
11.35 4+;0
25.5 4+
19.25 3+;(0)
19.07 3+;(1)
16.92 2+;(0+1)
16.63 2+;(0+1)
Kπ=2+
20.10 2+;0
18.15 1+;0
17.64 1+;1
Kπ=1+
21.50 3(-);0
18.91 2-;0(+1)
Kπ=2-
19.4 1-;0
Kπ=1-
α
8Be
All States: E* < 19.5 MeV Jπ;T



Philip R. Page, R-Matrix Analysis: ^{8}Be*(21.5 MeV) is a 3^-
Phys. Rev. C 72, 054312 (2005).

Robin Smith, Liam Gafney, September 21, 2020



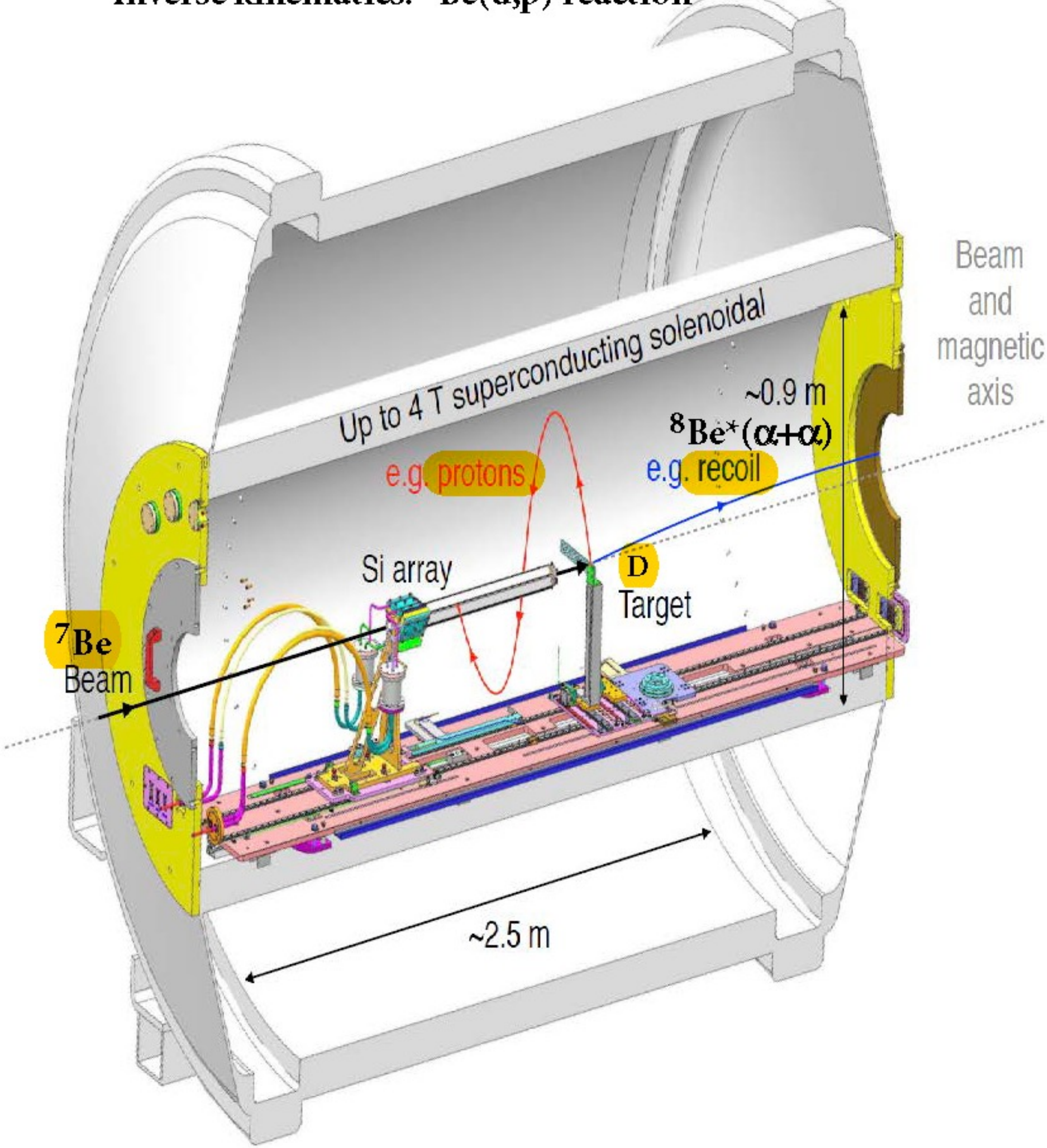
HIE-ISOLDE Approved Experiment IS692 (15 Shifts + 13 Days irradiation: ^7Be production)

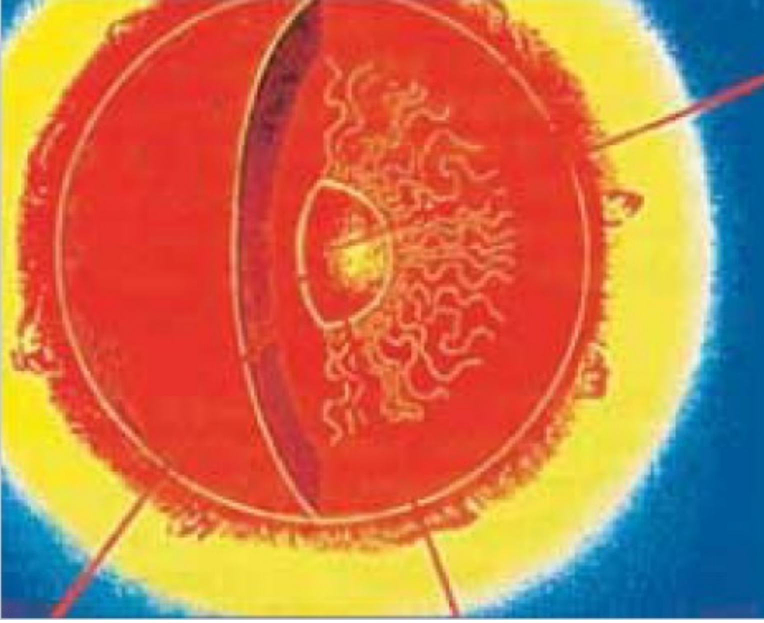
HIE-ISOLDE Experiment: IS692

ISOLDE Solenoidal Spectrometer (ISS)

ISOLDE Solenoidal Spectrometer (ISS)

Inverse kinematics: $^{7}Be(d,p)$ reaction





University of Connecticut
Laboratory for Nuclear Science
at Avery Point
(AKA Laboratory for Astrophysics)

Conclusions

1. **ACM New paradigm for cluster states (even-even).**
2. **CSM New paradigm for molecular orbits of s.p. (odd-mass)**

<u>Theoretical Motivations:</u>

3. **Phenomenology of hole states: ^{7}Be, ^{19}F.**
4. **Phenomenology of p-h state: ^{8}Be**