Soft monopoles and bubble excitations in ^{34}Si, ^{36}S and ^{28}Si

A bit of history

Soft breathing modes excitations

Bubble structure excitations

O. Sorlin (GANIL) – November 2020

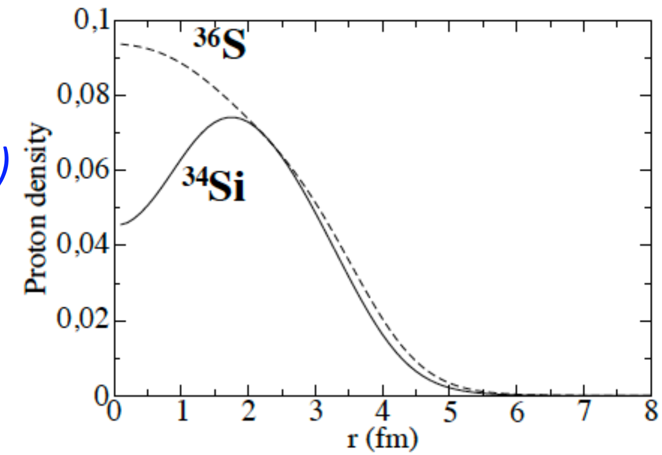
From bubble stucture to soft modes in ^{34}Si - a bit of history

Original goal :

Study the density dependence of the SO interaction

-> Find a nucleus with abnormal density ... most have a constant density with a decrease at the surface

-> ^{34}Si was ideal in 'classical shell model picture'



Central depletion of ^{34}Si first predicted by *M. Grasso et al. PRC 79 (2009)*

-> comes from the lack of proton in $s_{1/2}$ orbital (L=0)

E. Khan proposed the name of 'bubble' nucleus

This central density depletion induces a strong reduction of the SO splitting for L=1 orbitals probing the nuclear center *G. Burgunder et al. PRL 112 (2014), T. Duguet at al. PRC 95 (2017)*

The depletion of the $s_{1/2}$ orbital ^{34}Si has been inferred by comparing ^{36}S(-1p) and ^{34}Si(-1p) KO reactions cross sections for L=0 states *A. Mutschler et al. Nature Phys. 13 (2017)*

I was expecting that ^{34}Si could be more 'easily' be compressed and would have soft a breathing mode.

-> Calculations indeed find soft modes, but their nature is not based on proton excitations!

D. Gambacurta, M. Grasso, O. Sorlin PRC 100 (2019)

The next chapters of this history will hopefully bring other interesting discoveries ...

Soft monopoles and bubble excitations

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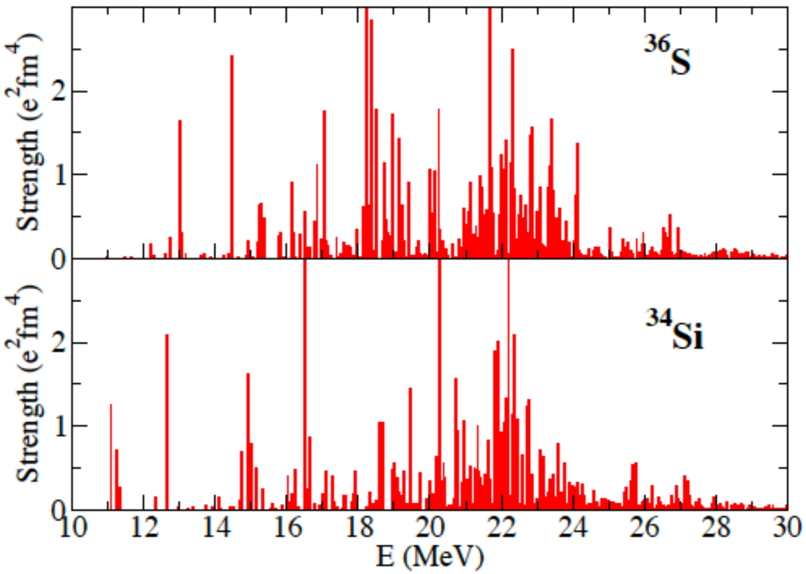
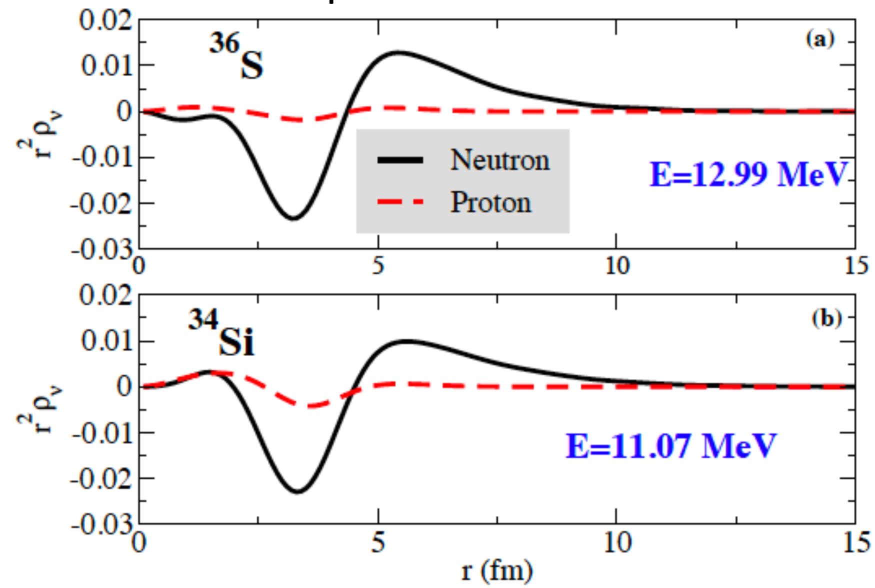
Soft modes in the N=20 nuclei ^{34}Si and ^{36}S



Almost pure neutron oscillations

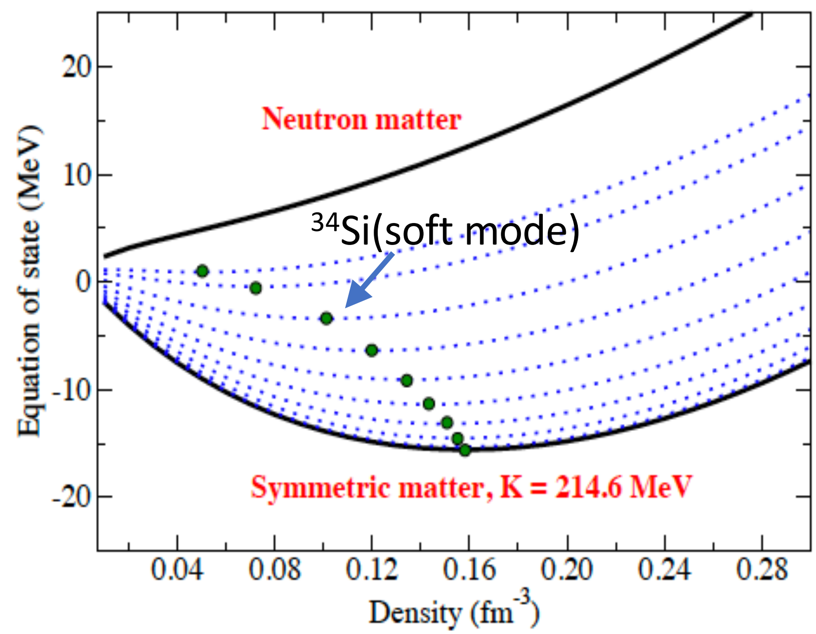


$$X = \frac{X_N - X_P}{X_N + X_P}.$$

$$E(X) \sim 5.22 A^{-1/3} \sqrt{K_X},$$

^{34}Si: K_X = 45.5 MeV, E(X) = 11MeV, X=0.73
^{36}S: K_X = 68 MeV, E(X) = 13 MeV

-> Such low-energy modes might have some connection with pure neutron matter oscillations



M. Grasso et al. PRC (2019)

Experimental /theoretical procedure

EXPERIMENTAL STRATEGY:

1- Search if soft E0 modes exist in the 11-13 MeV region using suitable reaction(s) to produce them

As they are predicted to represent a 4-5 %of the GMR sum rule -> high-intensity /efficiency needed
-> Inverse kinematics (^{34}Si) in an active target (see talk Marine with ^{68}Ni)
-> or Direct kinematics (^{36}S) in zero degree spectrometer

(2- Measure the full E0 strength in ^{36}S. – can be compared to that of ^{32}S -> dependance of K with A/Z)

3- Estimate the fraction of the sum rule of these low-energy modes.

4- Quantify their neutron component
-> Use the comparison between their (p,p') and (α,α') cross sections

Hyp: (p,p') reaction more sensitive to neutron excitations while (α,α') is sensitive to both (IS modes).

NEEDS FROM THEORY :

-> (p,p') and (α,α') inelastic scattering calculations and angular distributions using the calculated w.f. of the soft breathing modes
-> Determine the sensitivity of the different probes, from their relative cross sections
-> What is the best suited beam energy ?
-> Is their any information to extract from the pattern of their angular distribution ?

Study of monopole excitation in direct kinematics @ Ithemba-Labs

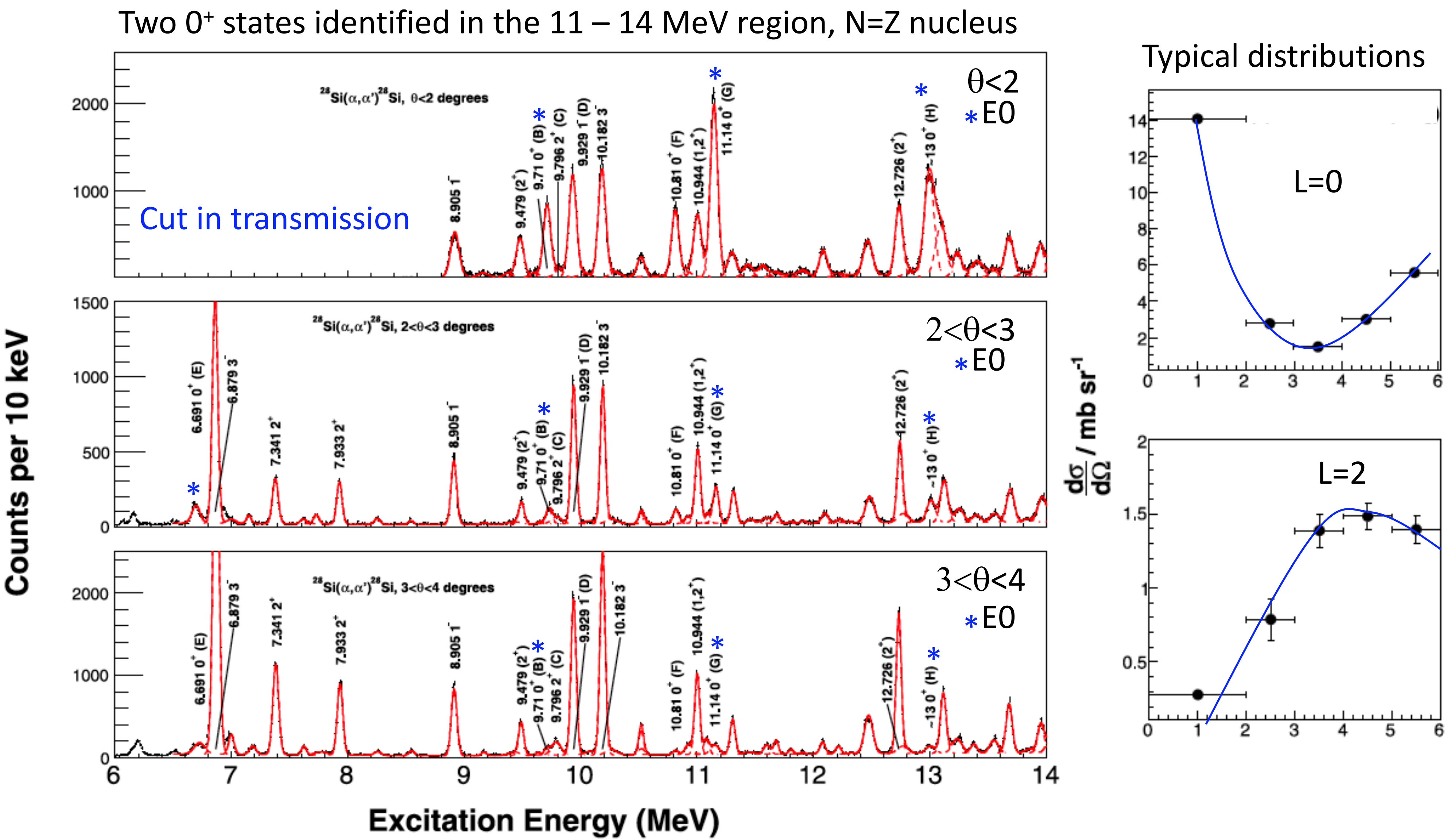
A 99.6% pure ^{36}S has been produced and already used during a week

beam

K600 @ Ithemba-Labs

≈ 30 keV resolution for 200 MeV (p,p') reaction, angular resolution about 0.4 degrees

Typical results $^{28}Si(\alpha,\alpha')^{28}Si$ @ 200 MeV (Ithemba-Labs)



In general no need to make detailed Multiple Decomposition Analysis in this energy range

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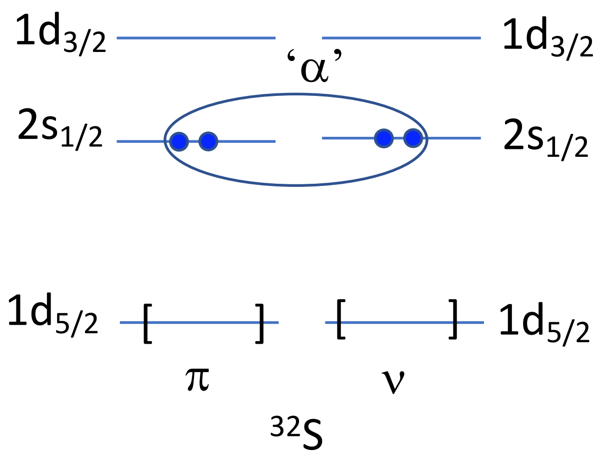
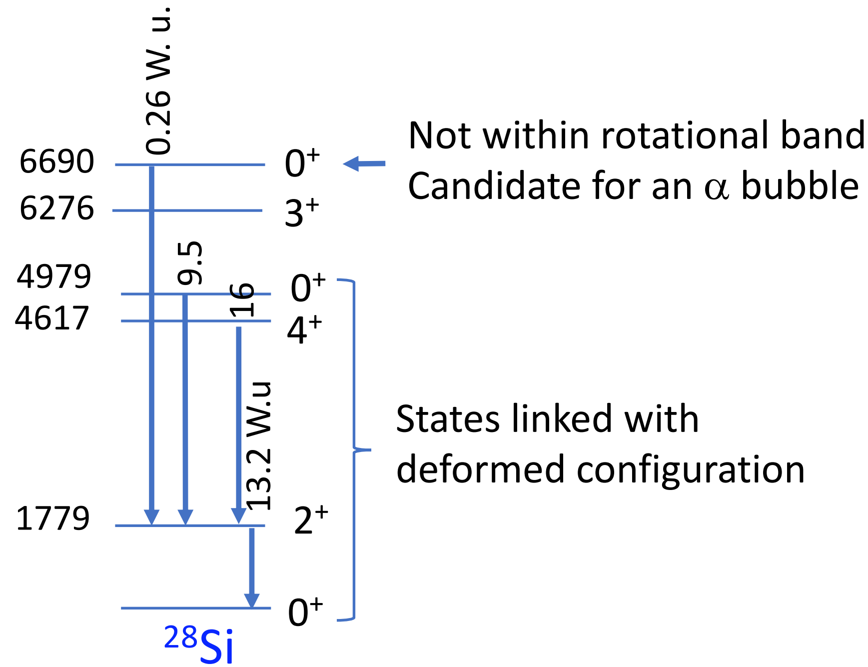
Search of an 'α'-bubble in ^{28}Si (relative to ^{32}S)

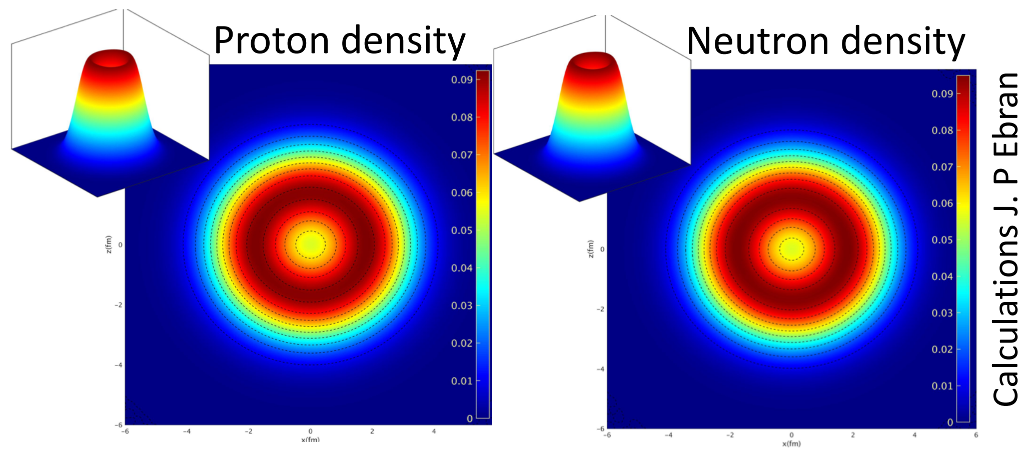


Why is the oblate shape energetically preferred to a spherical 'α' bubble structure in ^{28}Si ?

Does it exist or is it mixed with other 0^+ states ?
If yes, at which energy ?



Predictions J.P Ebran
0^+_1 , E = 0, β_2 = -0.14 oblate
0^+_2 , E = 4.11 MeV, β_2 = +0.22 (prolate)
0^+_3, E = 5.05 MeV, β_2= 0.036 (-> spherical)

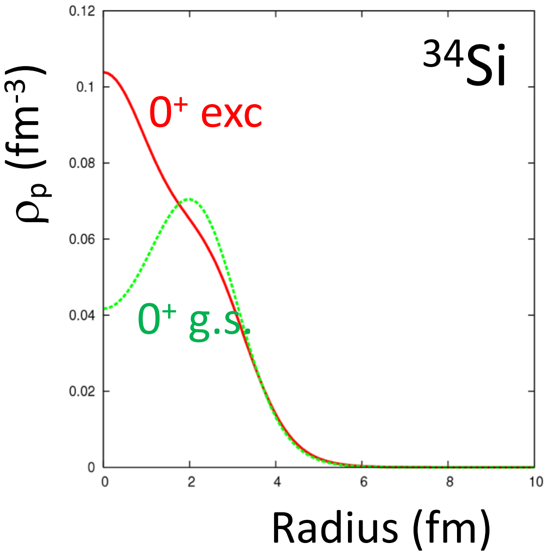


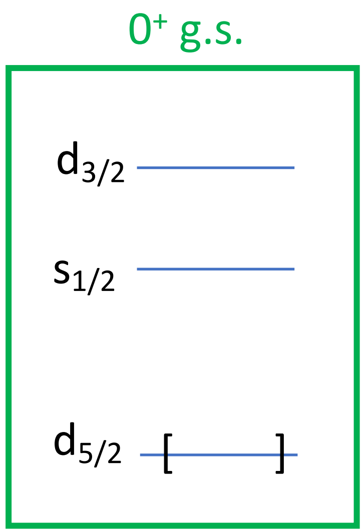
Strategies to reveal an ‘α’ bubble state in ^{28}Si with hadronic probes

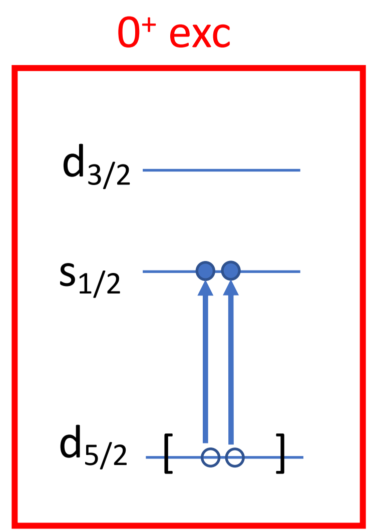
Are inelastic scattering studies sensitive enough to prove the existence of such an ‘α’ bubble structure ?

Does the ^{32}S(d,^{6}Li)^{28}Si reaction favors the 0^+_3 feeding as compared to other 0^+ states ?

Study of ‘bubble’ structure through inelastic scattering (hadronic probe)?



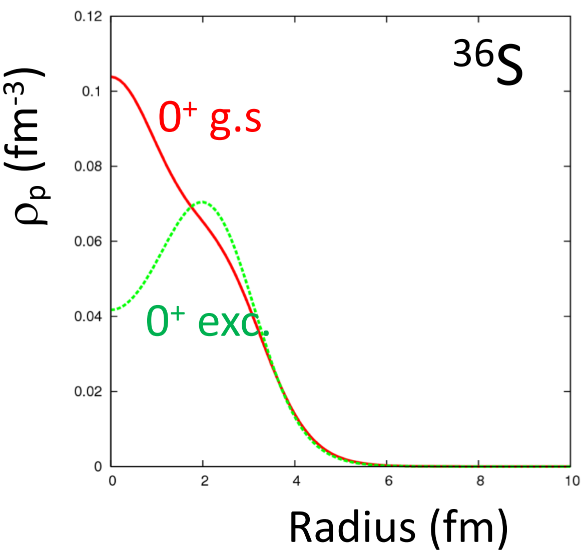


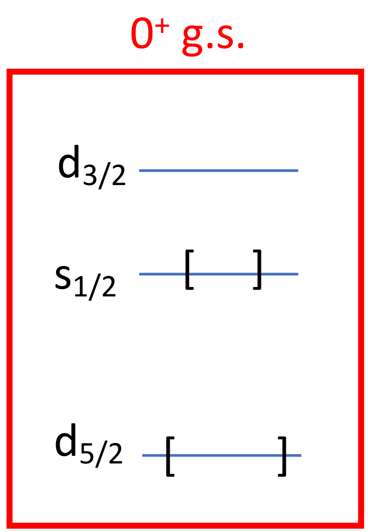


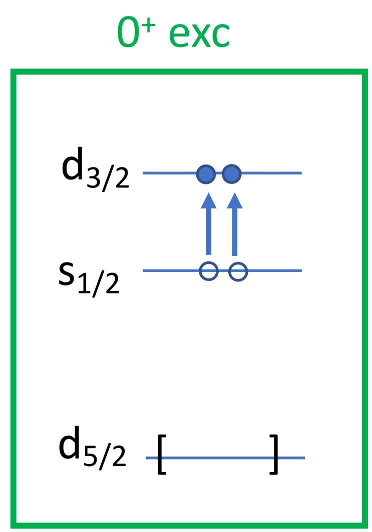
What would be the best probe/energy to identify a change from bubble structure to normal density ?

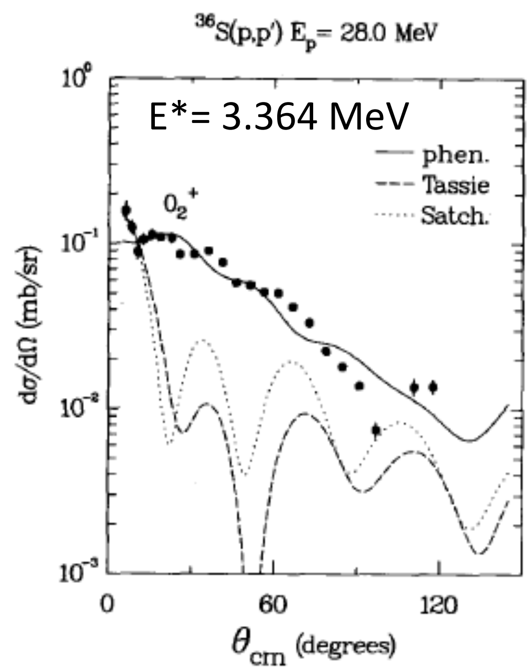
Does the transition density look like that of a breathing mode ?

How collective is it ?









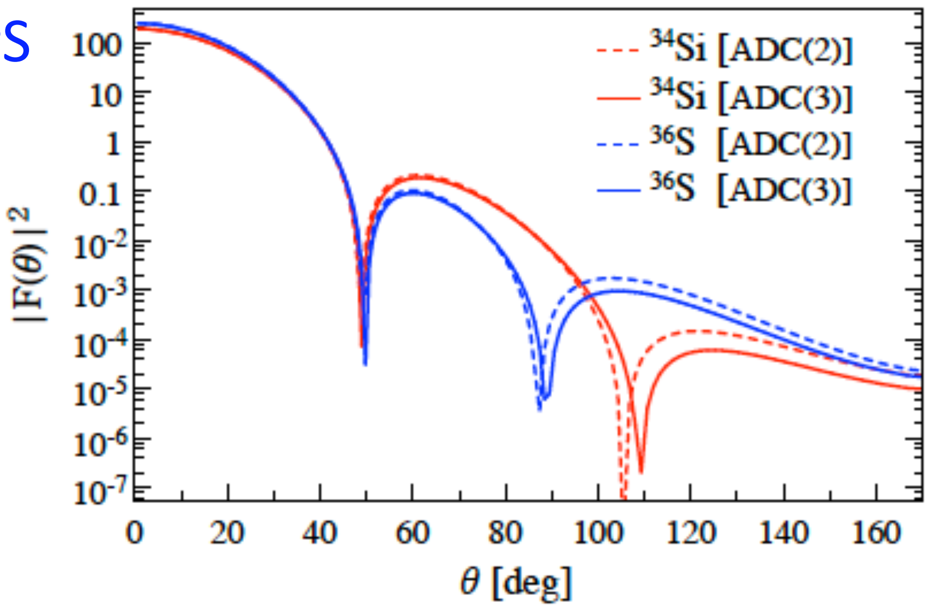
Hogenbirk et al. NPA 516 (1990)205

Bubble structure studies with electrons

Future experimental projects using electron beam colliders
Electrons can better probe the interior of a nucleus

Elastic form factor

^{34}Si, ^{36}S



Duguet at al. PRC 95 (2017)

A high luminosity is needed to observe the second minimum....

^{28}Si

What is the inelastic charge form factor to the 'α' bubble state in ^{28}Si ?
Is its shape of the inelastic form factor reflecting its specific structure ?

Thank you

Anyone is welcome to discuss / help / participate in one of these projects