Mirror symmetry of new (sub)-shell closures: ^{36}S – ^{36}Ca

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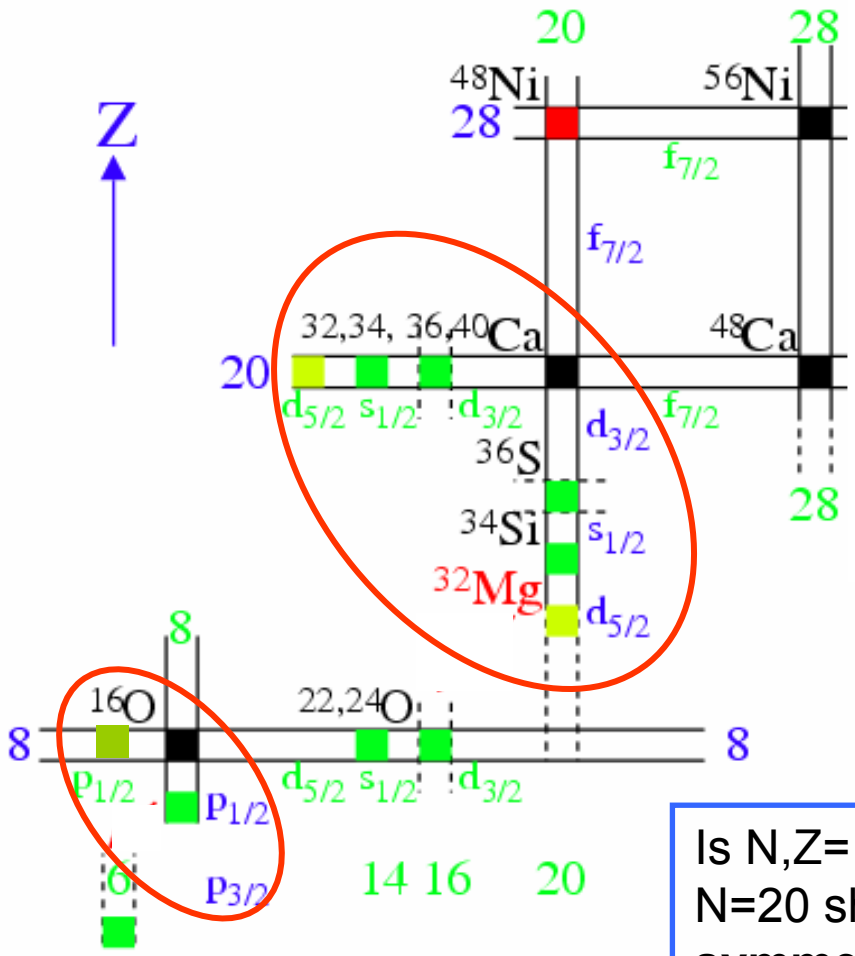
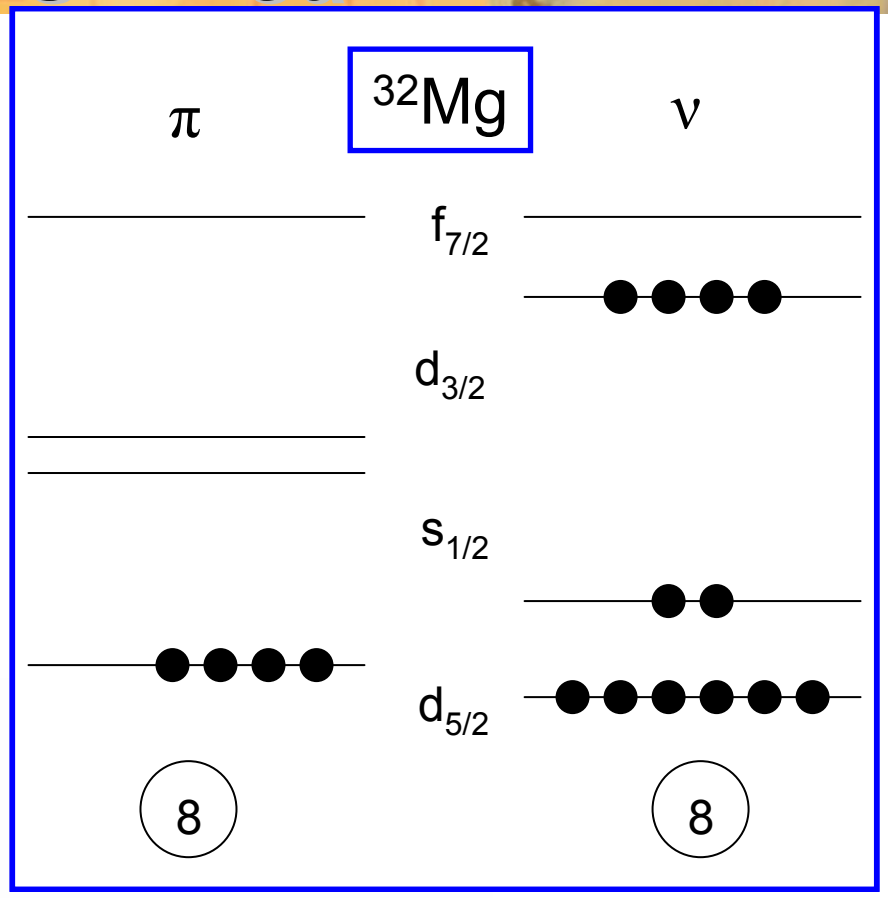
for the RISING collaboration

Rare ISotopes INvestigation at GSI
γ-Spectroscopy at relativistic energies

- Introduction and Motivation
- RISING Spectrometer
- Spectroscopy after fragmentation: ^{36}Ca
- Status of SM-calculations
- Summary and Outlook

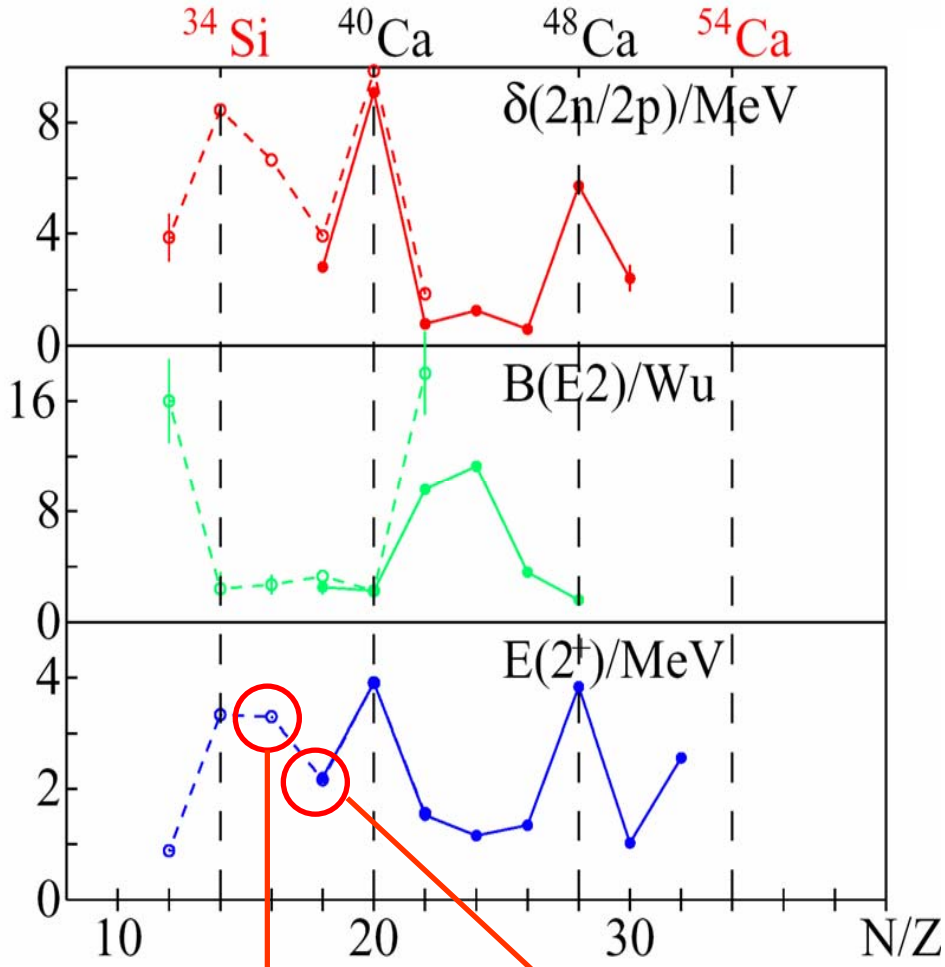
Mirror Symmetry of new (sub)shell closures ^{36}S – ^{36}Ca





Is N,Z=14(16) shell stabilisation and N=20 shell quenching in $^{32}Mg_{20}$ **symmetric in isospin projection T_z**?

New Shell Structure at N»Z
- the mirror point of view -



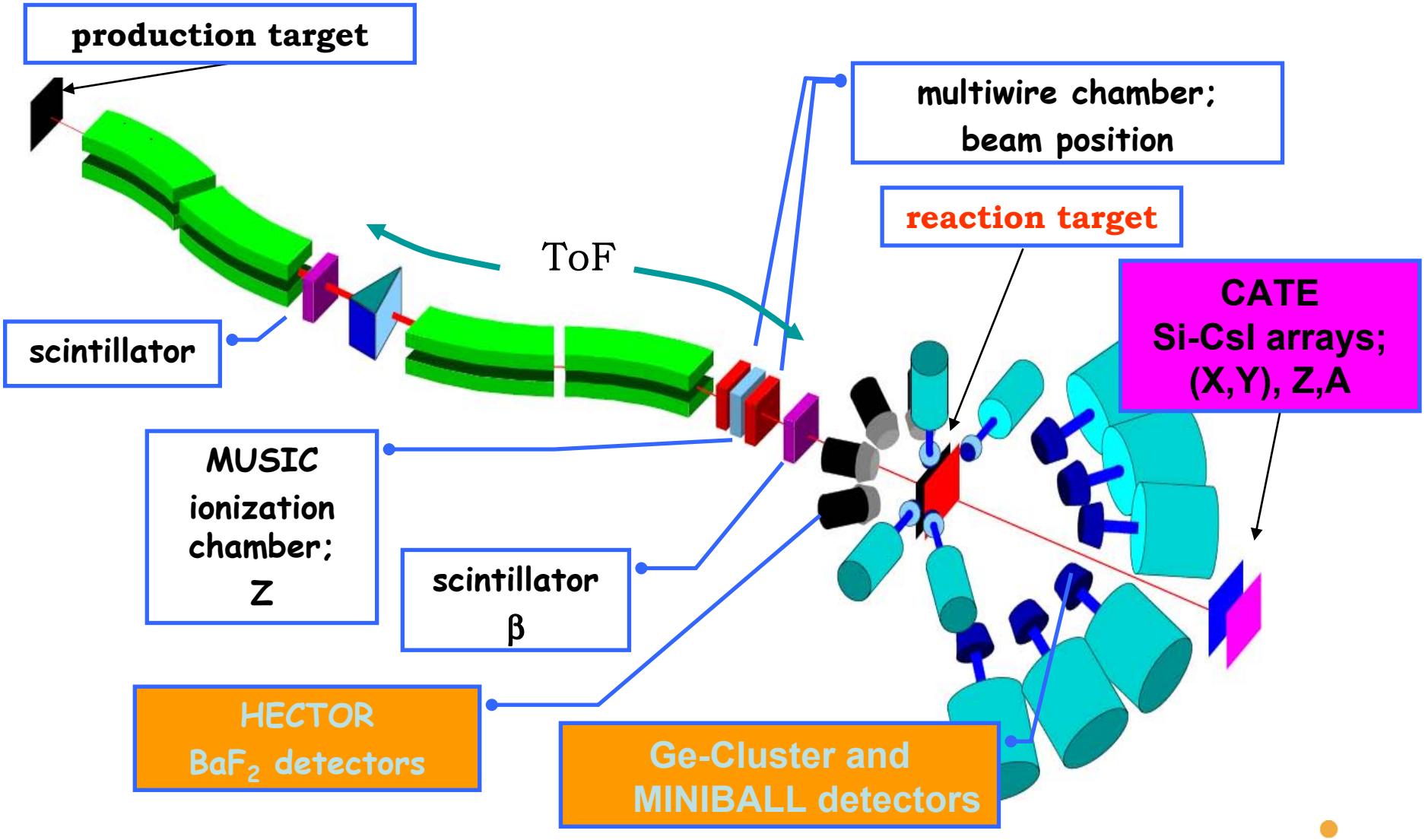
Is N,Z=14(16) shell stabilisation and N=20 shell quenching - symmetric in isospin projection T_z?

Isospin symmetry in Z=20 isotopes - excited states in ^{36}Ca vs ^{36}S

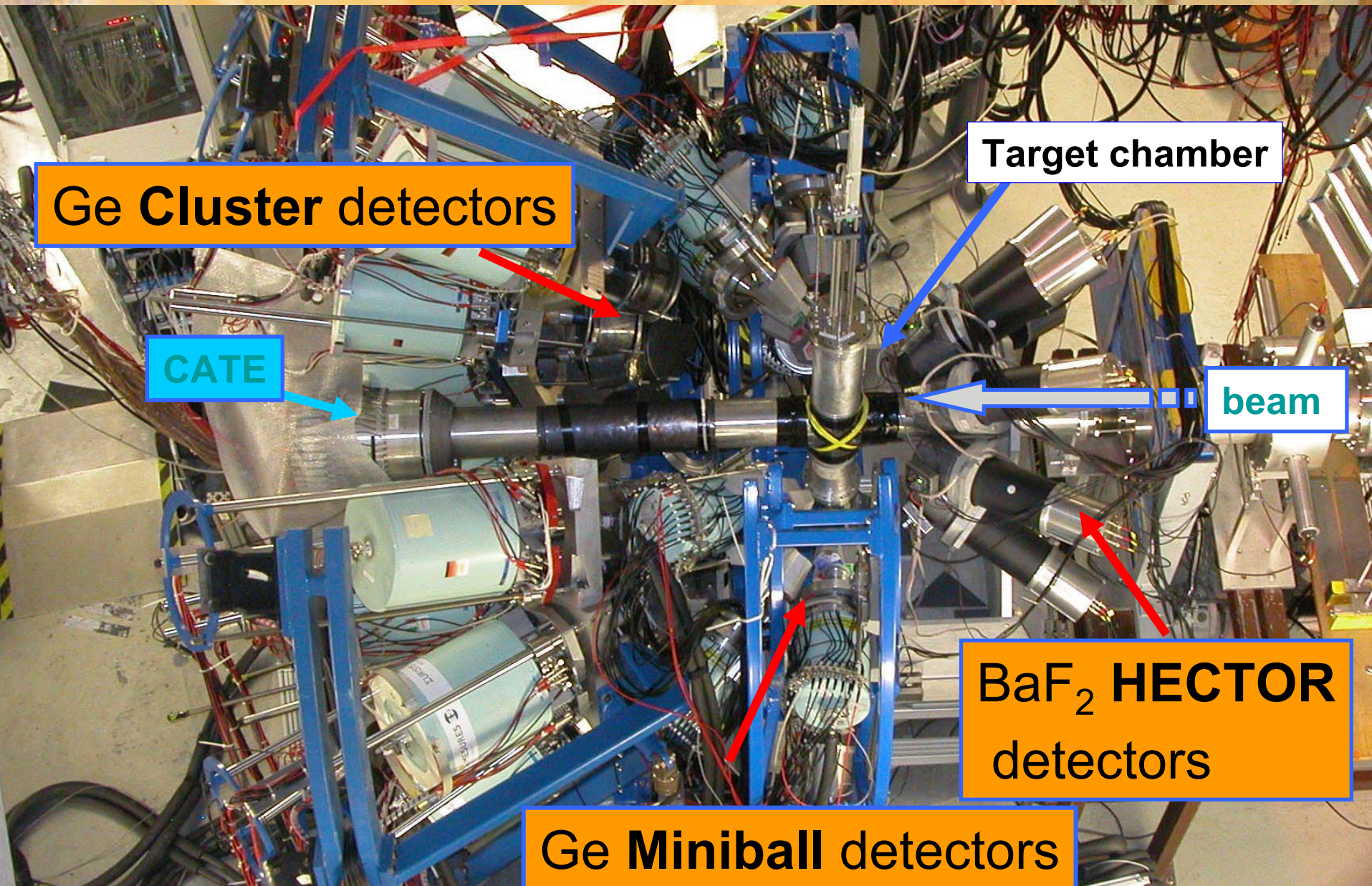
^{36}S; 2^+ = 3291 keV

$$^{38}Ca;2^+ - ^{38}Ar;2^+ = 39\ keV$$

Rising fast beam setup



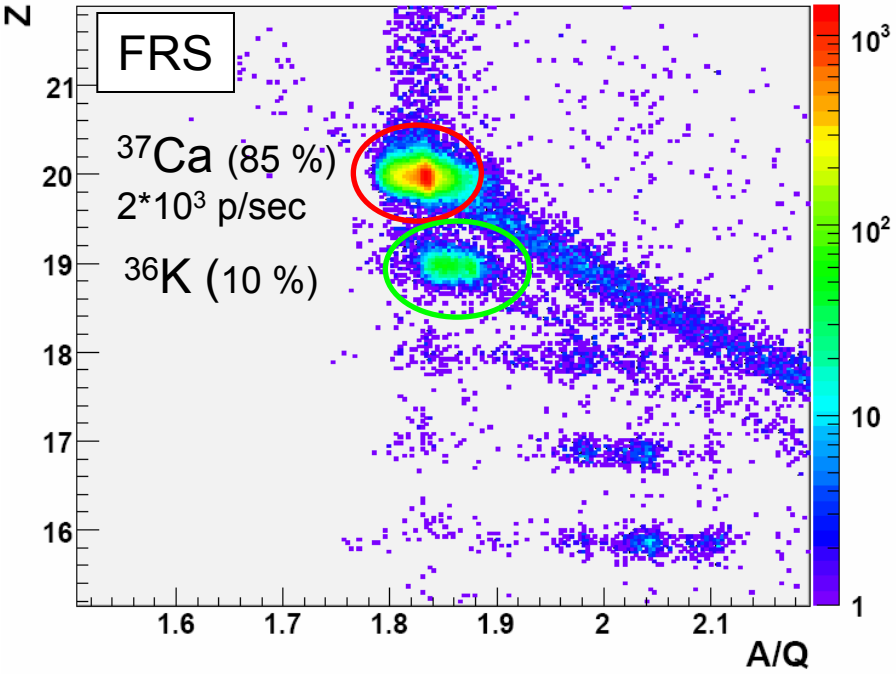
RISING γ-array

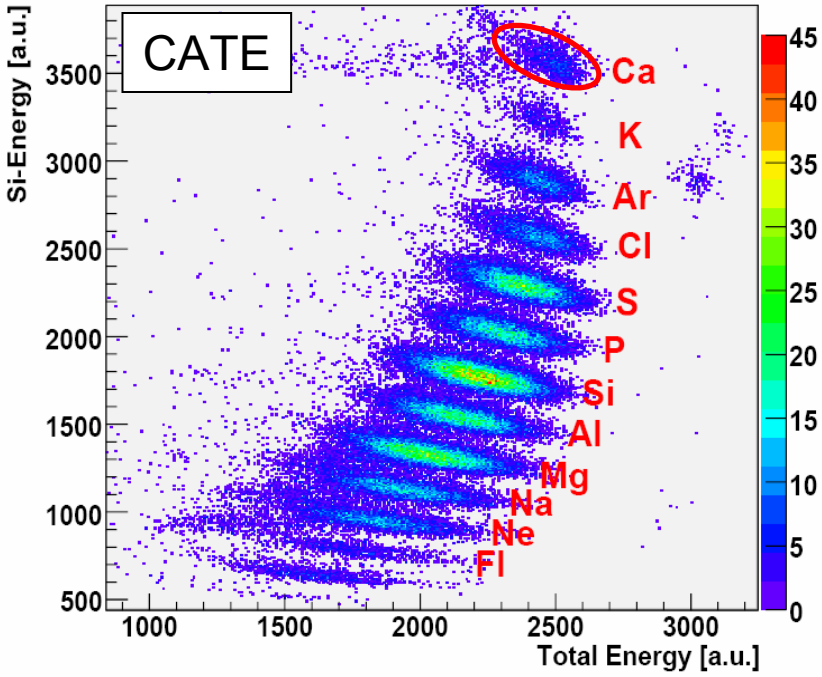


Secondary fragmentation of ^{37}Ca beam

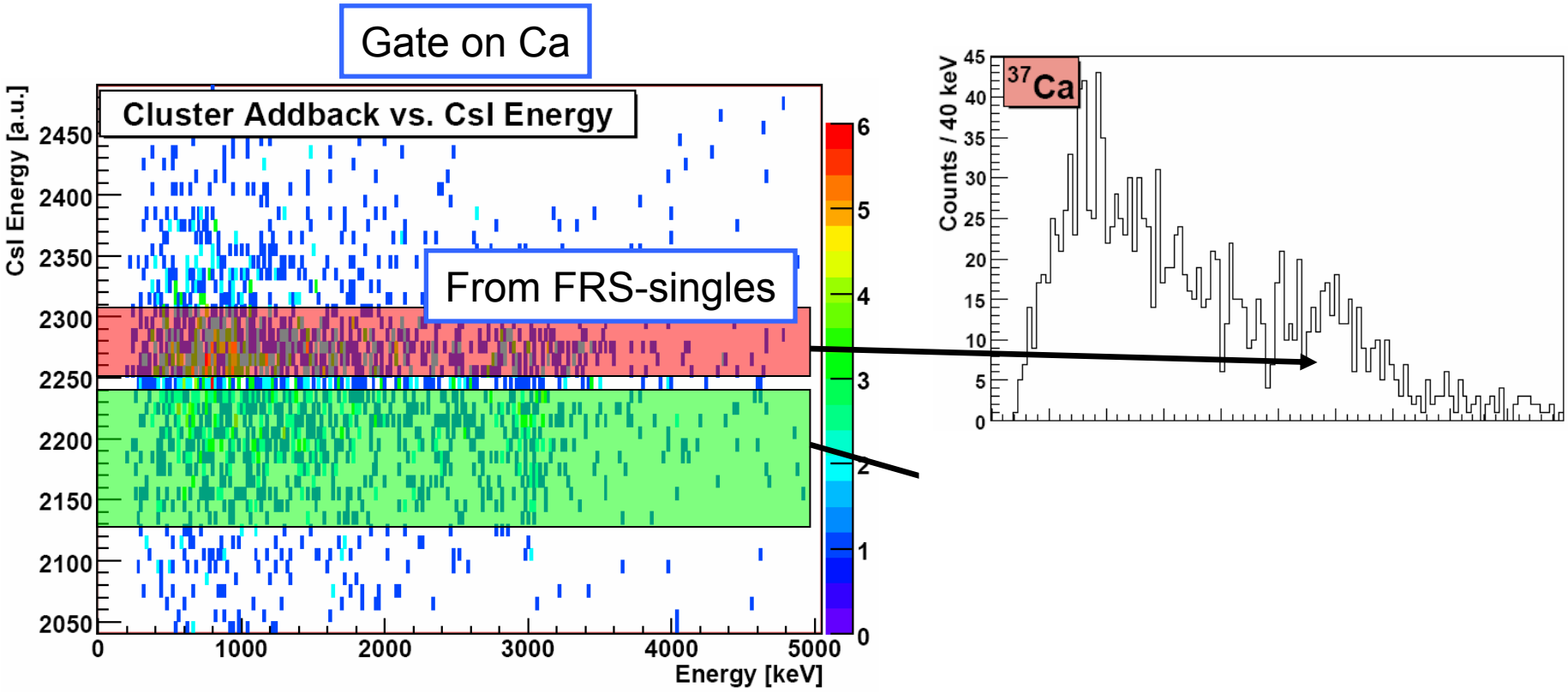
Double fragmentation reaction:

^{40}Ca (420 A MeV) + ^{9}Be (4.0 g/cm^2) → ^{37}Ca (200 A MeV) + ^{9}Be (0.7 g/cm^2)





Distinction of Projectile and 1n-Knockout

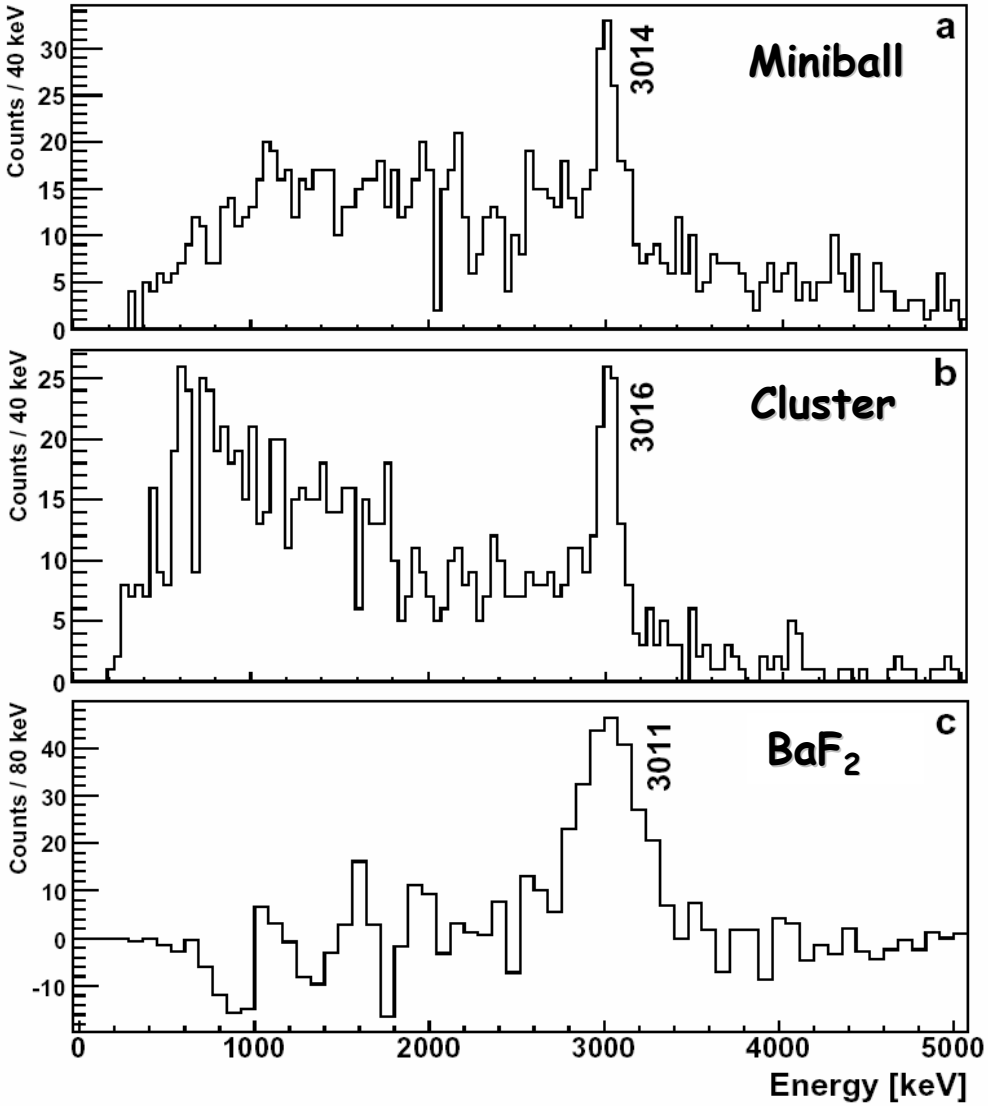


EPAX cross section ratios:

$\sigma(^{35}Ca)/\sigma(^{36}Ca) = 0.006$

Miniball and Cluster

^{36}Ca in the different γ-branches



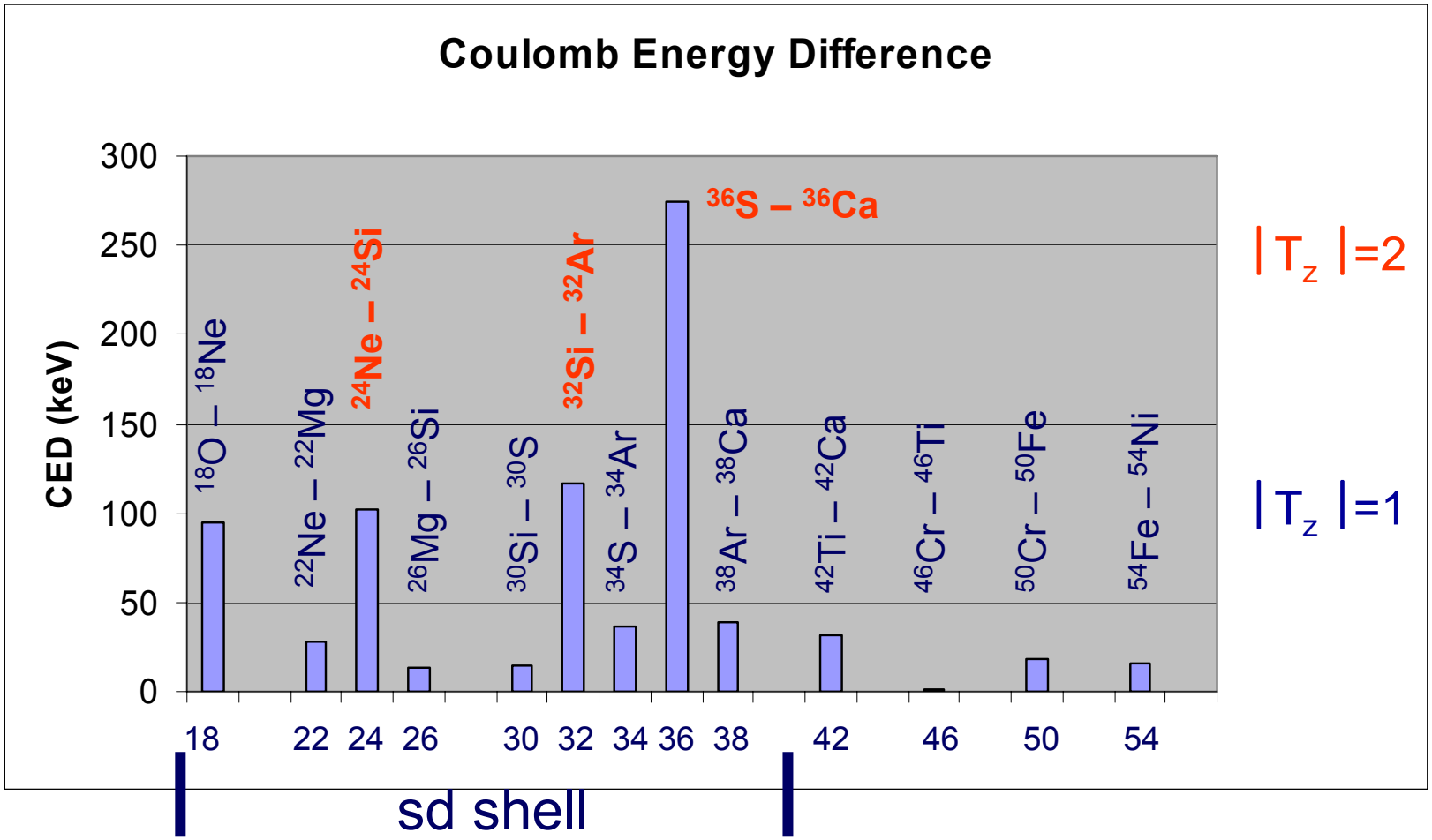
^{36}Ca E(2$^+$) = 3015(16) keV

Ganil: 3023(30) keV

^{36}Ca E(2$^+$) - ^{36}S E(2$^+$) = -276 keV

Coulomb Energy Differences

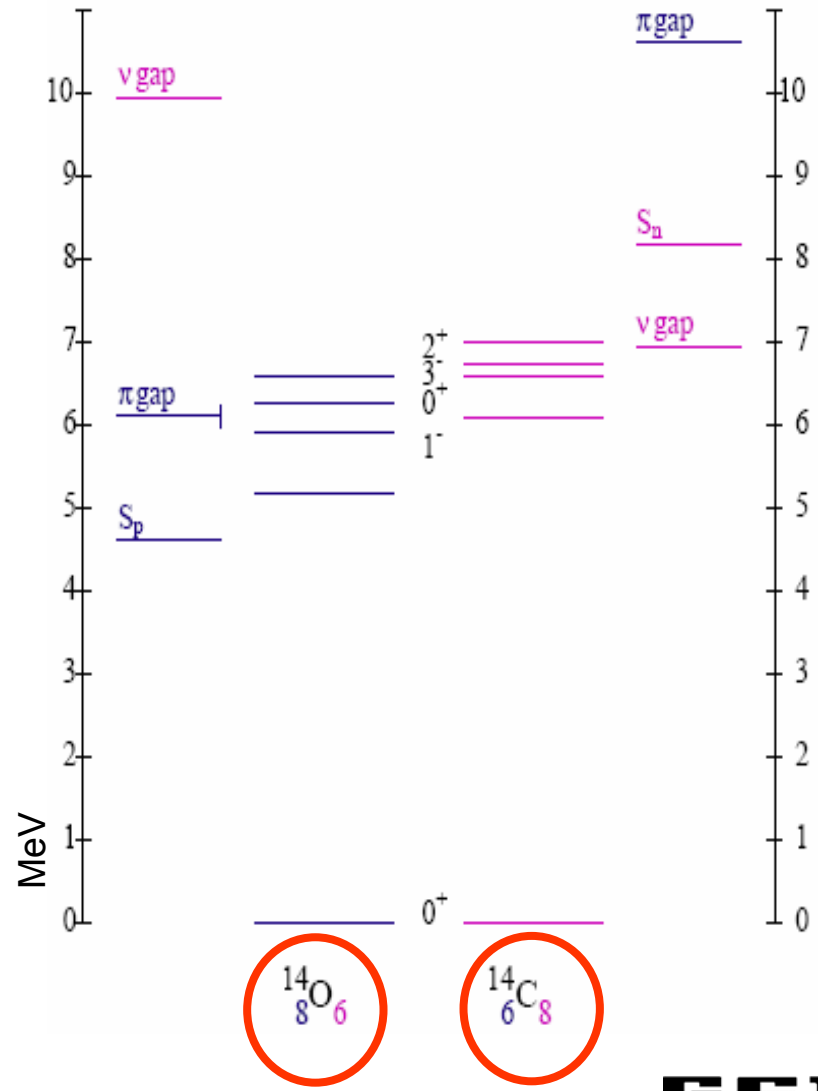
$$CED(I) = E_x(I, T_z = -T) - E_x(I, T_z = +T)$$



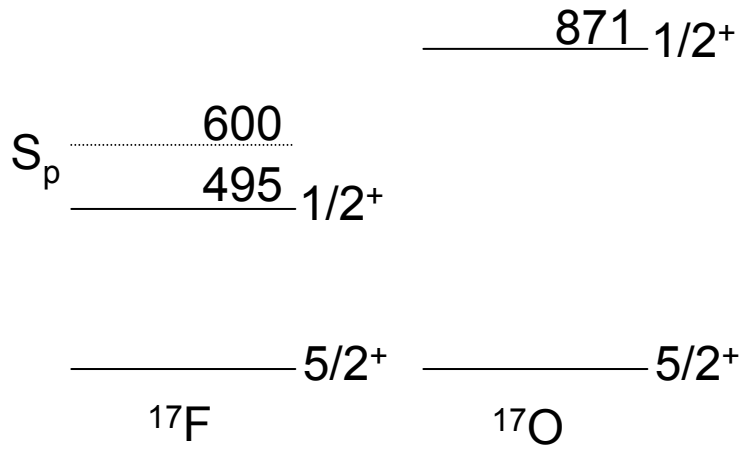
A well known case: The N=1 harmonic oscillator shell

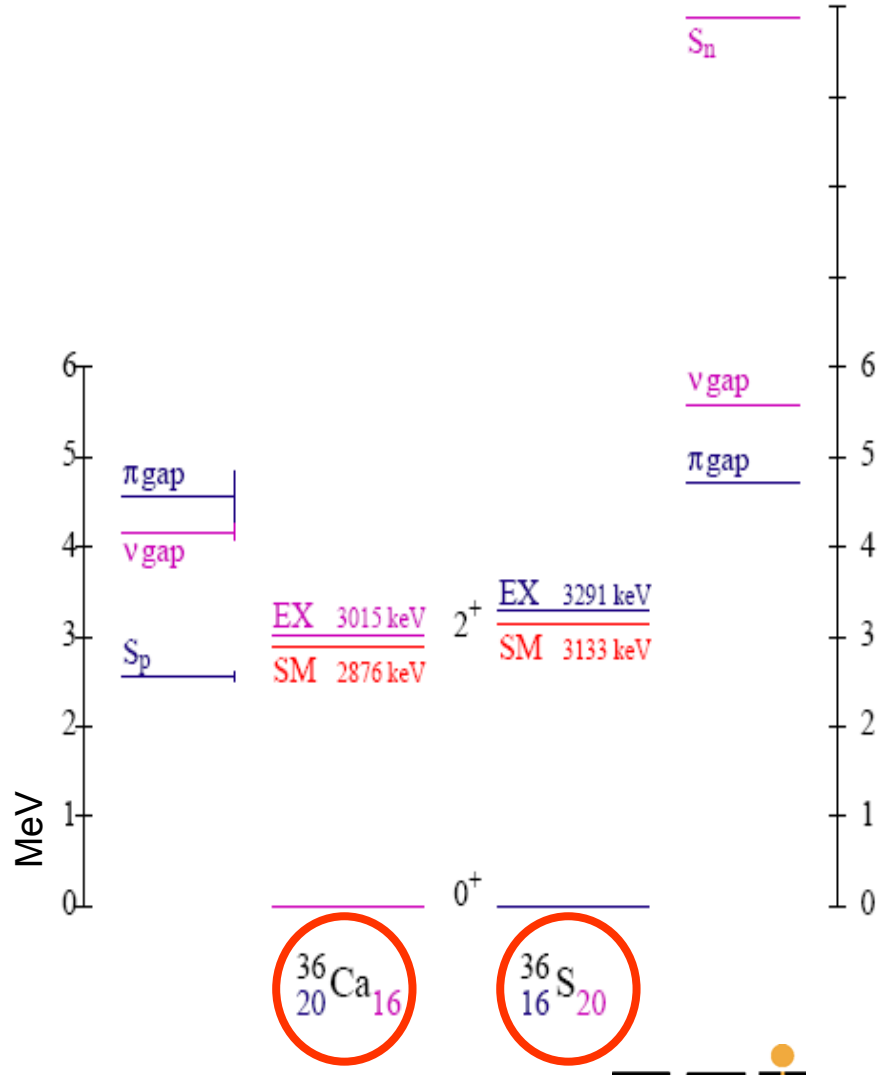
Experimental facts:

- Excited states in ^{14}O are above the proton separation energy S_P
- The proton (π=8) gap in ^{14}O is smaller than the neutron (ν=8) gap in ^{14}C
- The neutron (ν=6) gap in ^{14}O is smaller than the proton (π=6) gap in ^{14}C
- Cross shell excitations for protons involve unbound states, which are coupled to the continuum (Thomas-Ehrmann shift)
- This affects neutrons via N-P interaction



Shell model calculations for ^{36}Ca and ^{36}S

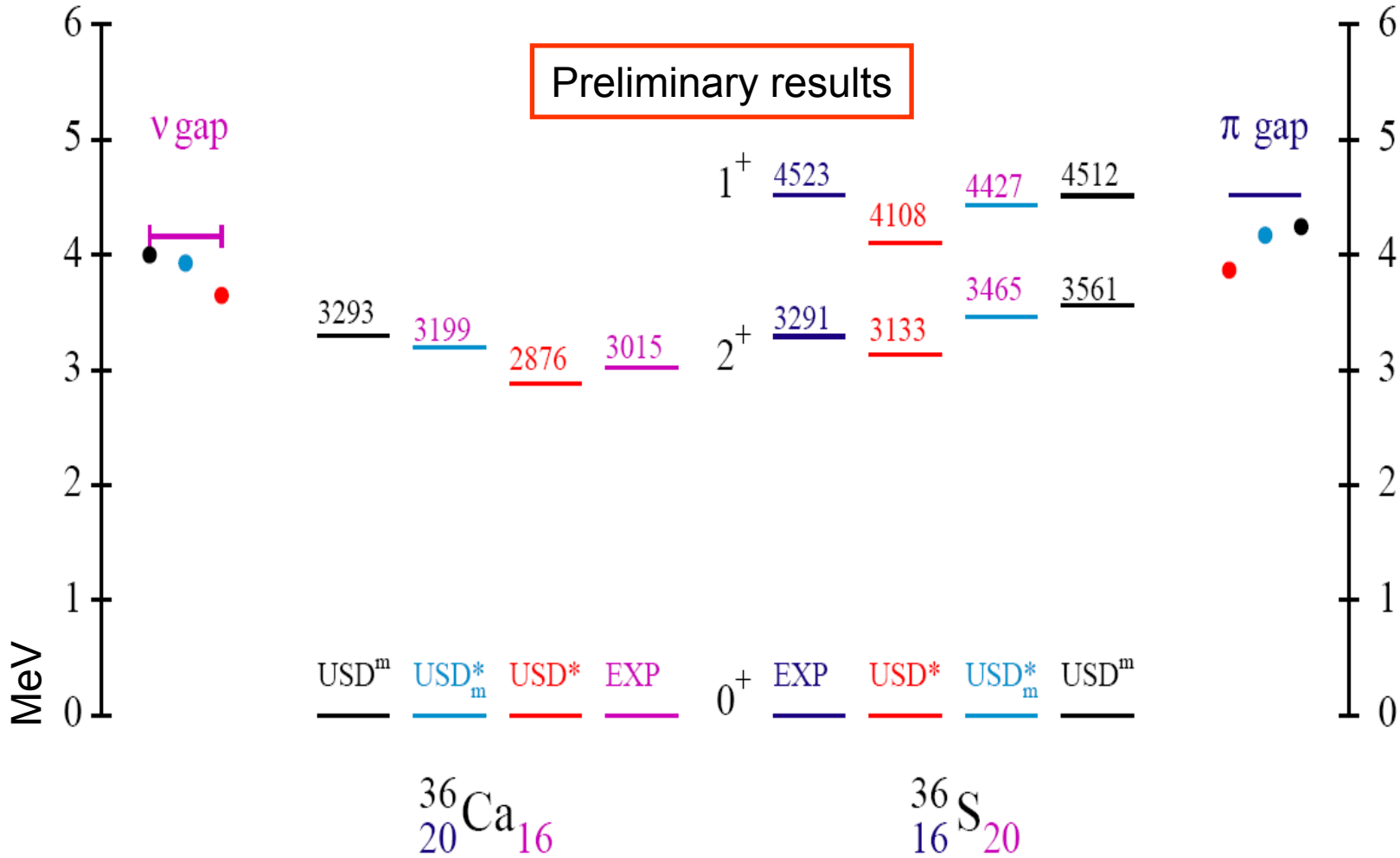




- sd shell model with (USD)* interaction and experimental single particle energies (SPE) from ^{17}O and ^{17}F reproduce the energy shift qualitatively

*B.A. Brown , B.H. Wildenthal: Ann. Rev. of Nucl. Part. Sci. 38, 29 (1988)

Shell model calculations for ^{36}Ca and ^{36}S



USD^m: Utsuno et al. Phys. Rev. C60, 054315 (1999)
USD*: USD using SPE from ^{17}O and ^{17}F
USD*$_m$: Modification of $\pi\nu s_{1/2}d_{3/2}$

Shell model calculations for ^{36}Ca and ^{36}S

Preliminary results, excitation energies in keV

	State	Exp/(p,d)	USD*	USD^m	$\pi\nu s_{1/2}d_{5/2}$	$\pi\nu s_{1/2}d_{3/2}$
^{39}Ca	$3/2^+$	0	0	0	0	0
	$1/2^+$	2650	2134	2608	2492	2372
^{39}K	$3/2^+$	0	0	0	0	0
	$1/2^+$	2730	2426	2899	2783	2663
^{36}Ca	2^+	3016	2876	3293	3089	3089
^{36}S	2^+	3291	3133	3561	3353	3353
^{36}Ca	ν gap	4160 (90)	3647	3999	3825	3928
^{36}S	π gap	4524(2)#	3867	4244	4061	4170

#Coulomb corrected by B.H. Wildenthal

Summary

- Large Coulomb energy difference between ^{36}S and ^{36}Ca
- Can be associated to Thomas-Ehrmann shift
- Preliminary shell model calculations using isospin symmetric USD reproduce this shift qualitatively
- At a later stage excitation across Z,N=20 have to be included

RISING fast-beam collaboration

Mirror symmetry of new subshell closures: ^{36}Ca vs ^{36}S

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