Discovery of collective states in the heavy nucleus 208Pb by complete spectroscopy

Andreas Heusler (Heidelberg, Germany)

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Description of states in 208Pb

- The nucleus 208Pb is studied since 120 years

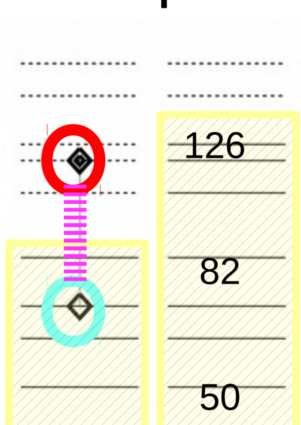
1899 energy estimate of lowest state [now 2615 keV]
1920s relative energy of next three lowest states [now 5-(1) 4-(1) 5-(2)]
1954 spin and parity of lowest state [now 3-(1)]
1965 *discovery of IAR exciting neutron 1p1h configurations*
2015 lowest 150 states below Ex=6.2 MeV (completely) identified
2019 most negative parity states below Ex=7.0 MeV identified

- Most states are 1p1h states but some definitely not

1970 (2015) neutron (proton) pairing vibration calculated and identified
2017 3- yrast state recognized as tetrahedral rotation and
nine more states identified as tetrahedral rotations and vibrations
2019 coupling of 3- yrast state to 1p1h states calculated and identified

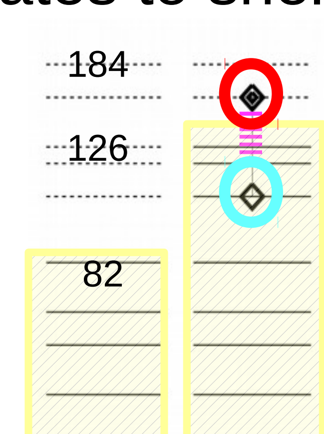
- ¿ How to find more non-1p1h states ?

- ¡ Compare structure of all states to shell model calculations !



proton
1p1h *states*

by (d,3He)



neutron
1p1h *states*

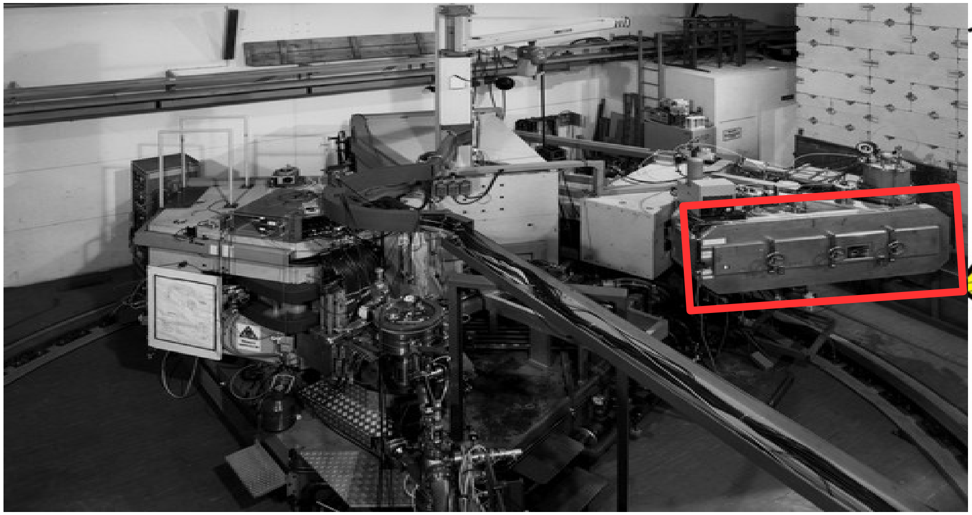
by (p,p') via IAR
and by (d,p)

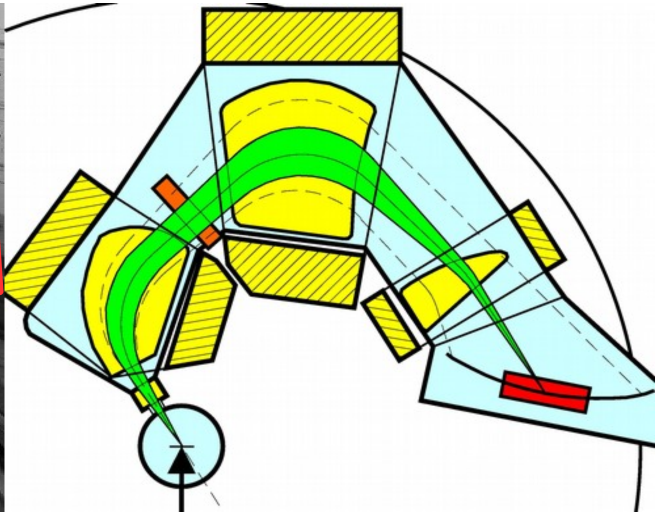
Experimental tools

13 MV van de Graaff accelerator
and
Q3D magnetic spectrograph
at the Maier-Leibnitz-Laboratory
(Garching, Germany)

2003-2019

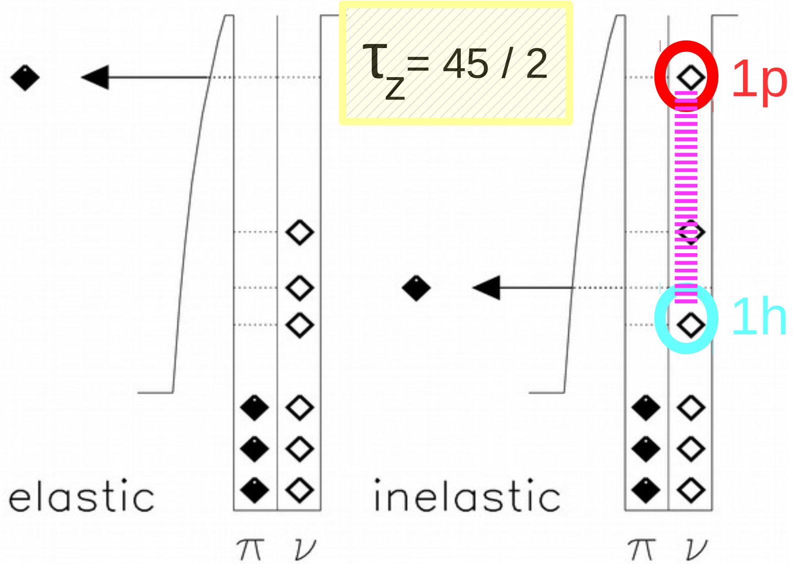
Q3D magnetic spectrograph yields 3 keV resolution





length of spectrum ~ 1 MeV

Experimental tools and theoretical reaction models



inelastic proton scattering
via Isobaric Analog Resonances
excites neutron 1p1h states

44 excess neutrons

*the **particle** is chosen by the proton energy*

*the **holes** are determined from the angular distribution*

seven neutron particle orbits in 209Pb
and
six neutron hole orbits in 207Pb
y i e l d

4 proton 1p1h configurations in 208Pb excited by
209Bi(d,3He)
209Bi(t,αγ)

7 neutron 1p p1/2 configurations in 208Pb excited by
207Pb(d,p)

42 neutron 1p1h configurations in 208Pb excited by
208Pb(p,p')
via IAR in 209Bi

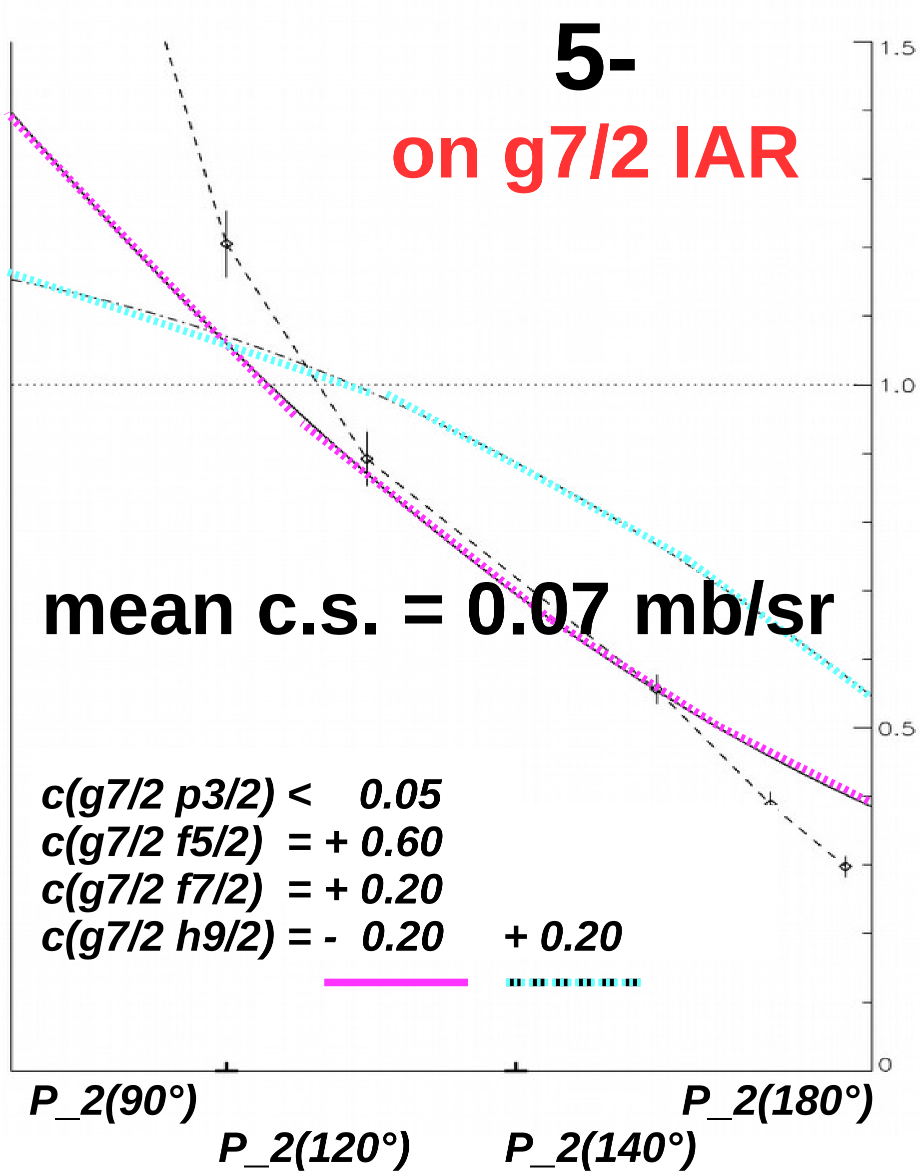
14 1p1h configurations in 208Pb unobservable

sign of amplitudes allow to investigate orthogonality, normalization, sum rules

in total distribution of 132 configurations among
nearly 200 1p1h states in 208Pb below Ex ~ 7.0 MeV determined

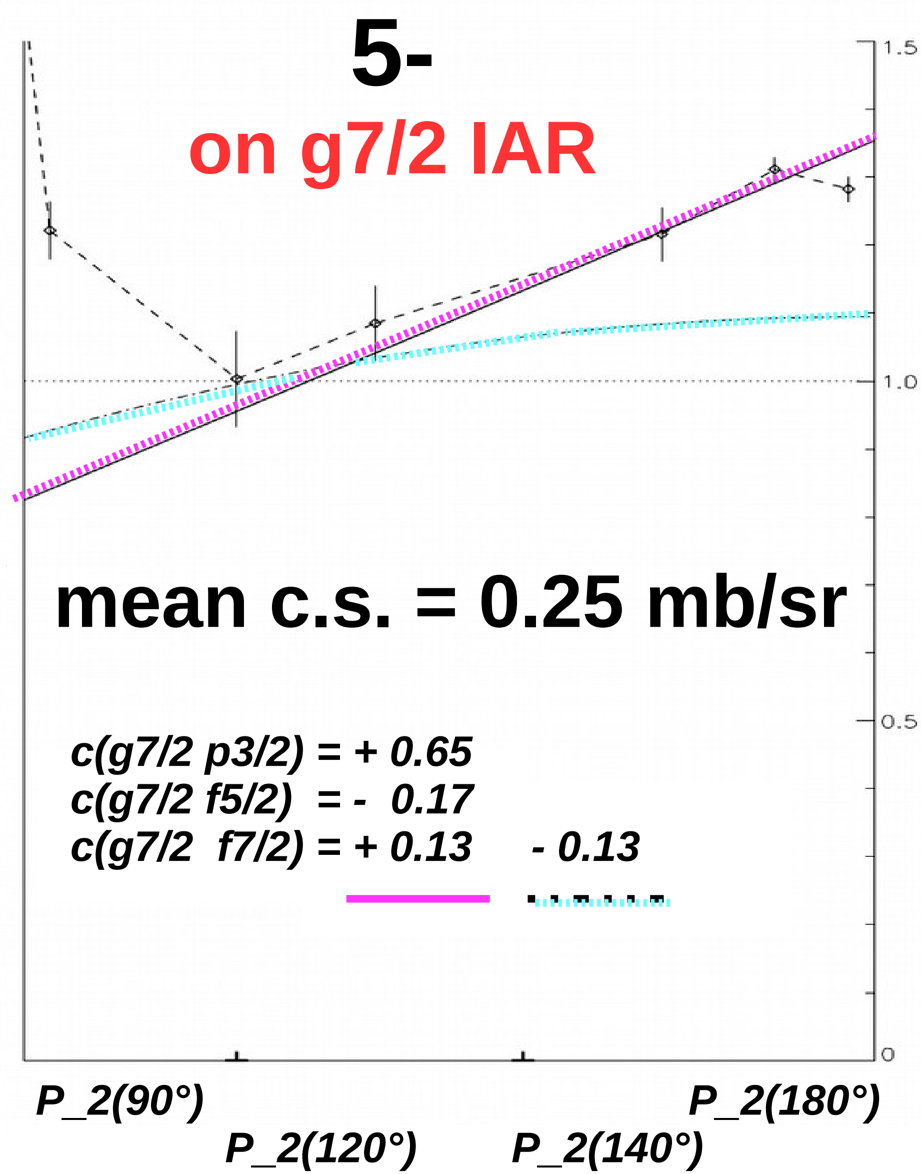
Angular distribution from 208Pb(p,p')

Ex = 6389 keV

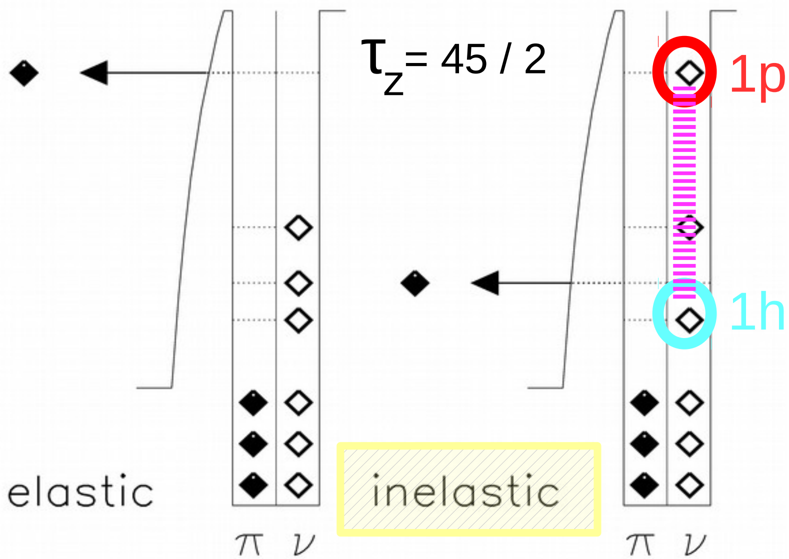


relative units

Ex = 6688 keV



Experimental tools and theoretical reaction models

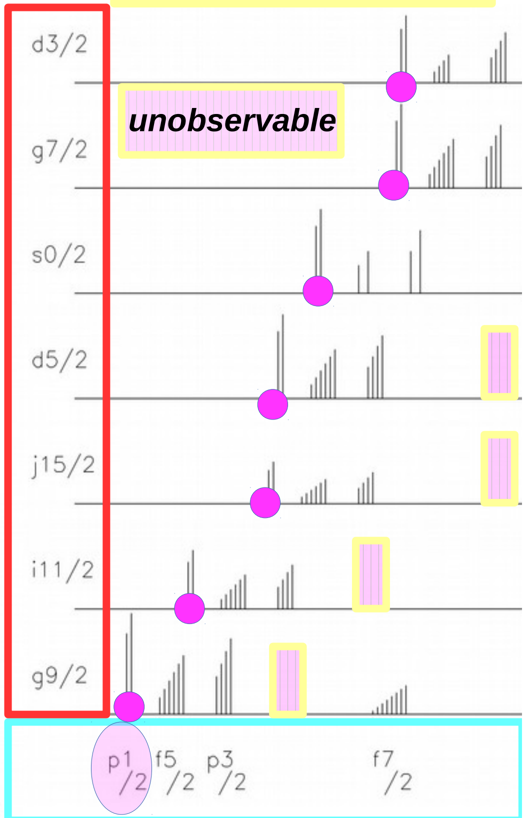


inelastic proton scattering
via Isobaric Analog Resonances
excites neutron 1p1h states

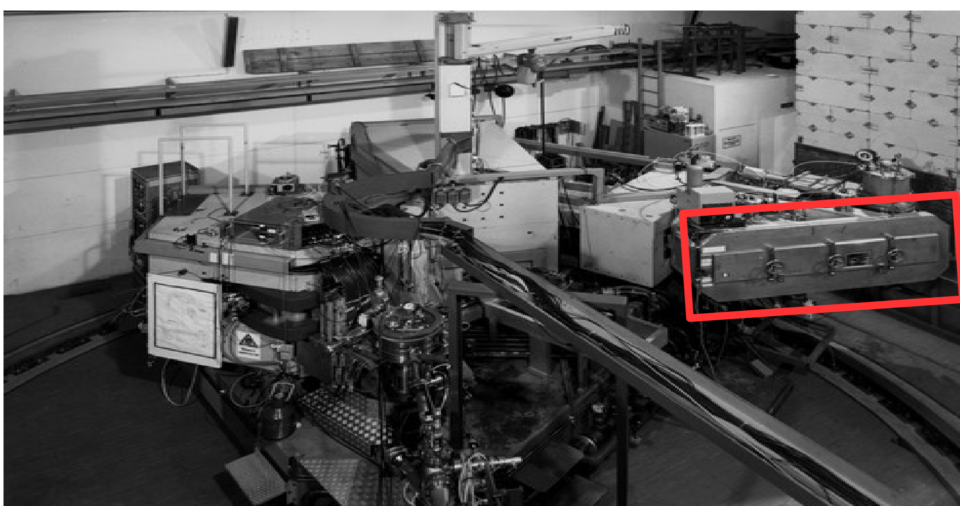
all *neutron 1p1h configuations in* ***each*** *state are excited*

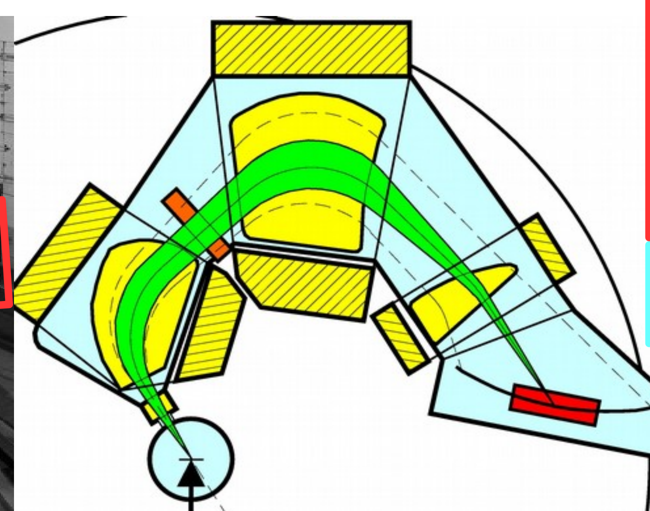
the ***particle*** *is chosen by the proton energy,*
the ***holes*** *are determined from the angular distribution*

● ***by 207Pb(d,p)***



Q3D magnetic spectrograph yields 3 keV resolution



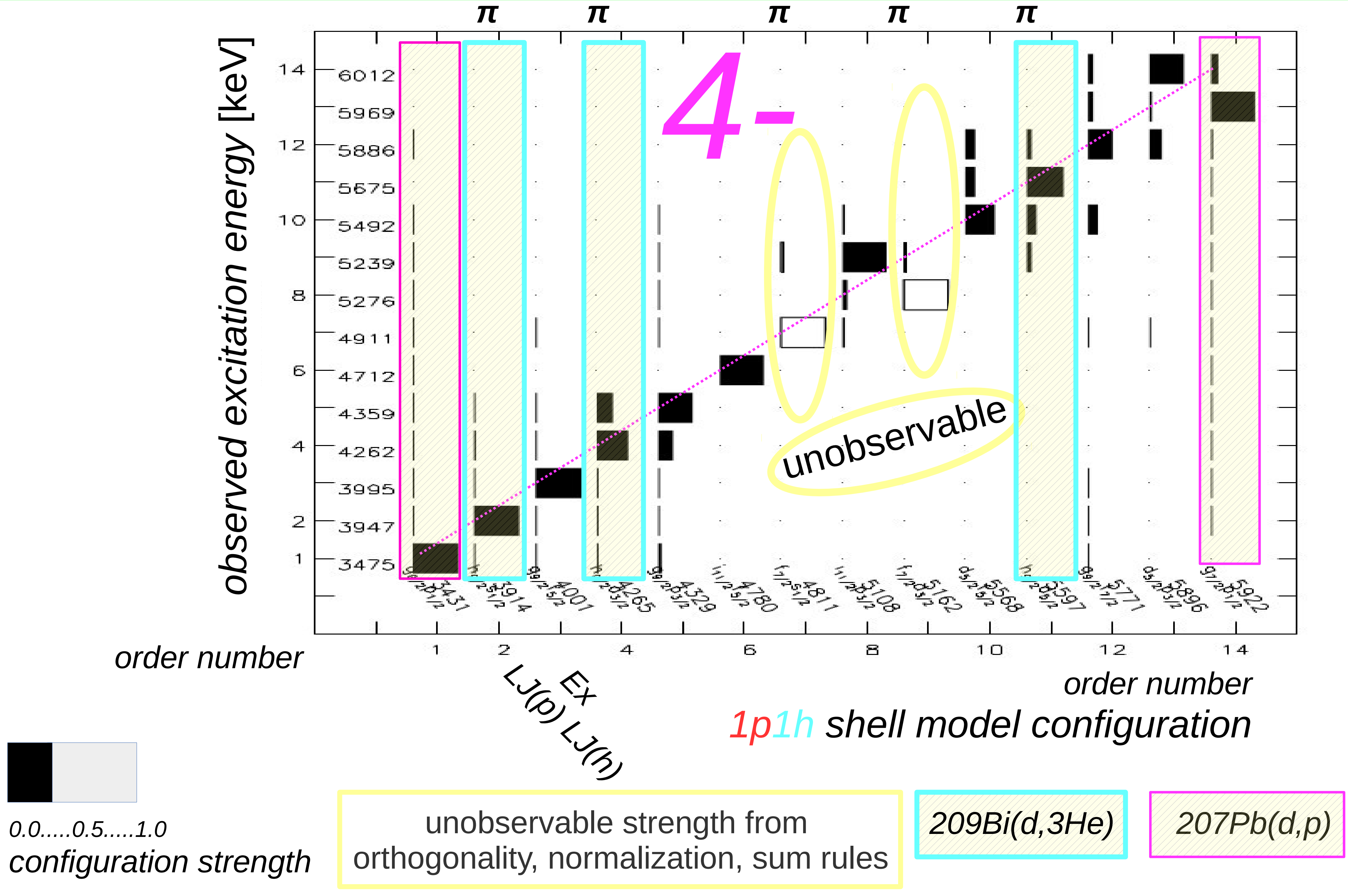


structure of
~200 1p1h states
at Ex < 7.0 MeV
determined

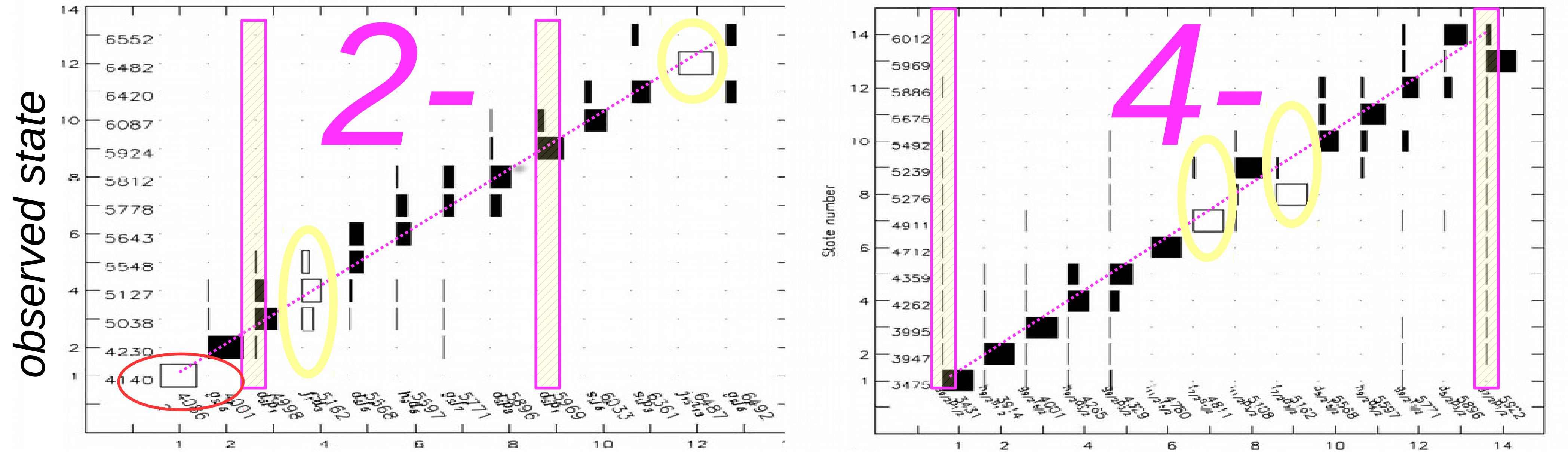
Experimental data and results

Resolution [keV]	Reaction	Period and results
1	β-decay	1899-1975: States at Ex < 4.5 MeV with spins from 3- to 6-
	208Pb(p,p')	since 1962: ***experiments using accelerators***
8	– high proton energy	1965-2018: States at Ex < 7.8 MeV
12	– via IAR in 209Bi with semiconductor detectors	1965-1969: 1p1h states with g9/2 d5/2 g7/2 d3/2 particles and p1/2 f5/2 p3/2 holes
3	– via IAR in 209Bi with Q3D	2003-2019: 1p1h states with g9/2 i11/2 j15/2 d5/2 s1/2 g7/2 d3/2 particles and p1/2 f5/2 p3/2 f7/2 holes
15	208Bi(d,3He)	1981-1985: proton 1p1h states at Ex < 5.8 MeV
	- (t,αγ)	1995
3	207Pb(d,p)	1962-2013: States at Ex < 7.8 MeV
	- (d,pγ)	1995
2	208Pb(n,n'γ)	1990-2000: States at Ex < 6.2 MeV
3	208Pb(d,d')	1971-2013: States at Ex < 7.8 MeV

Spectroscopy of negative parity states



Spectroscopy of negative parity states



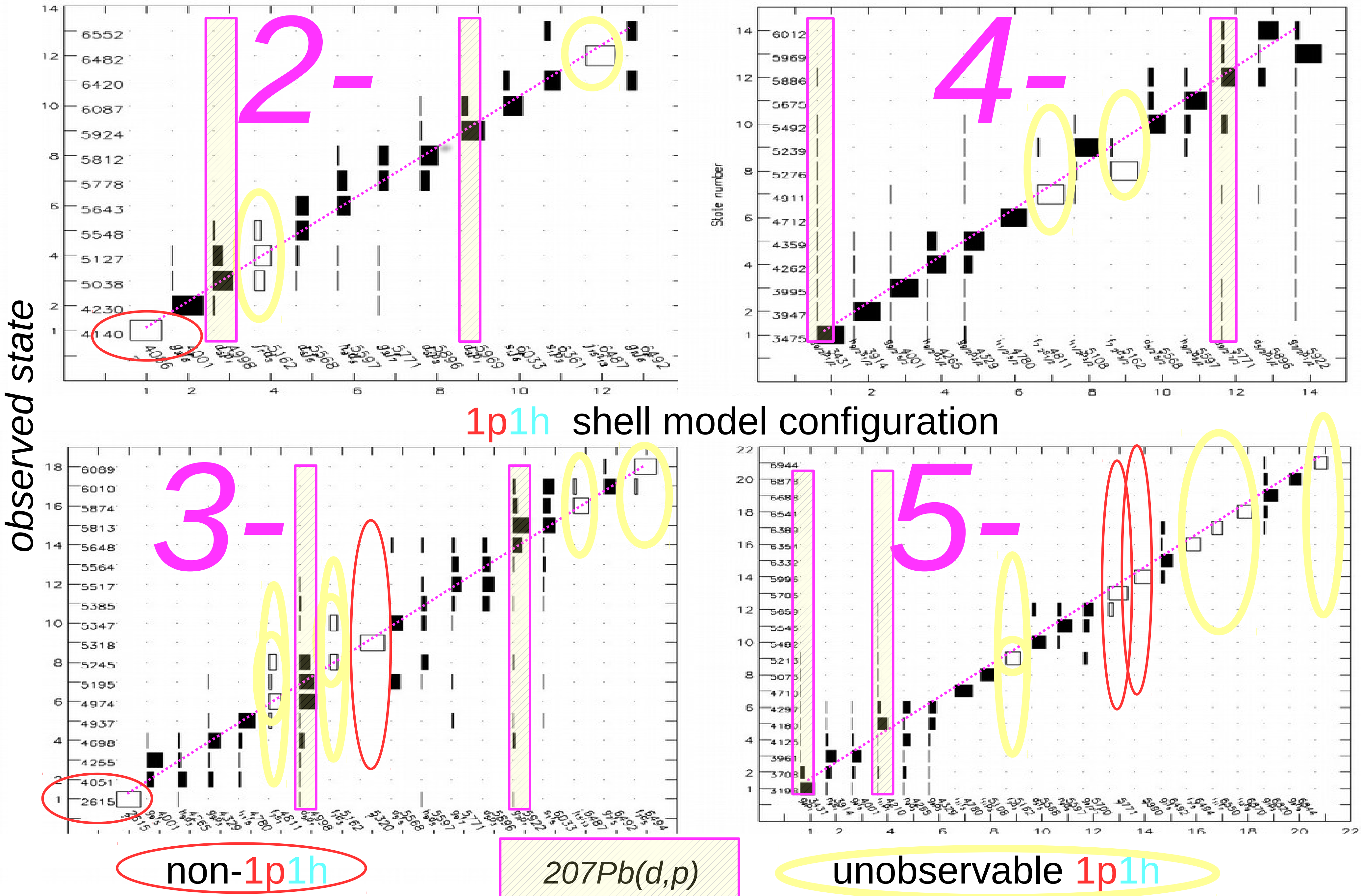
1p1h shell model configuration

non-1p1h

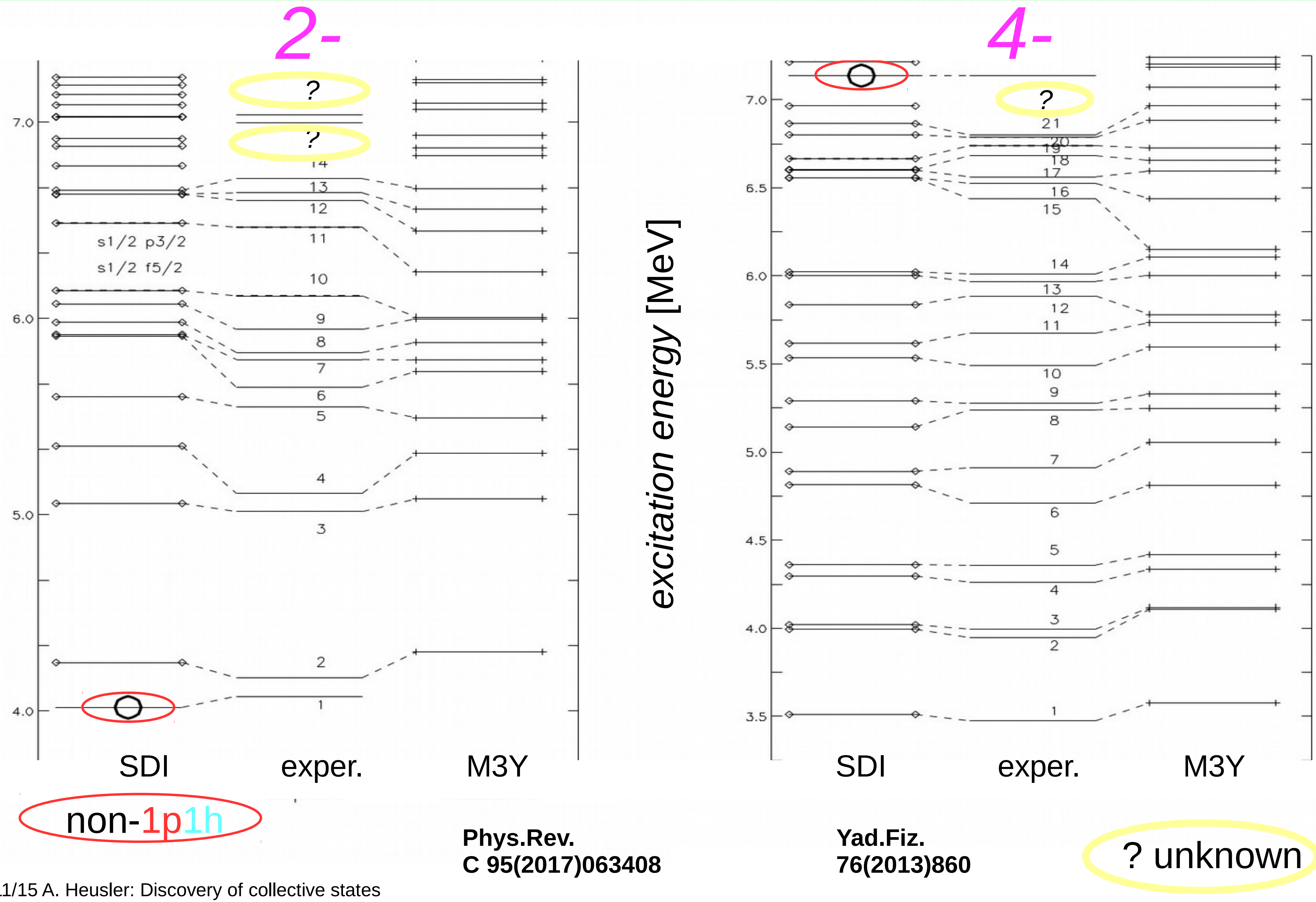
207Pb(d,p)

unobservable 1p1h

Spectroscopy of negative parity states



Comparison to shell model for *2-* and *4-*



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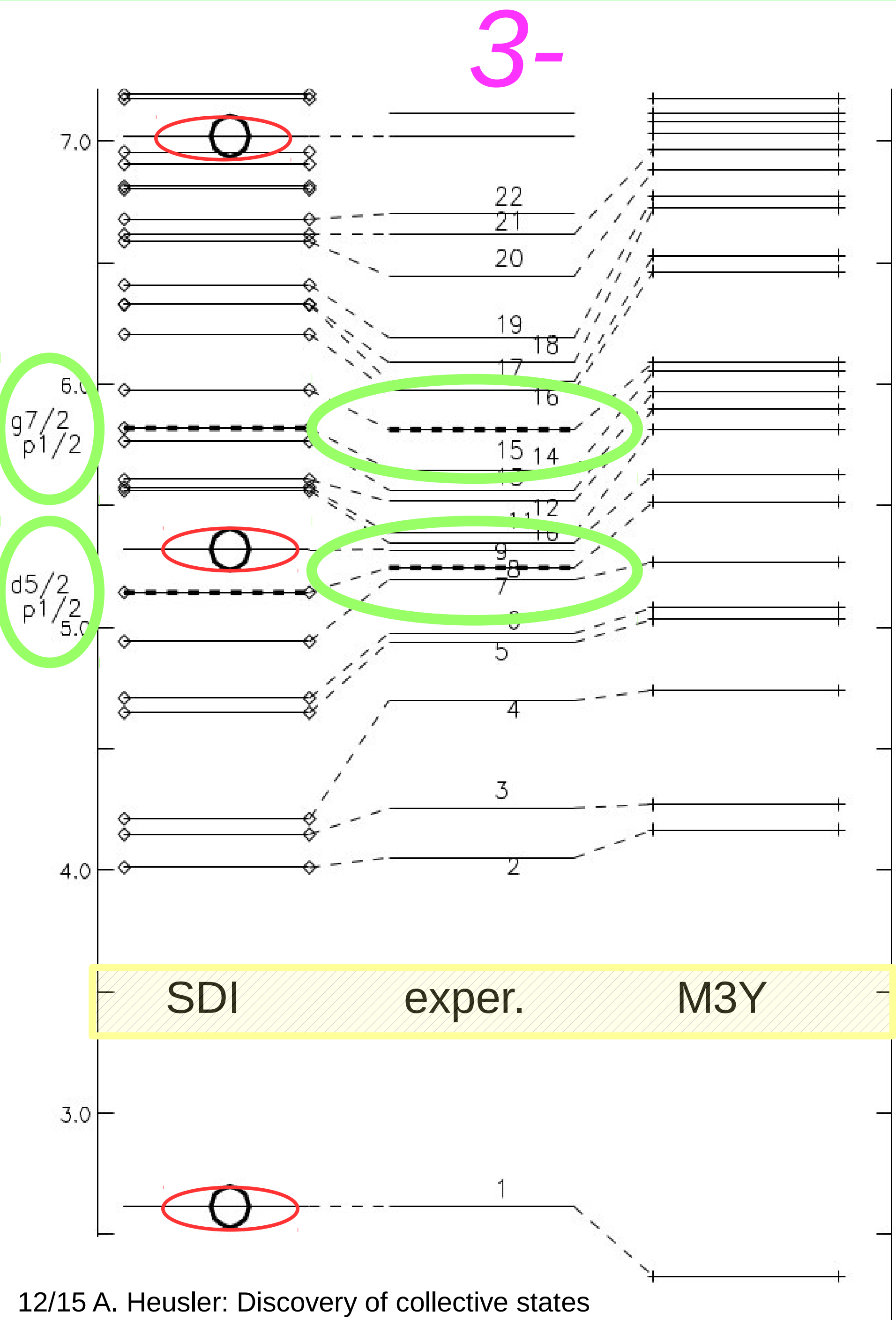
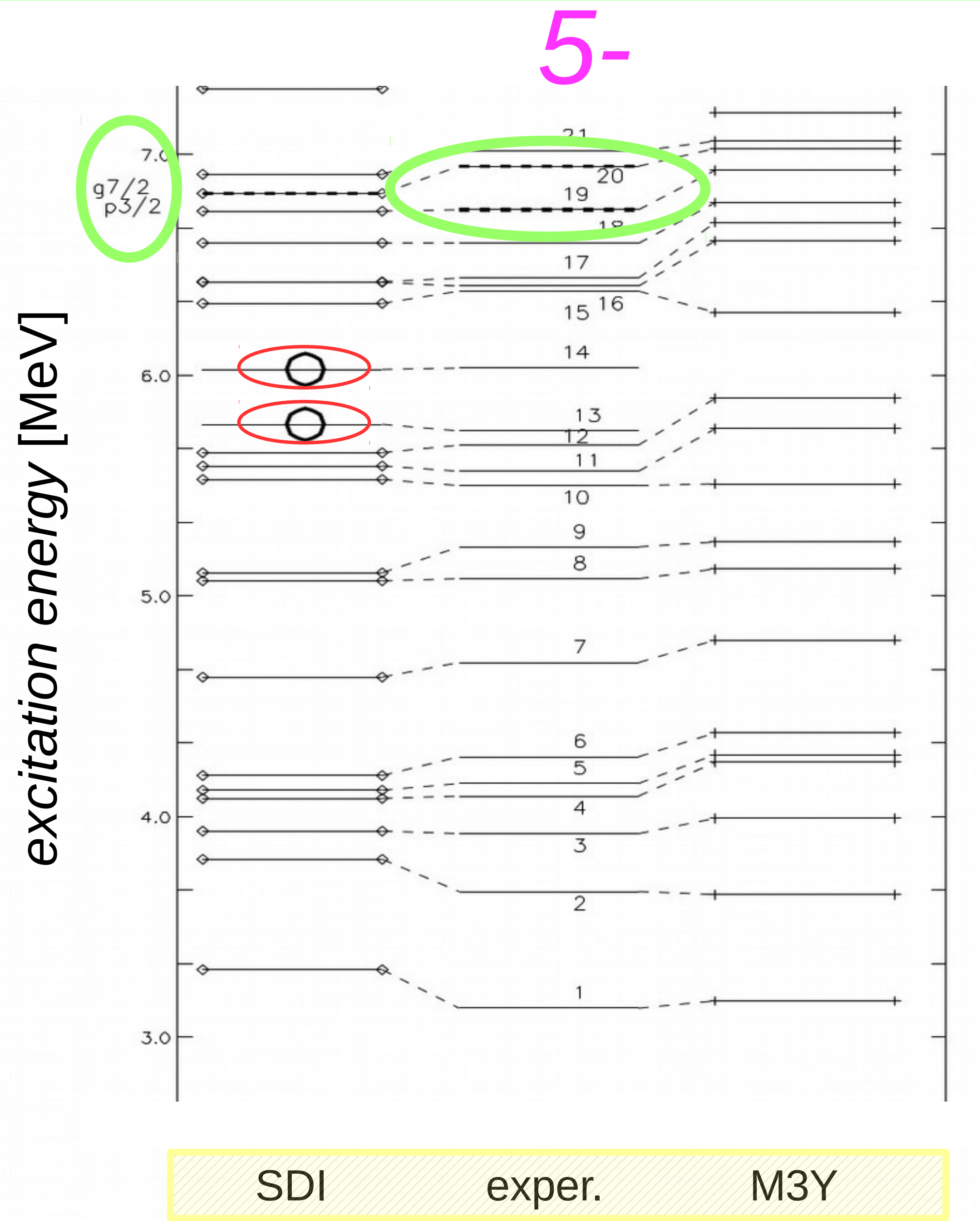
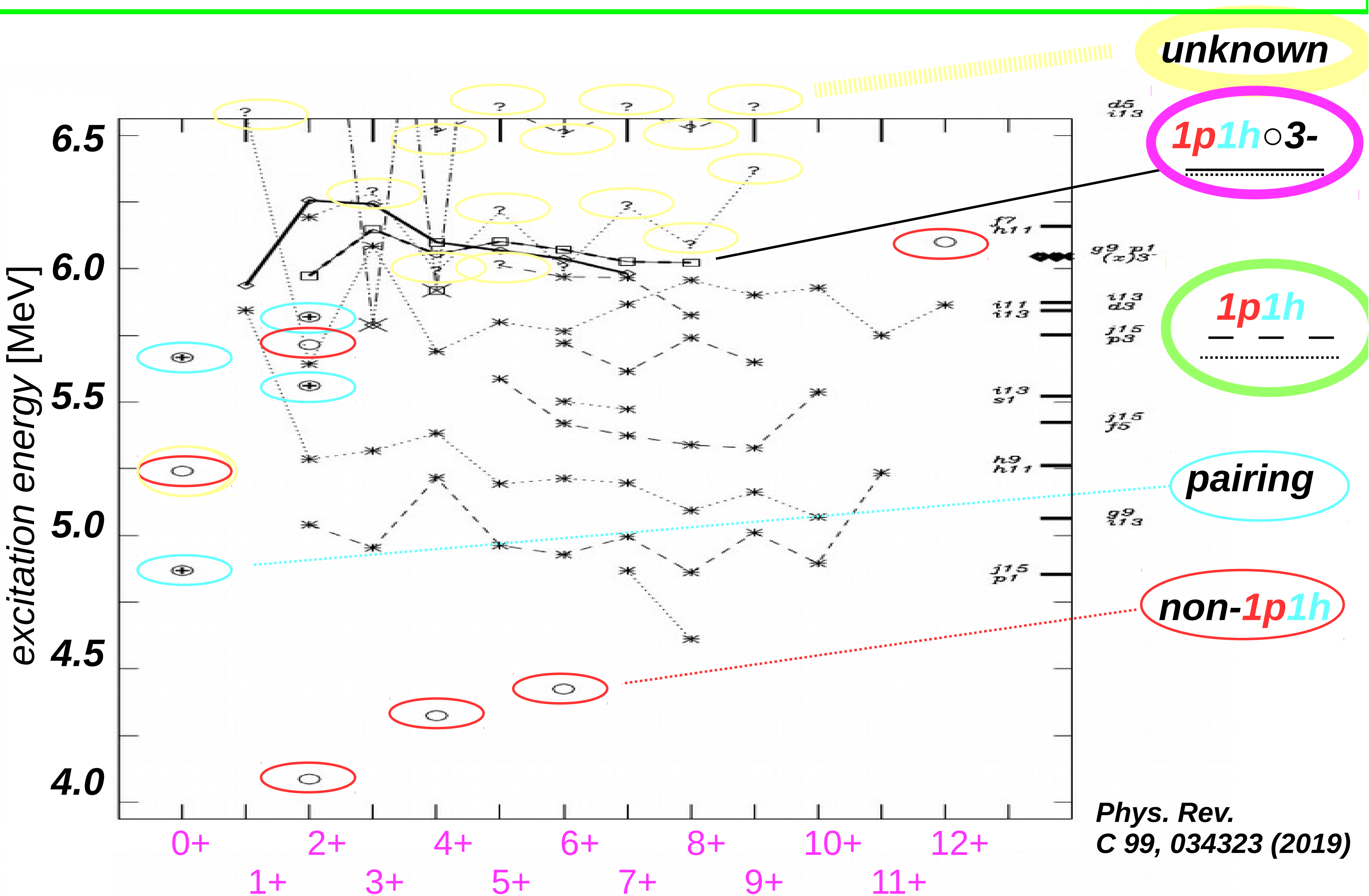
Comparison to SM for *3-* and *5-*





Comparison to SM for positive parity



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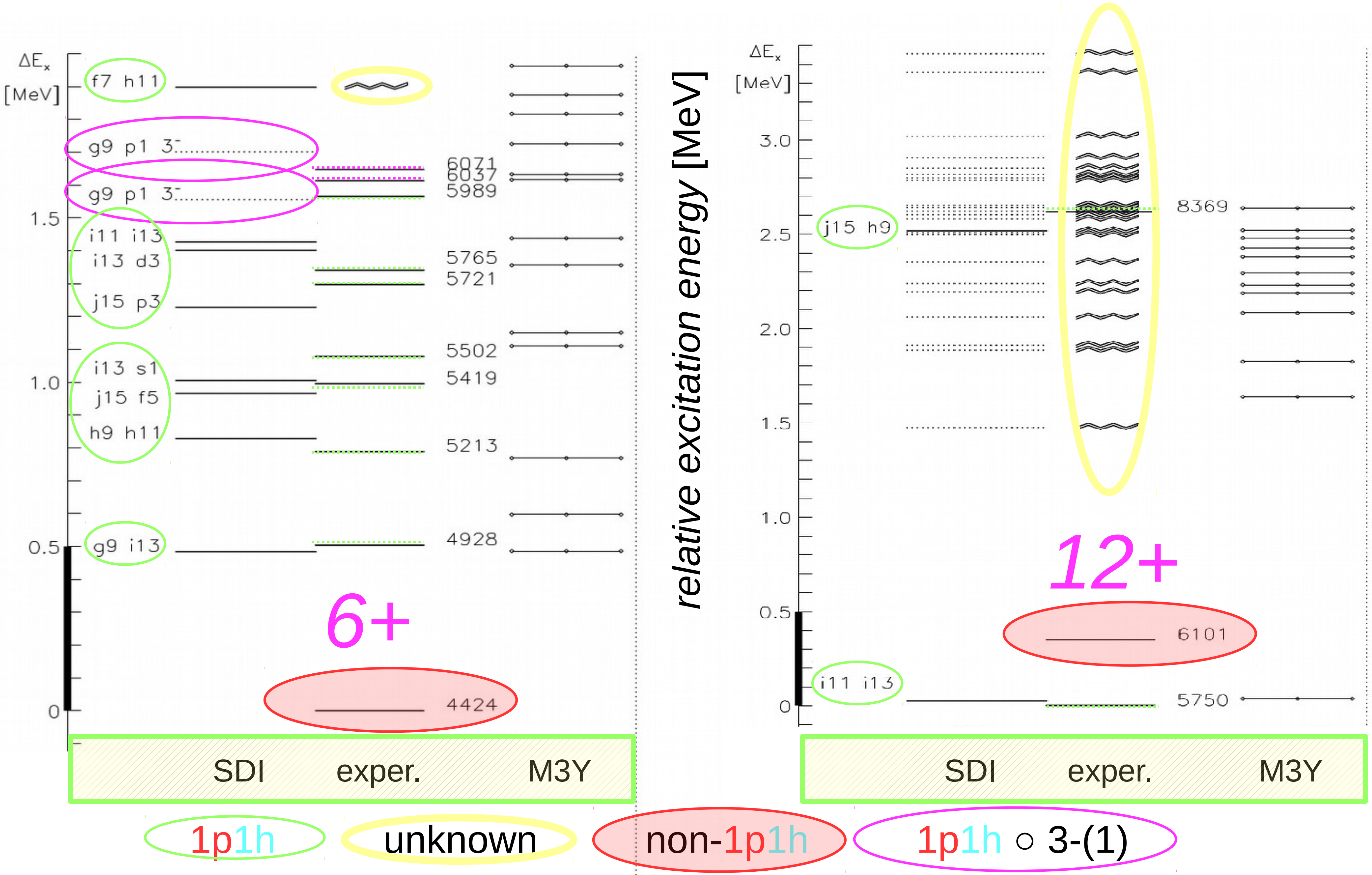
Comparison to SM for *6+* and *12+*



Summary

Different classes of excitations

- 1p1h configurations — calculations since 1960
- 1p1h configurations coupled to 3- yrast state — calculations 2019
- pairing vibrations — calculations 1970 / 2015
- tetrahedral rotation and vibrations — calculations 1937 / 2017
- configurations related to the 6+ yrast state – unknown type
- configurations related to the 12+ yrare state – unknown type
- configurations related to the additional 3- state – unknown type
- configurations related to the additional 5- states – unknown type

Open questions

- identify more positive parity states above Ex=6.2 MeV !
- where are the missing 1p1h states with spins 3+, *4*+ and *5*+ predicted near Ex = 6.0 MeV ?
- where are the tetrahedral overtones with spins *0*+ and *0*- predicted at Ex= 5.5 MeV ?
- exists the *2*+ state with composition [*j15/2 i13/2]1-* ○ 3- yrast predicted near Ex = 0 MeV ?

Outlook

- Need theory of dodekahedral configurations similar to tetrahedral model (ACM)

- Need new experiments

  - especially gamma-spectroscopy (neutron capture on 207Pb) *thank you for your attention*