Recent advances in understanding of shell evolution in N=7 isotopes and Nitrogen isotopes

G.V. Rogachev

TEXAS A&M UNIVERSITY

Acknowledgement

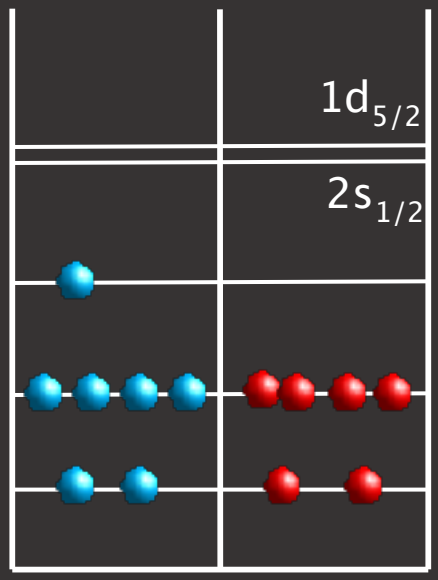
- ***Texas A&M University:*** G. Chubarian, V.Z. Goldberg, J. Hooker, C. Hunt, E. Koshchiy, H. Jayatissa, D. Melconian, B. Roeder, E. Uberseder, A. Saastamoinen, A. Spiridon, R.E. Tribble.
- ***TRIUMF:*** M. Alcorta, B. Davids

Main questions

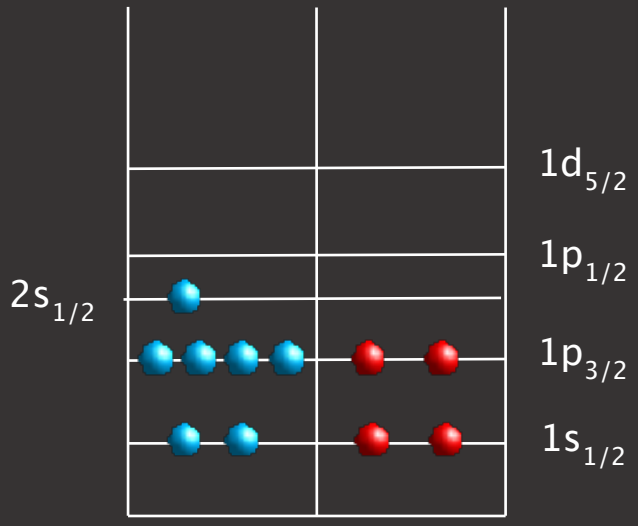
- Do we understand the general trends of nuclear shells (specifically 2s1/2, 1p1/2 and 1d5/2 shell) in Z=7 isotopes and N=7 isotopes *in light of the most recent experimental data*?

  - ^{9}N, ^{10}N, ^{11}N, ^{12}N, ^{13}N, ^{13}C, ^{12}B, ^{11}Be, ^{10}Li, ^{9}He

Z=7 isotopes
N=7 isotones

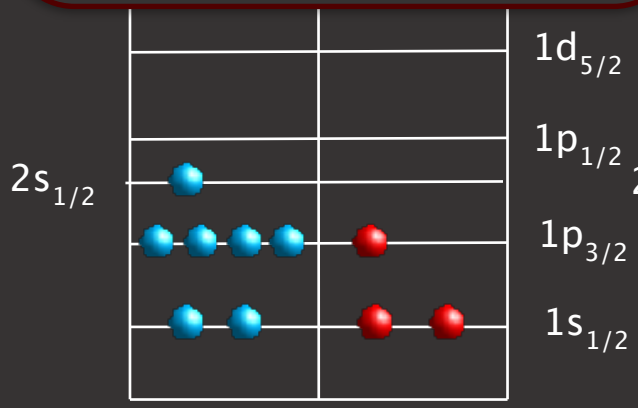


^{13}C (1/2$^-$; g.s.)



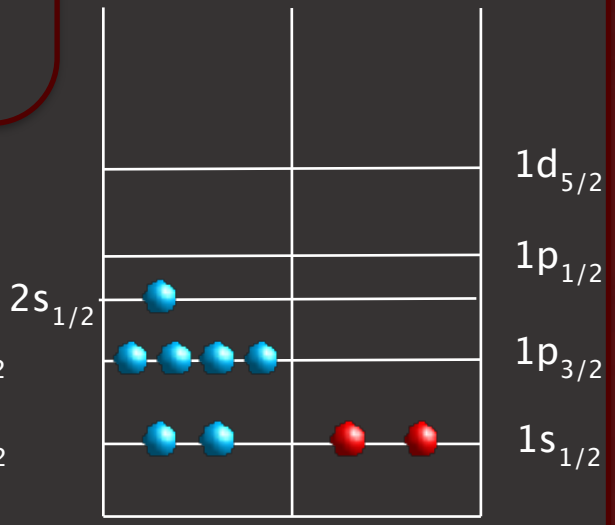
^{11}Be ½+ g.s.

^{11}N ½+ g.s.



^{10}Li (2$^-$;1$^-$) L=0 g.s.?

^{10}N 2− L=0 g.s.

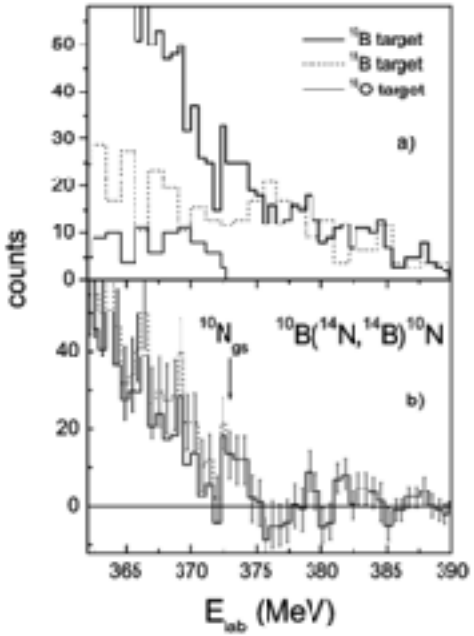


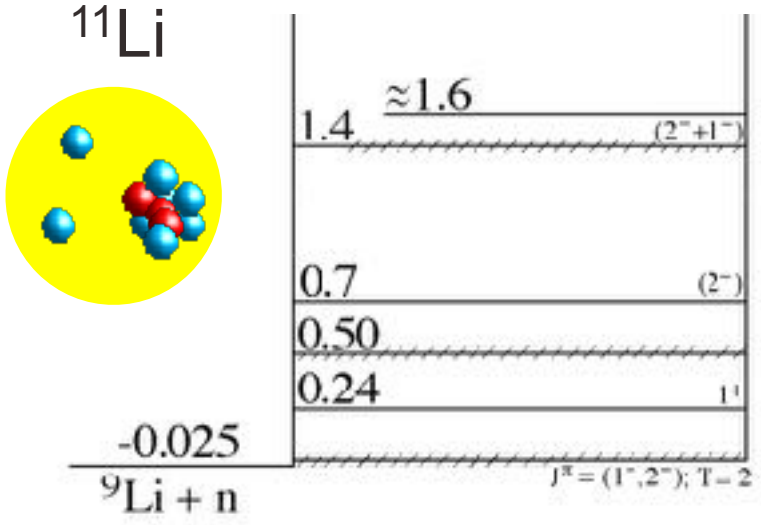
^{9}He ½+ g.s. at ~3 MeV above the neutron separation energy

Structure of ^{10}N

- Very little is known about ^{10}N
- Possibly a state observed at 2.6 MeV above p-decay threshold. [A. Lepine-Szily, et al., PRC 65 (2002)]
- Odd-odd psd-shell challenge to both experiment and theory.

$$3/2^- \otimes 1/2^- = 2^+; 1^+$$
$$3/2^- \otimes 1/2^+ = 1^-; 2^-$$



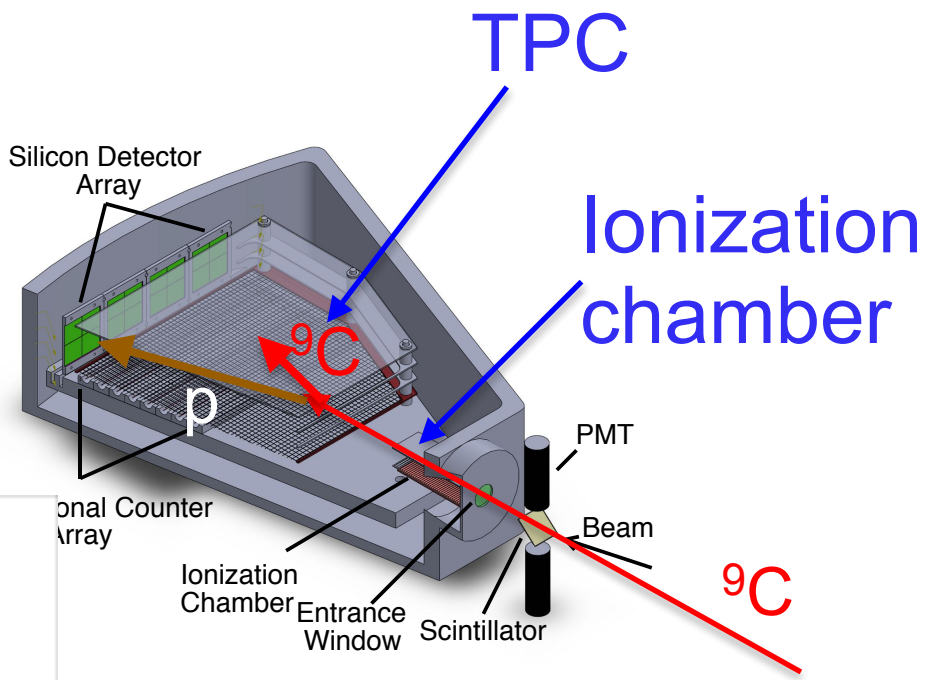


A. Lepine-Szily, et al., PRC 65 (2002)

Structure of ^{10}N

- Structure of ^{10}N studied using ^{9}C+p resonance elastic scattering
- ^{9}C beam produced by MARS separator at Texas A&M U

$^{9}C + p \Rightarrow {}^{10}N \Rightarrow {}^{9}C + p$



^{9}C

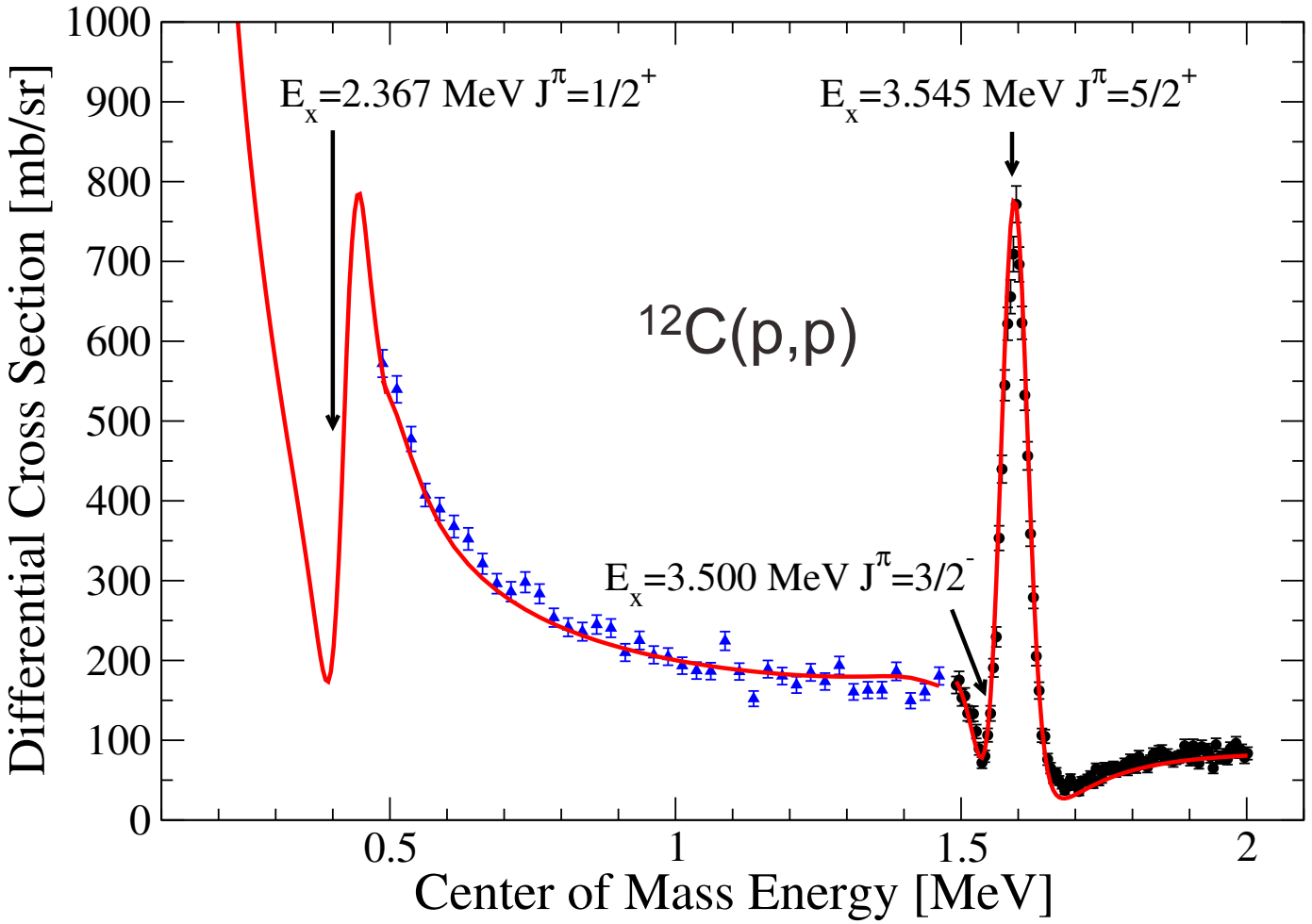
^{10}B

25 MeV/u

^{9}C 8 MeV/u

^{3}He 20 MeV/u

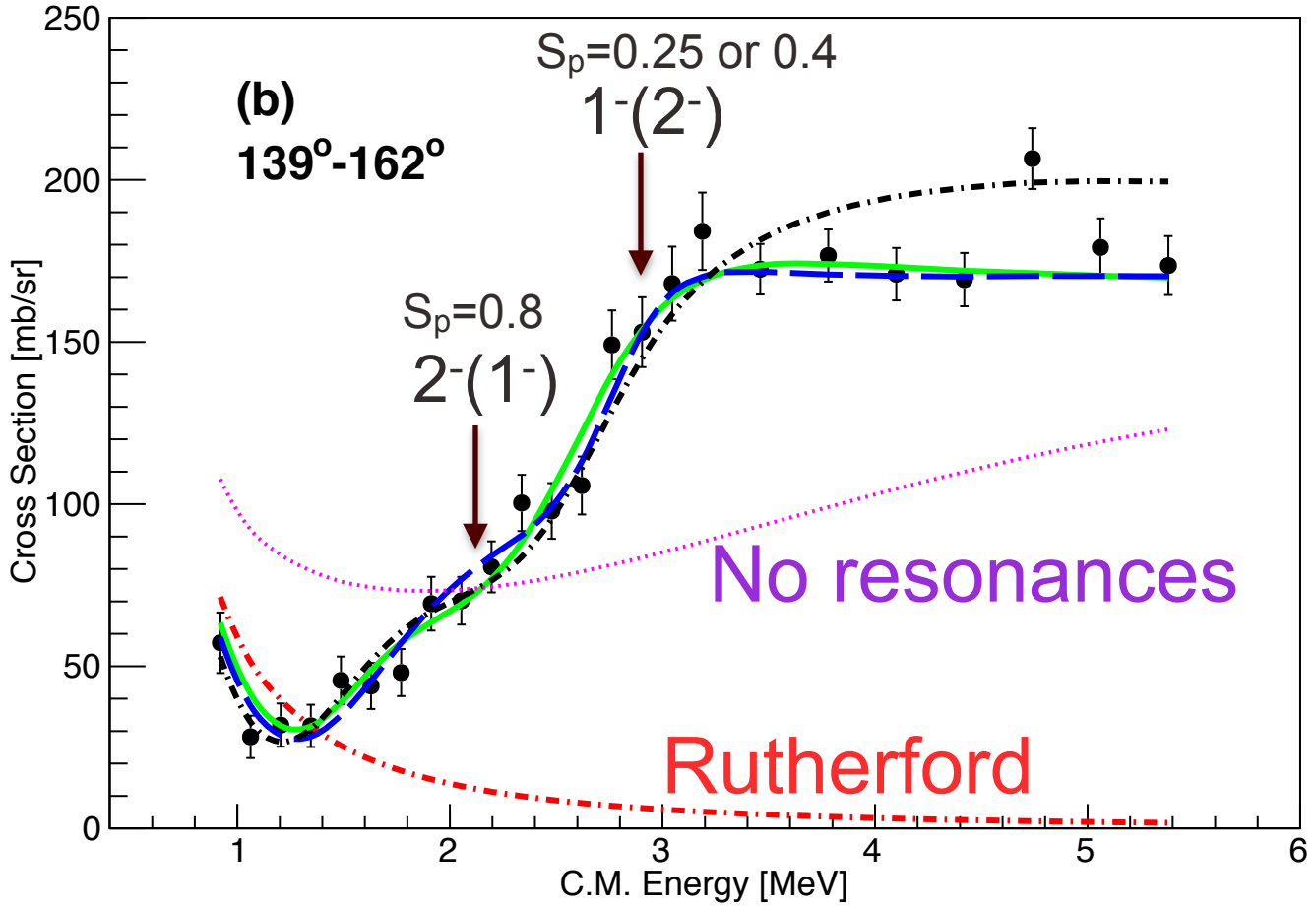
Test with ^{12}C beam - states in ^{13}N



Cross Section

Structure of ^{10}N

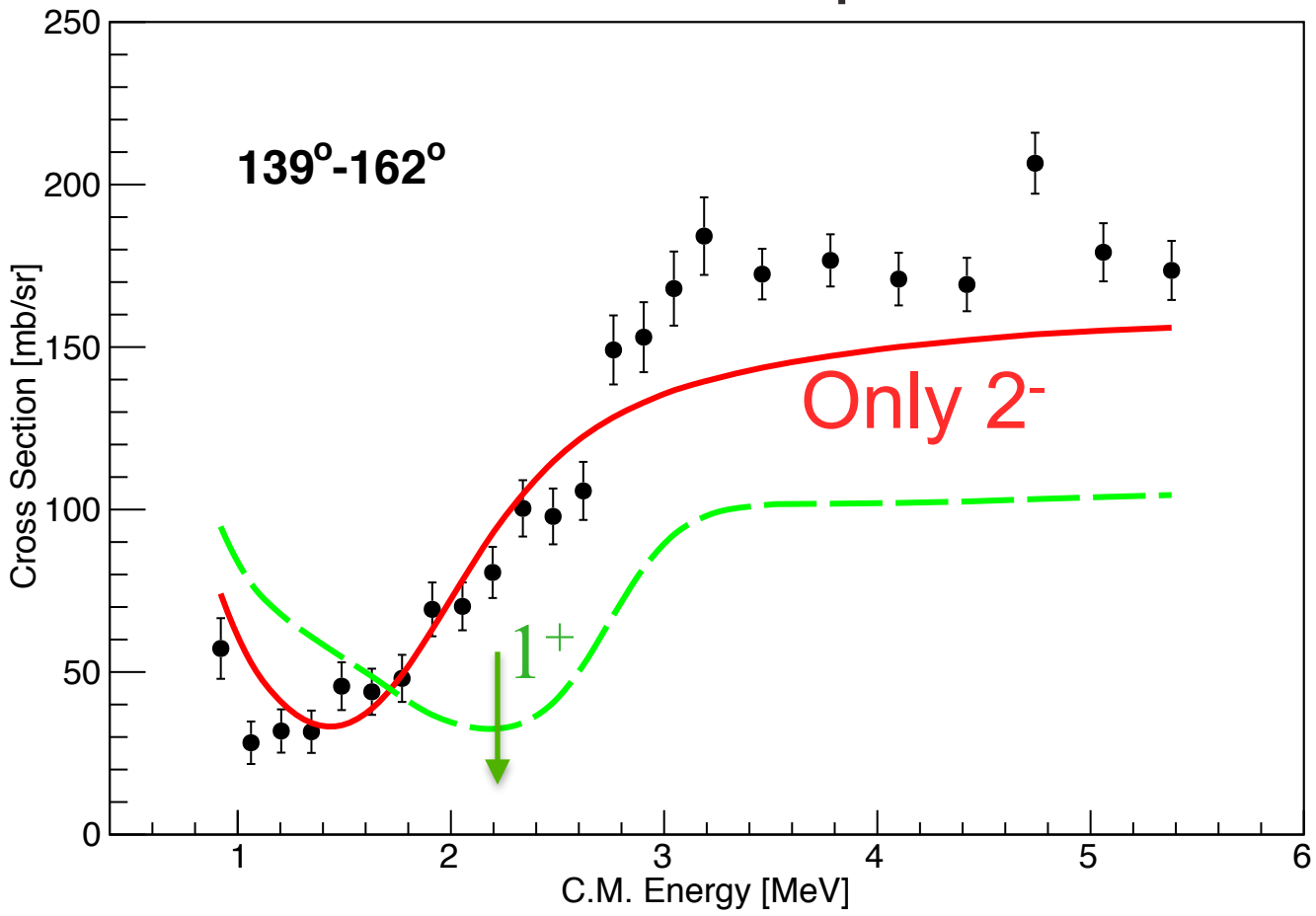
Excitation function for ^{9}C+p elastic scattering



J. Hooker, et al., arXiv:1703.01366, submitted to PLB

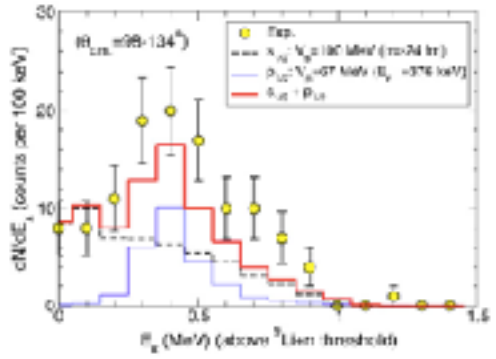
Structure of ^{10}N

Excitation function for ^{9}C+p elastic scattering



^{10}Li structure

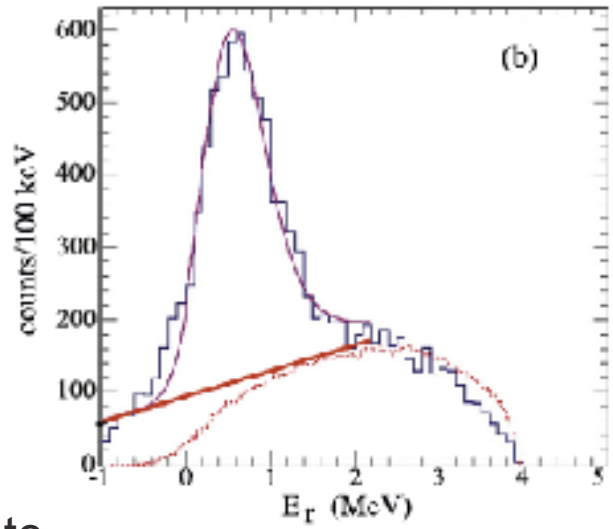
^{9}Li(d,p)



E=22 keV - virtual s-state
E=0.38 MeV, Γ=0.20 MeV

H.B. Jeppesen, et al.,
PLB 642 (2006) 449

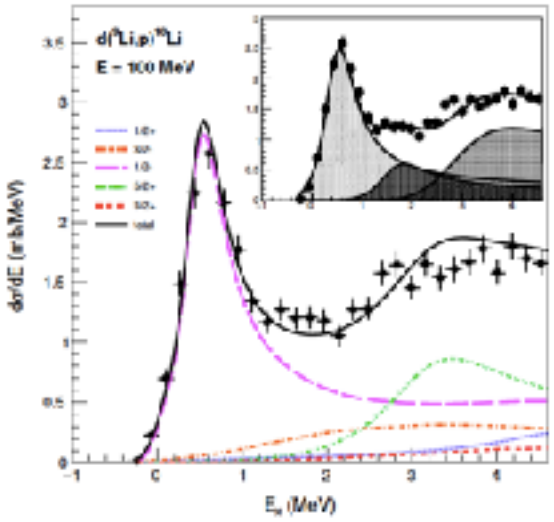
^{11}Li(p,d)



E=0.62 MeV, Γ=0.33 MeV

A.Sentullaev, et al.,
PLB 755 (2016) 481

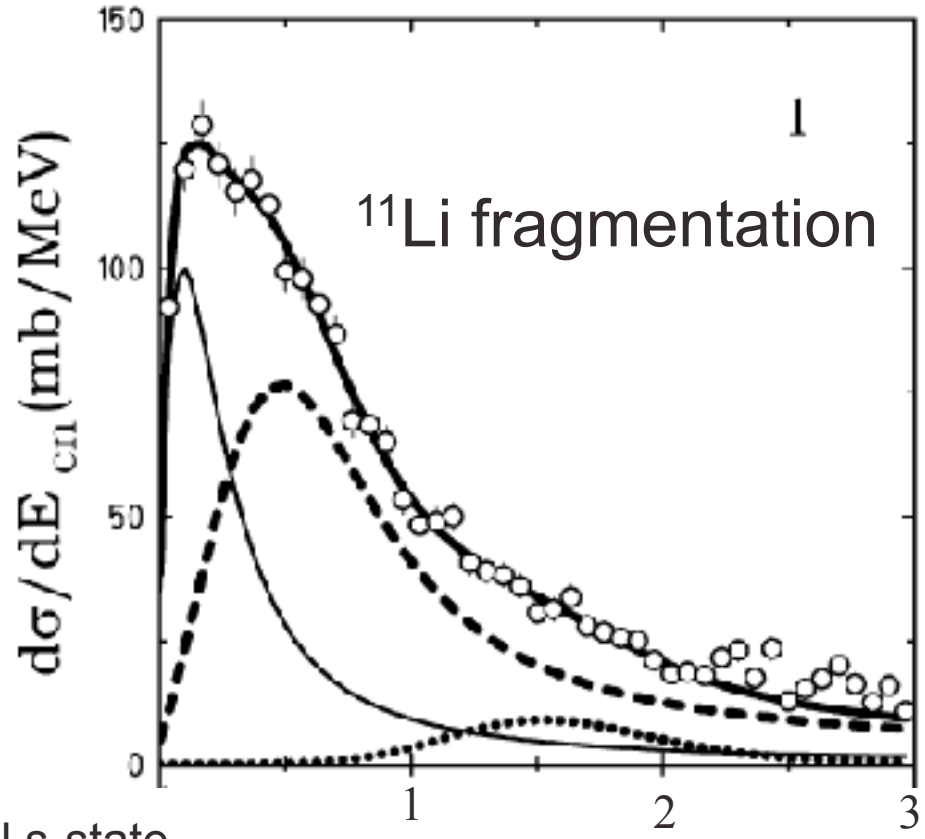
^{9}Li(d,p)



E=0.45 MeV, Γ=0.68 MeV

M. Cavallaro, et al.,
PRL 118 (2017) 012701

^{10}Li structure

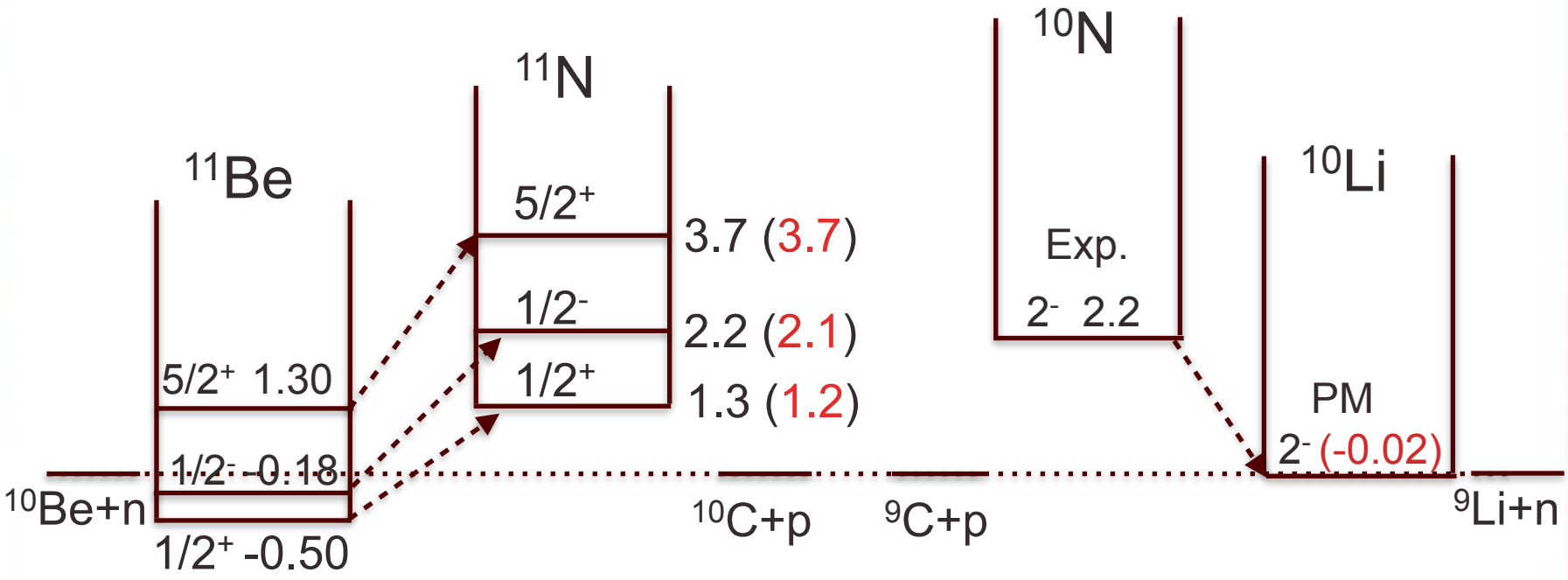


a = -30 fm - virtual s-state
E = 0.51 MeV, Γ=0.54 MeV

H. Simon, et al.,
Nucl. Phys. A 791 (2007) 267

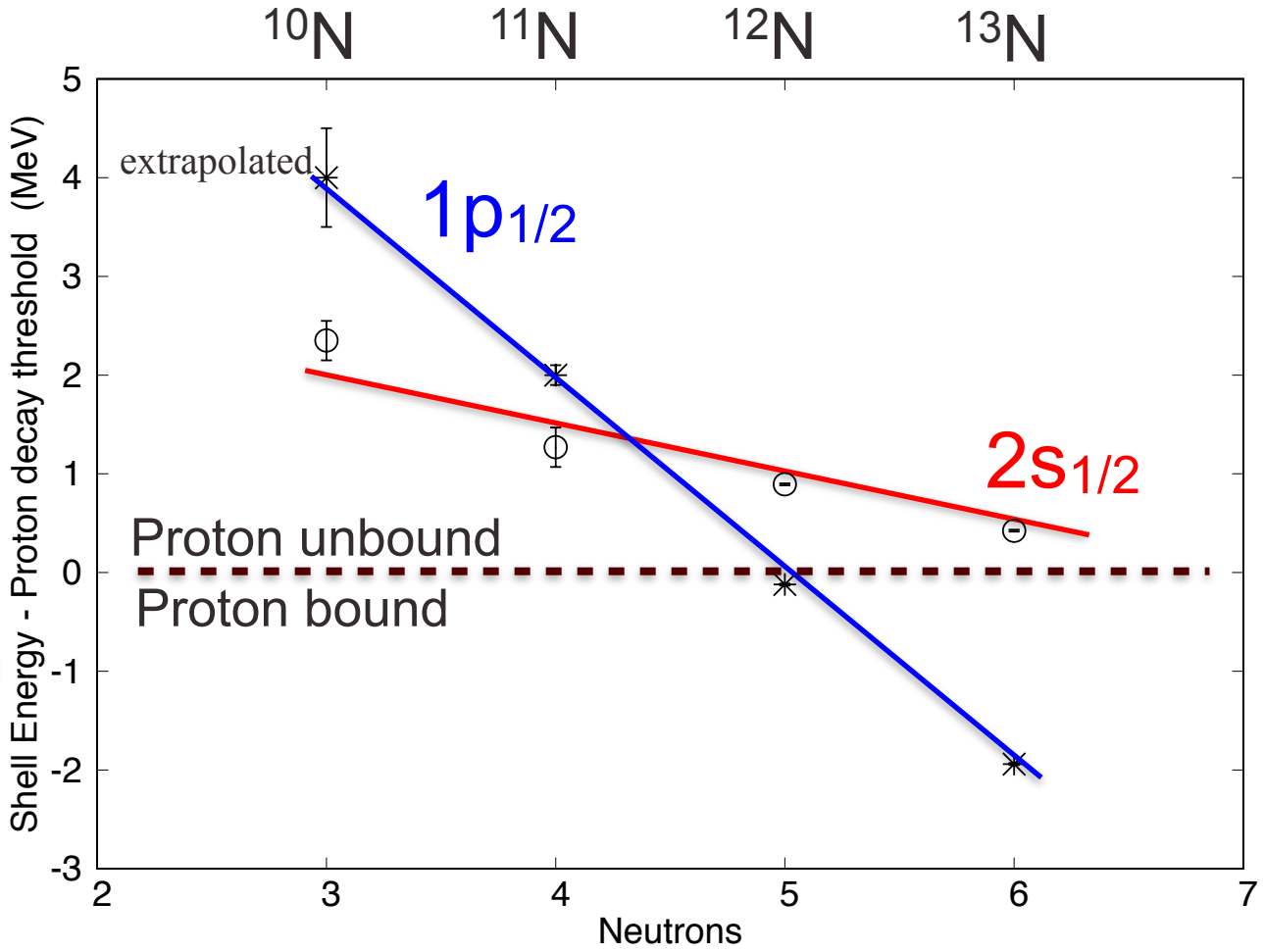
Potential model extrapolation

PM parameters: r_o = 1.25 fm, a=0.7 fm, r_c = 1.3 fm



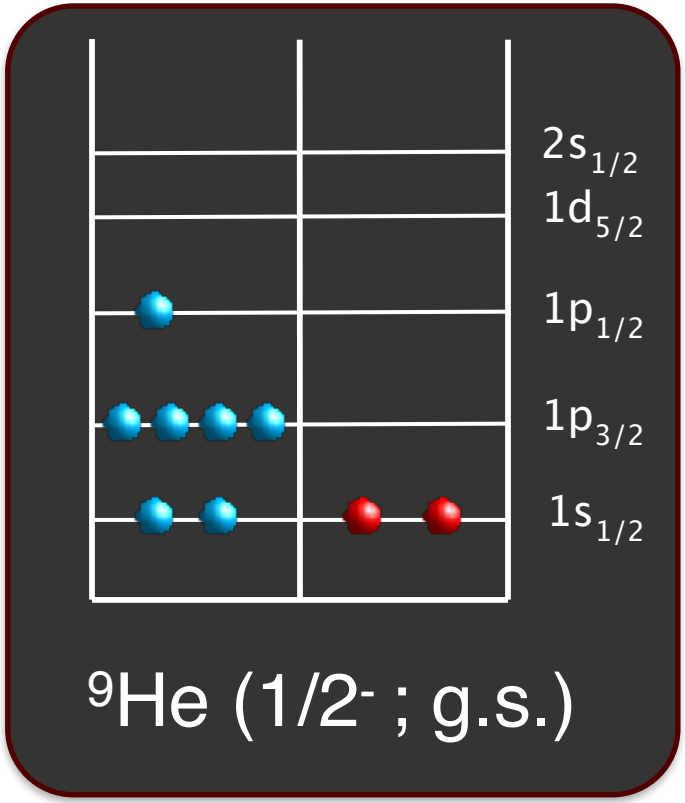
All values are in MeV. The experimental values for the known states are given. Potential model extrapolation are in parenthesis in red.

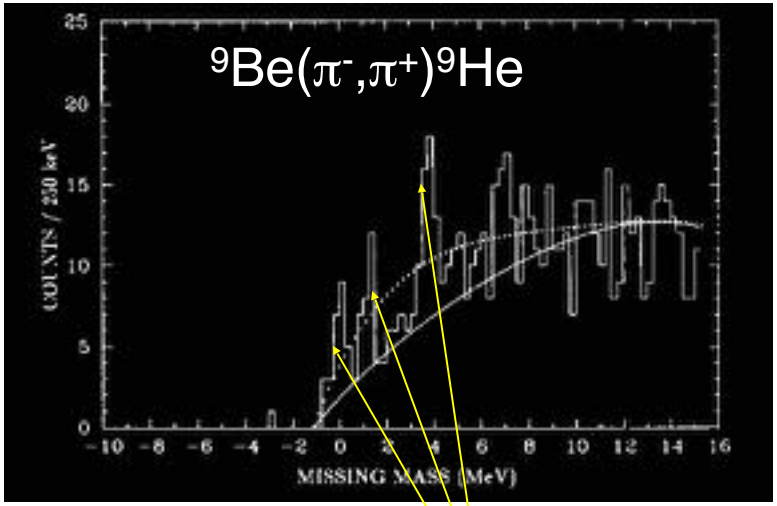
☑ 2s1/2 shell is located at 2.3(2) MeV in ^{10}N.



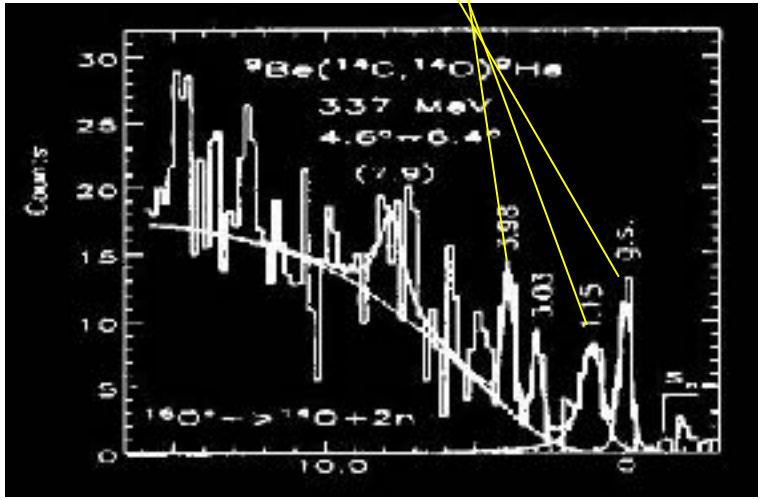
Proton Separation Energy

Structure of ^{9}He





K. Seth et al., Phys. Rev. Lett. 58, (1987) 1930



H.G. Bohlen et al.,
Prog. Part. Nucl. Phys., 42 (1999) 17

^{9}Be(^{14}C,^{14}O)^{9}He

Structure of ^{9}He

- The width of the ½⁻ ground state was claimed to be 100+/−60 keV [H.G. Bohlen et al., Prog. Part. Nucl. Phys., 42 (1999) 17]!

- However: The ground state is unbound by 1.2 MeV with respect to neutron emission and expected to be single particle state (in SM, NCSM and GFMC).

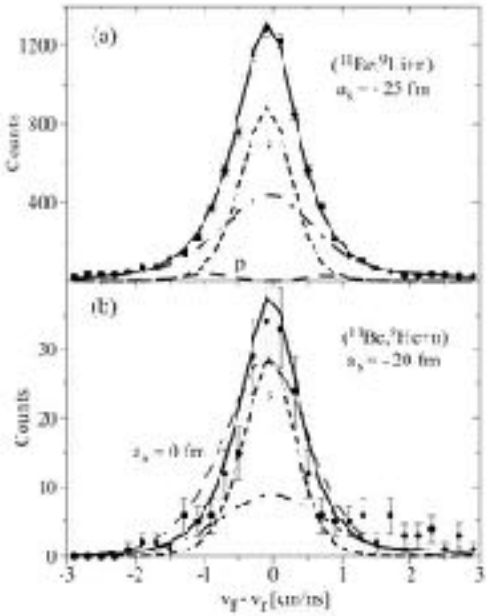
$$\Gamma_{1/2^-} = \mathrm{SF} \times \Gamma_{sp} \sim 1.0 \text{ MeV}$$

There appears to be a dramatic disconnect between theoretical expectations and the experimental data

Structure of ^{9}He

- It was suggested that Ground state of ^{9}He is $1/2^{+}$ L=0 virtual resonance at energy just above the n+^{8}He decays threshold, corresponding to scattering length of $\mathbf{a_s < -10\ fm.}$

  L. Chen, et al., Phys. Lett. B 505 (2001) 21

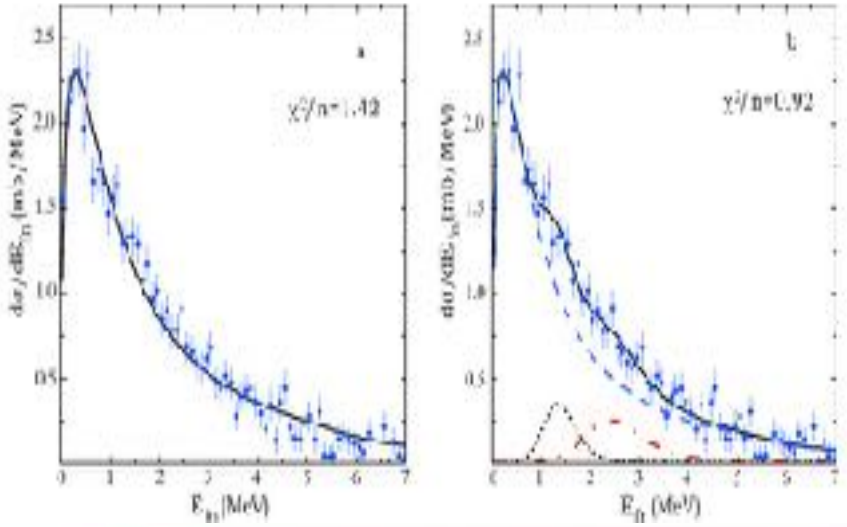


- More recently it was not confirmed and scattering length was determined as $\mathbf{a_s > -3\ fm.}$

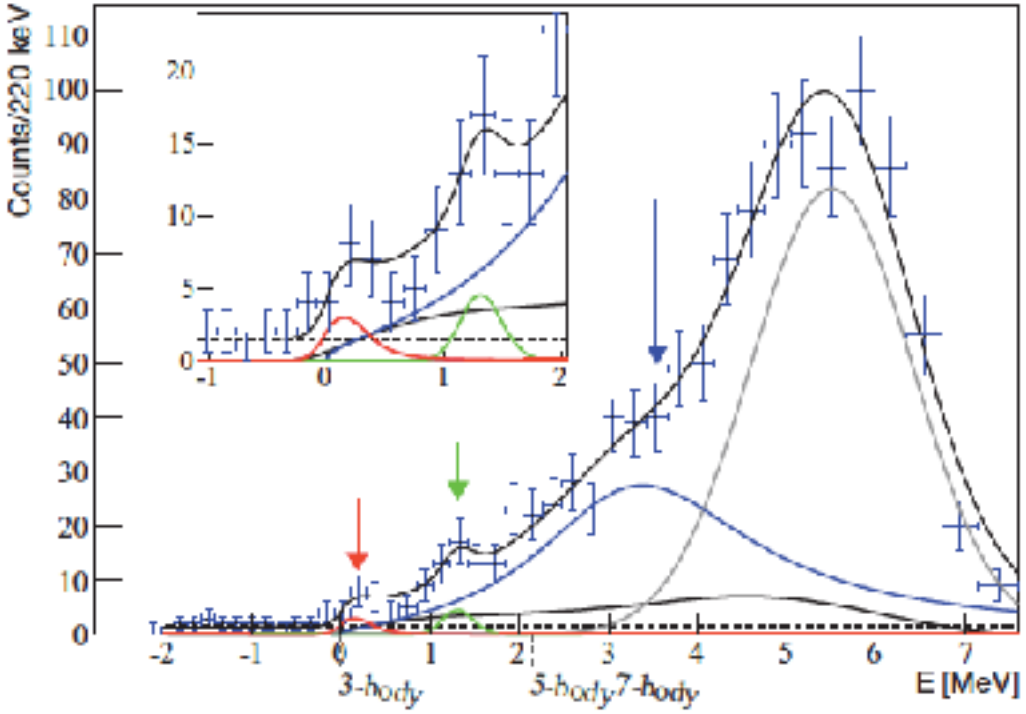
H.T. Johansson, et al.,

NPA 842 (2010) 15

H.Al. Falou, et al., (2010) arXiv:1008.0543v1

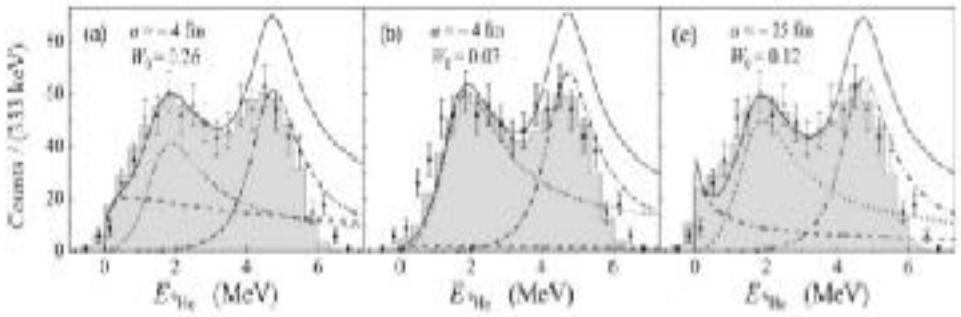


d(^{8}He,p)^{9}He reaction studies



- Recent ^{8}He(d,p) measurements indicate low lying $1/2^{+}$ and $1/2^{-}$ states

  T.Al. Kalanee, et al., PRC 88 (2013) 034301

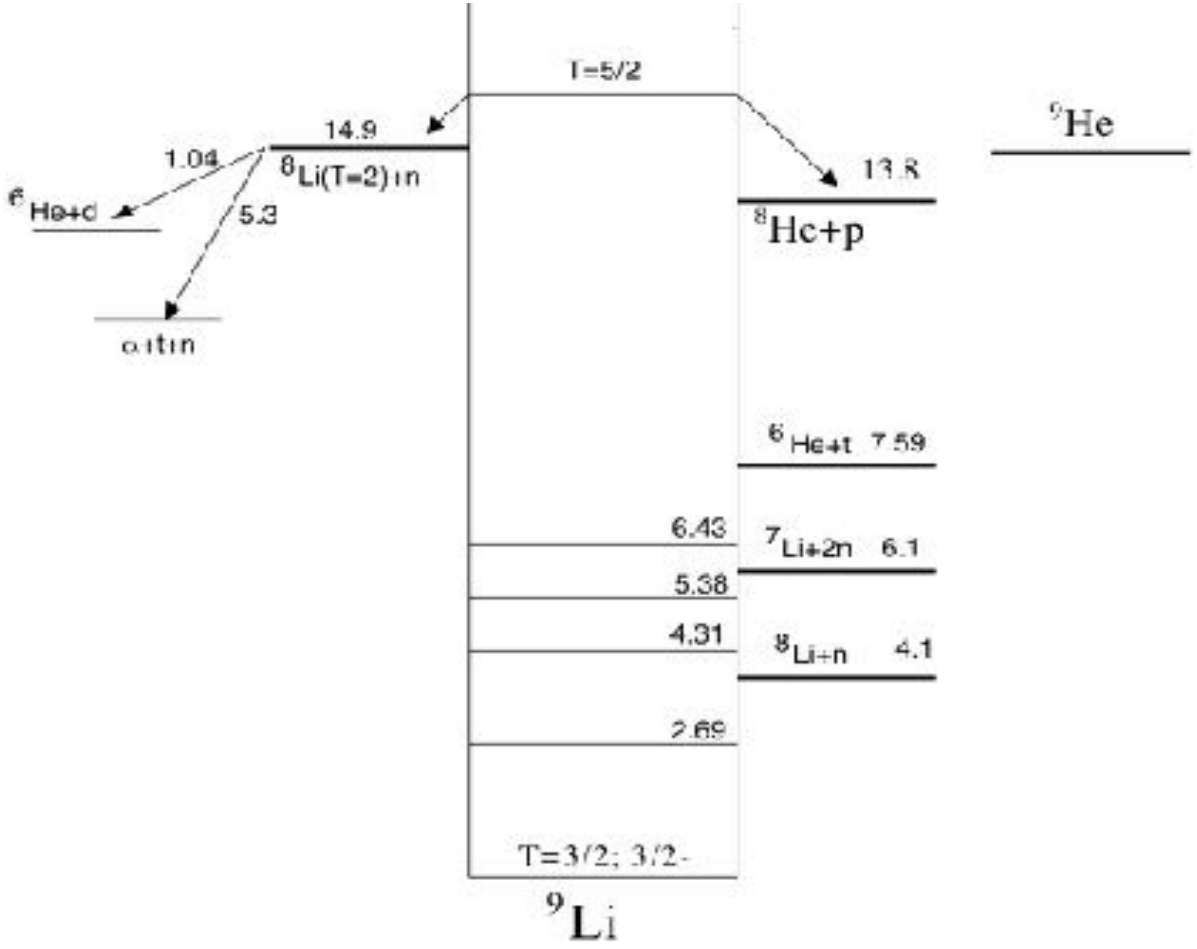


- This contradicts earlier ^{8}He(d,p) data

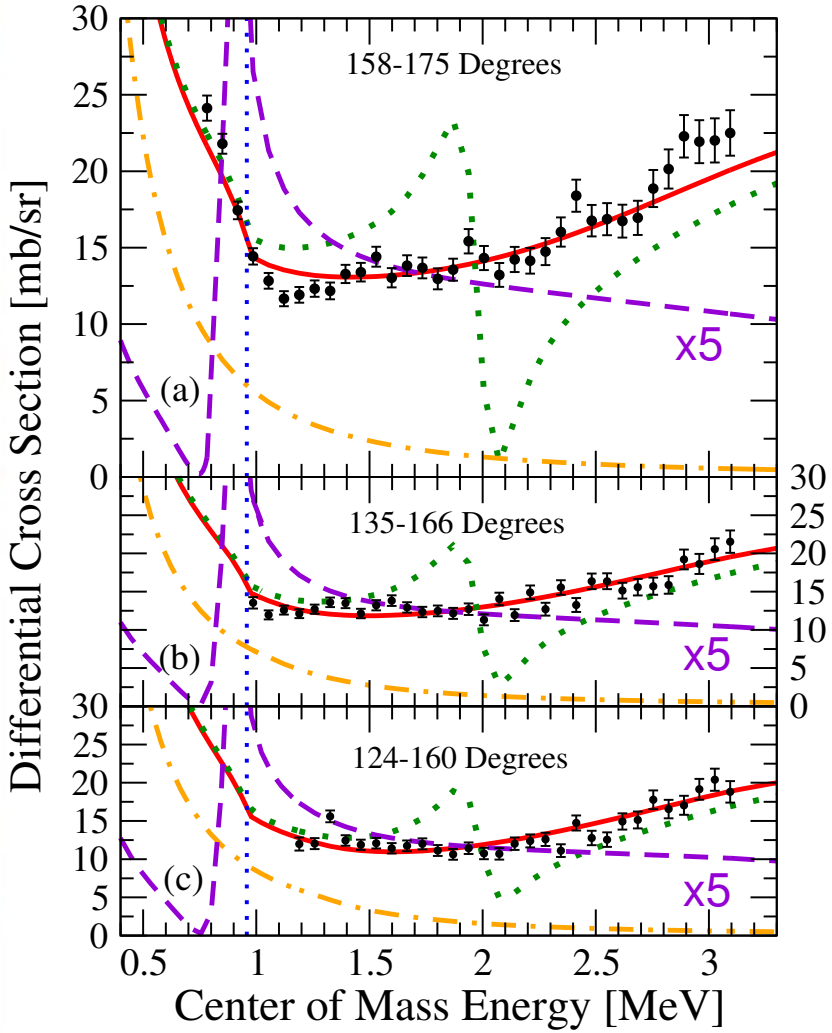
  M.S. Golovkov, et al., PRC 76 (2007) 021605

^{9}He through the T=5/2 IAR in ^{9}Li

p + ^{8}He -> ^{9}Li(T=5/2) -> p + ^{8}He



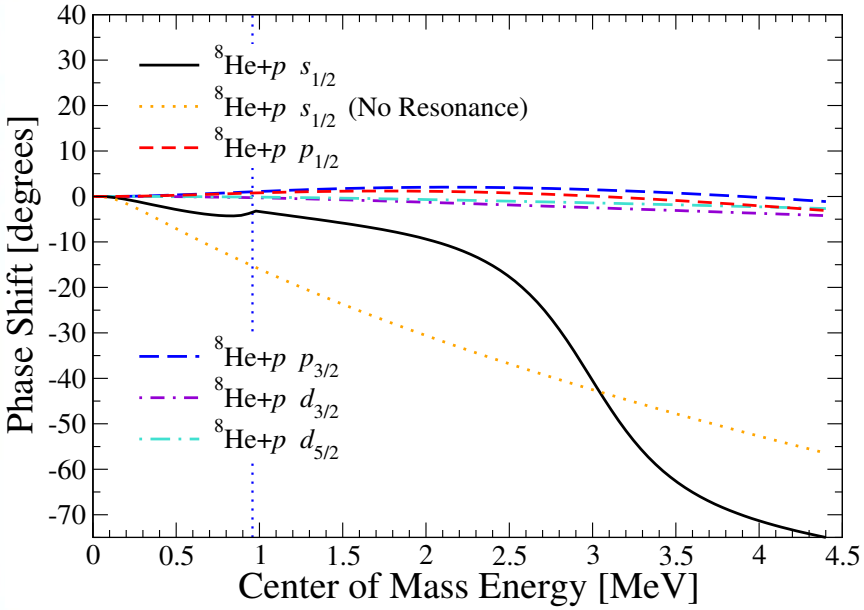
Excitation function for ^{8}He(p,p) elastic scattering

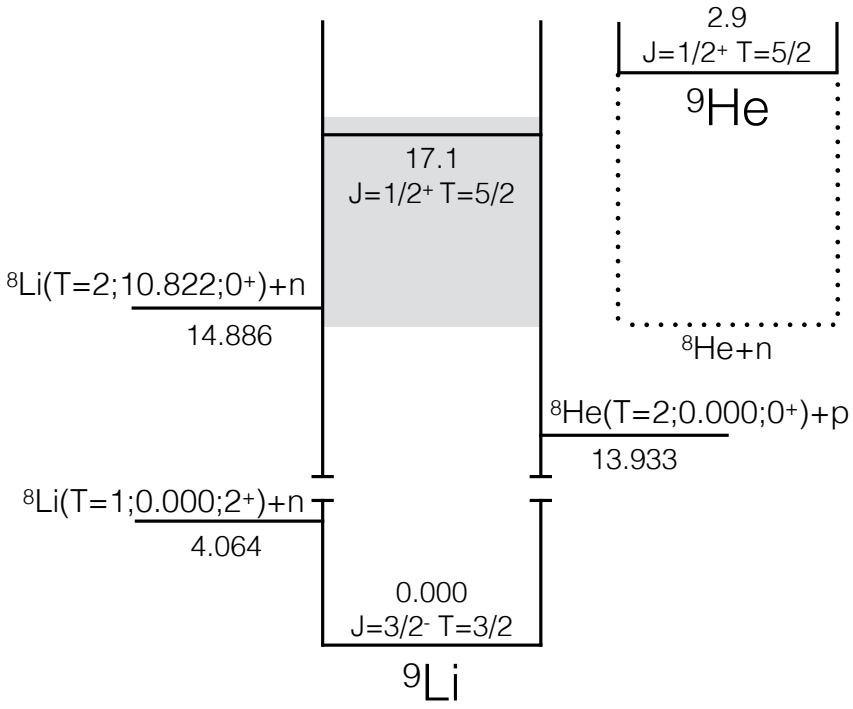


- T=5/2 states in ^{9}Li populated in ^{8}He+p resonance elastic scattering
- ^{8}He beam produced by ISAC facility at TRIUMF
- No narrow states were observed
- There is clear evidence for a very broad $1/2^{+}$ state at ~2.5 MeV above the proton threshold, this corresponds to a ground state of ^{9}He that is unbound by ~3 MeV

E. Uberseder, GR, et al., Phys. Lett. B, 754, 323 (2016)

Level structure of ^{9}He inferred from the ^{8}He+p measurements and the phase shifts





So, what is the level structure of ^{9}He after all?

$1/2^{+}$ wave - very broad structure around 3 MeV above the n+^{8}He threshold. The n+^{8}He diagonal scattering phase shift does not reach even 10 degrees. VERY HARD to identify in ^{8}He(d,p), probably was observed in Johansson, NPA 842 (2010) 15 and in H.Al. Falou, et al., (2010) arXiv:1008.0543v1 in breakup experiments. **Confidence level:** high

$1/2^{-}$ wave - broad (single particle) state at energy around 3 MeV above the n+^{8}He threshold. This state was observed in ^{8}He(d,p) reaction: M.S. Golovkov, et al., PRC 76 (2007) 021605 and likely in Kalanee, et al. PRC 88 (2013) (but misidentified)
Confidence level: medium

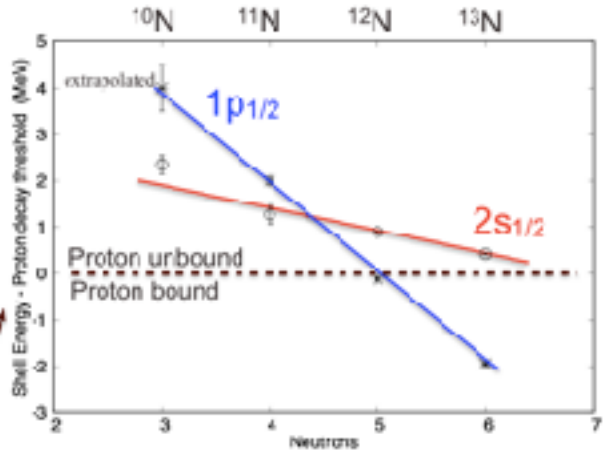
$5/2^{+}$ wave - broad state around 5 MeV (+/-1 MeV) above the n+^{8}He threshold. Some indications from ^{8}He(d,p) reaction experiments. Possibly observed in multi-nucleon transfer and pion charge exchange.
Confidence level: low

PHYSICAL REVIEW C **89**, 061305(R) (201

Neutron *s* states in loosely bound n

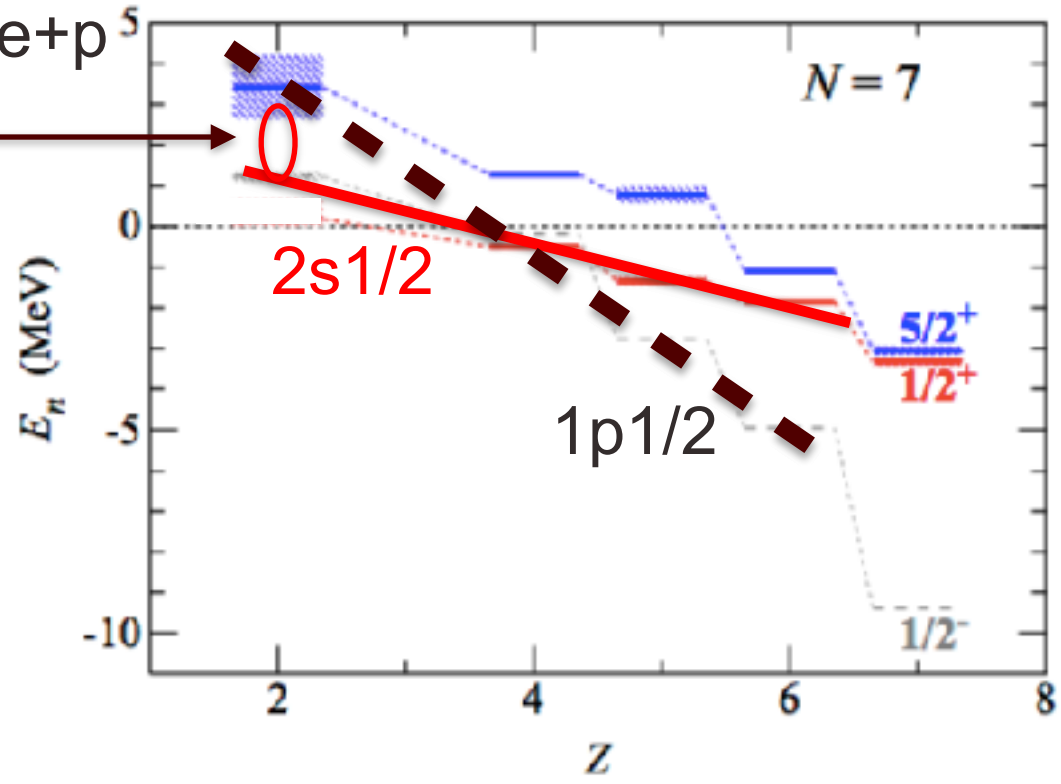
C. R. Hoffman, B. P. Kay, and J. P. Schif
Physics Division, Argonne National Laboratory, Argonne, Il

(Received 6 November 2013; revised manuscript received 13 May 201



^{9}He ^{10}Li ^{11}Be ^{12}B ^{13}C

From ^{8}He+p phase shift analysis



Conclusion

- Resonance scattering with active target detectors and rare isotope beams
- Knowledge of shell structure for Nitrogen isotopes (Z=7) and N=7 isotones have been extended toward more exotic species.
- High statistics and high energy resolution results were obtained for ^{9}He and ^{10}N.
- Location of 2s1/2 shell for ^{10}N have been determined.
- New data on T=5/2 IAS in ^{9}Li contradict existence of narrow low lying states in ^{9}He