Normal occupancy of deeply bound valence neutrons in ^{37}Ca

A. Bürger[1*], F. Azaiez[2], A. Algora[3], A. Al Khatib[1], B. Bastin[4], G. Benzoni[5], R. Borcea[6], C. Bourgeois[2], P. Bringel[1], E. Clément[7], J.-C. Dalouzy[8], Z. Dlouhy[9], Z. Dombradi[3], A. Drouart[7], C. Engelhardt[1], S. Franchoo[2], Z. Fülöp[3], A. Görgen[7], S. Grévy[8], H. Hübel[1], F. Ibrahim[2], W. Korten[7], J. Mrazek[9], A. Navin[8], F. Rotaru[6], P. Roussel-Chomaz[8], M.-G. Saint-Laurent[8], G. Sletten[10], D. Sohler[3], O. Sorlin[8], M. Stanoiu[11], I. Stefan[2], C. Theisen[7], C. Timis[12], D. Verney[2], and S. Williams[12]

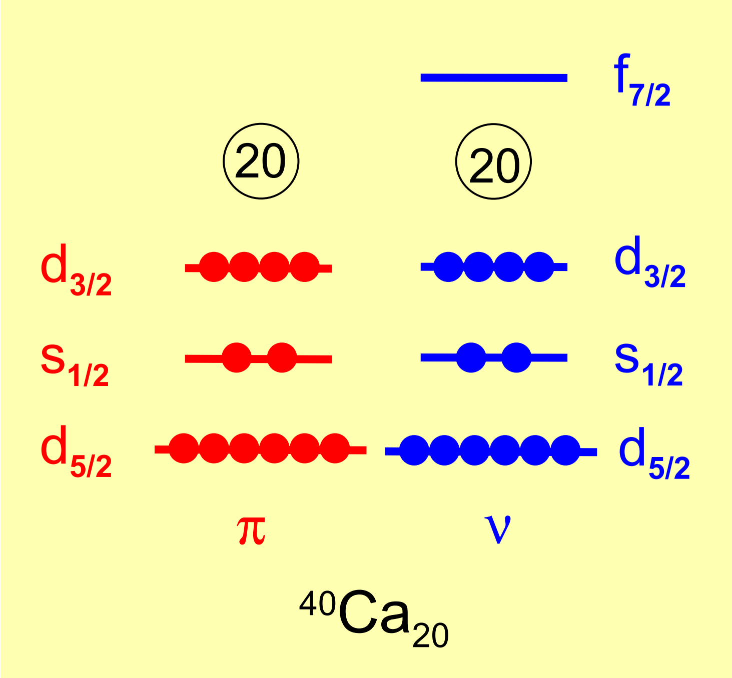
(1) University of Bonn, Germany (2) IPNO, Orsay, France (3) Institute of Nuclear Research, Debrecen, Hungary (4) LPC, Caen, France (5) University of Milan, Italy (6) IFIN-HH, Bucharest, Romania (7) Dapnia, Saclay, France (8) Ganil, Caen, France (9) Nuclear Physics Institute, Rez, Czech Republic (10) Niels Bohr Institute, Copenhagen, Denmark (11) GSI, Darmstadt, Germany (12) University of Surrey, Guildford, United Kingdom (*present address: Safe, University of Oslo, Norway)

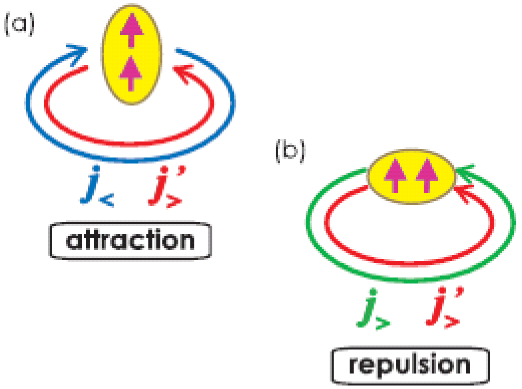
Motivation: tensor force

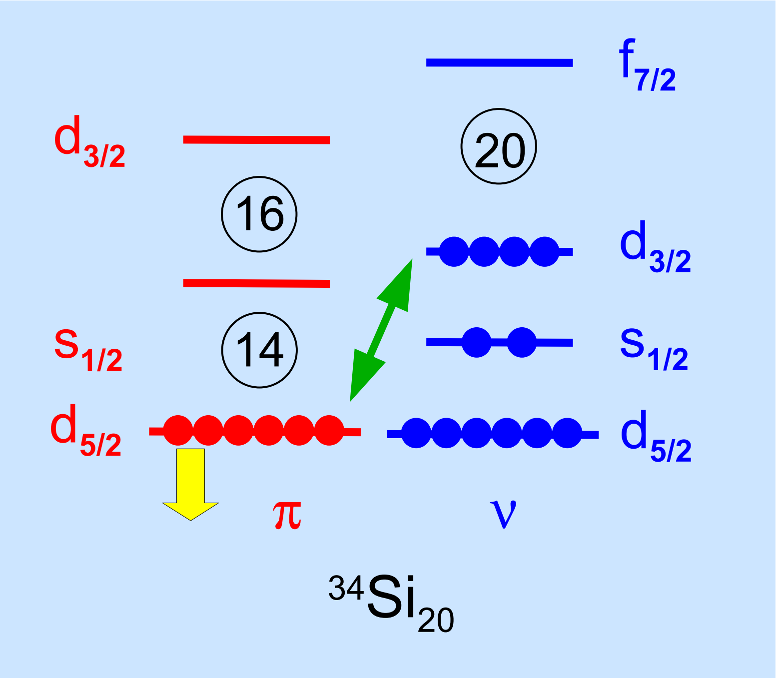
νd ↔ πd tensor force
T Otsuka et al,
PRL 97 (2006) 162501

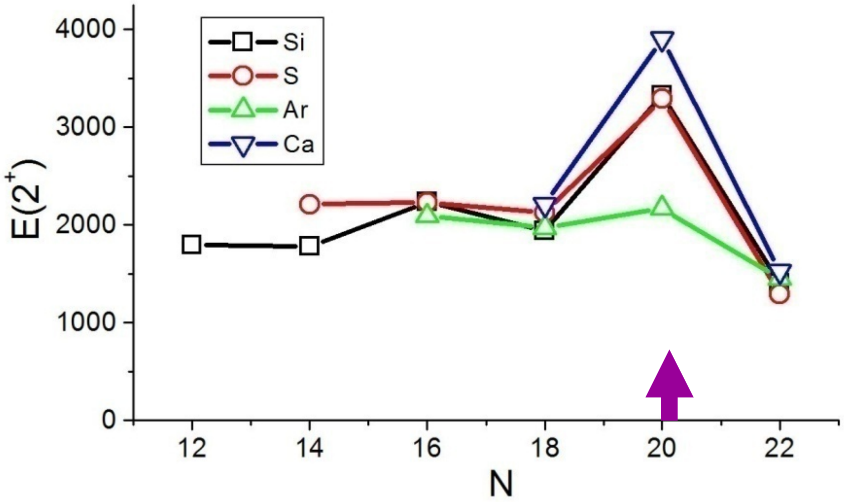
Z=14 ^{34}Si and Z=16 ^{36}S magic

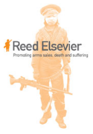
island of inversion!









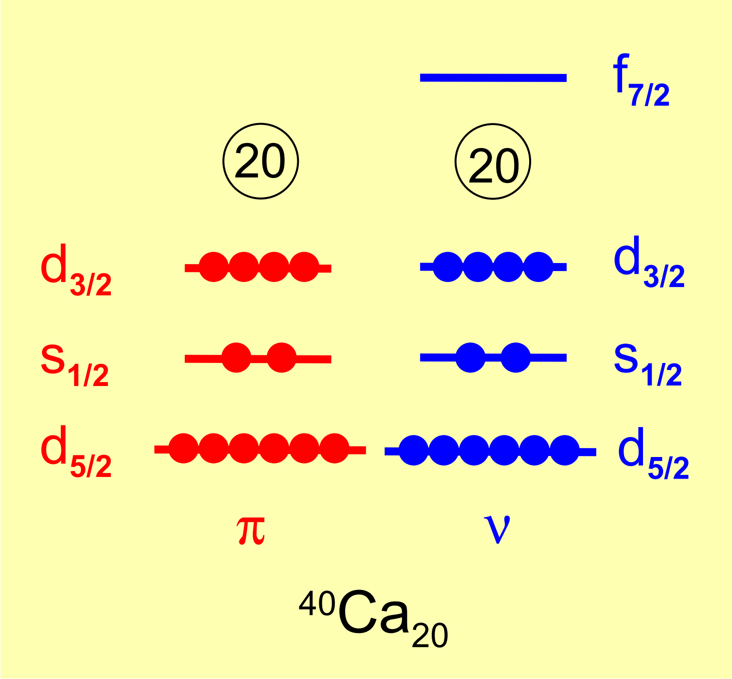


Motivation: tensor force

$\nu d \leftrightarrow \pi d$ tensor force
T Otsuka et al,
PRL 97 (2006) 162501

Z=14 ^{34}Si and Z=16 ^{36}S
magic

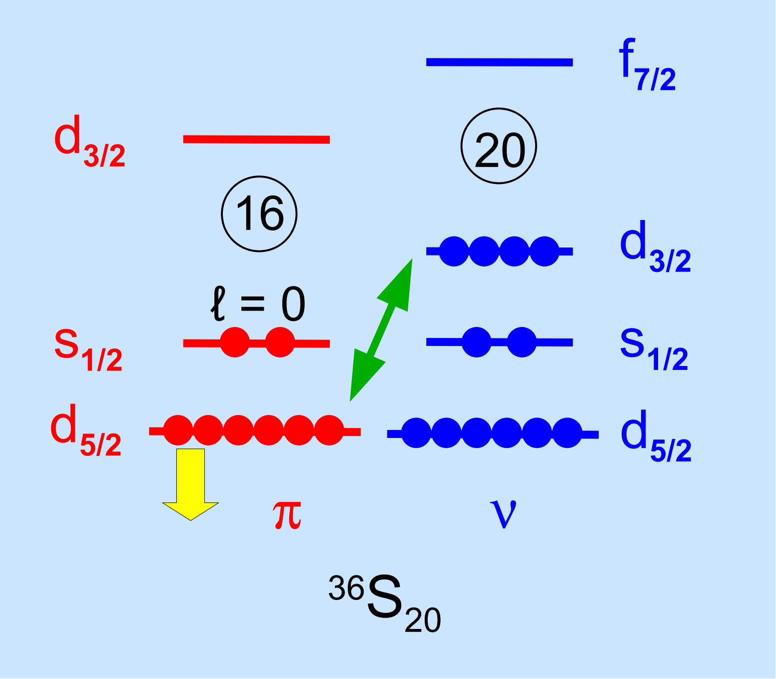
island of inversion

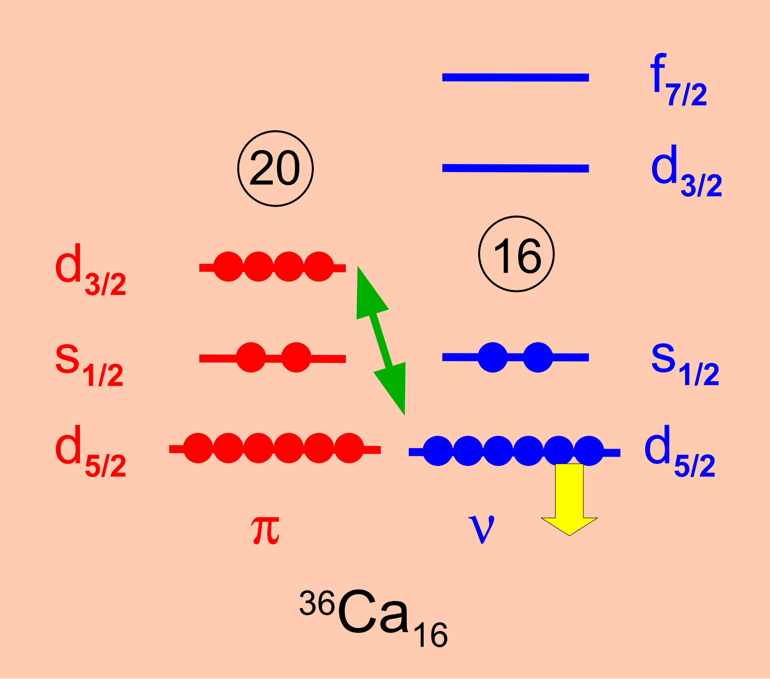


mirrors ^{34}Ca and ^{36}Ca
also doubly magic?

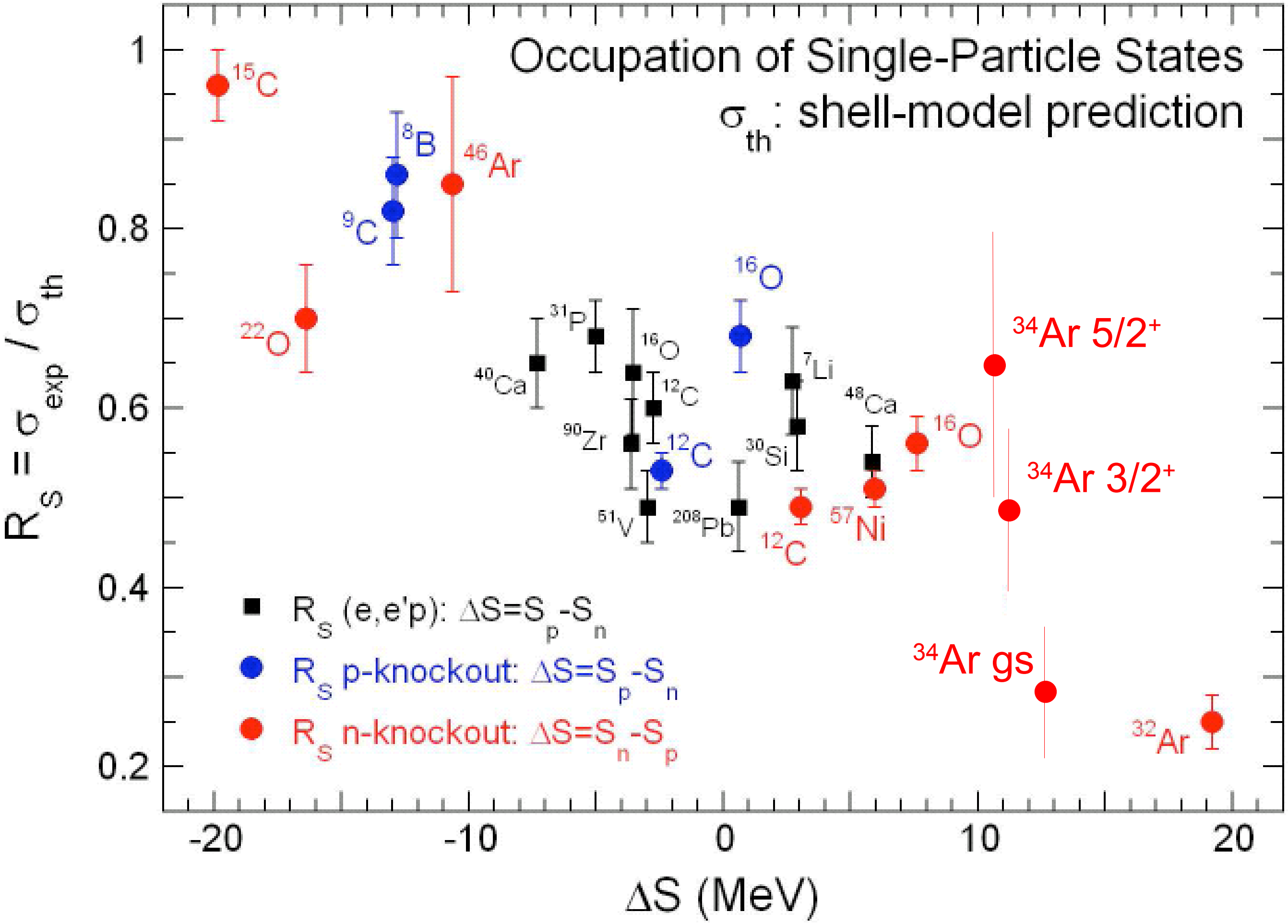
island of inversion
at proton drip line?

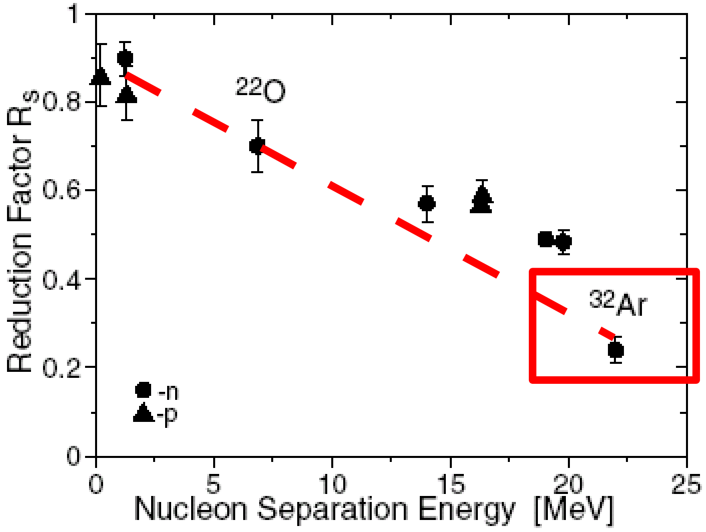
$\Rightarrow$ measure 2^+ ^{36}Ca !

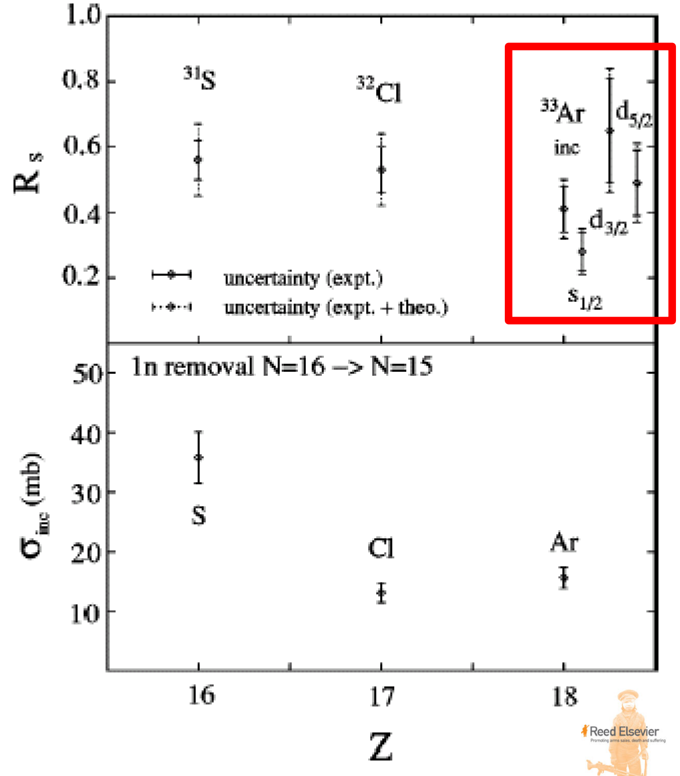




Motivation: knock-out quenching







$R_S(^{32}Ar \rightarrow ^{31}Ar, 1d_{5/2}) = 0.24$

$R_S(^{34}Ar \rightarrow ^{33}Ar, 2s_{1/2}) = 0.28$

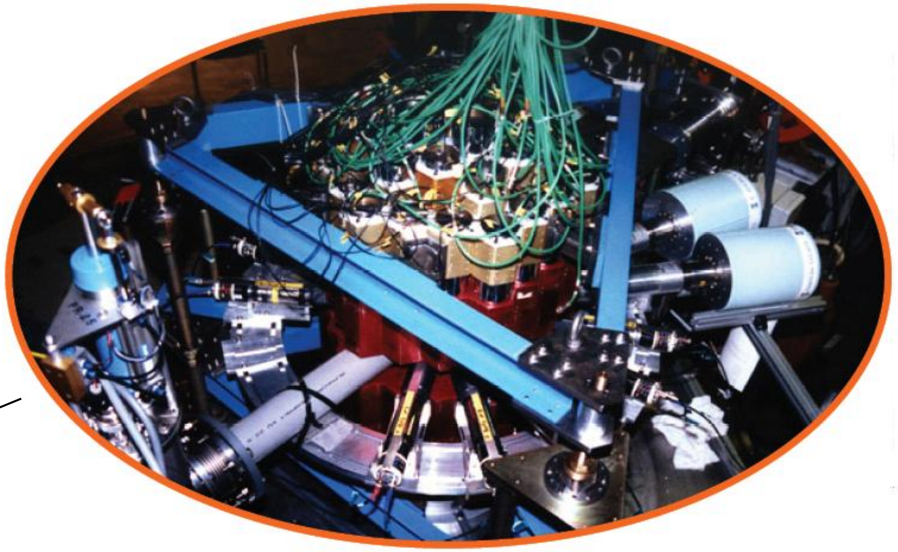
A Gade et al, PRL 93, 042501 & PRC 69, 034311 (2004)

⇒ measure R_s for closed shell nucleus ^{36}Ca !

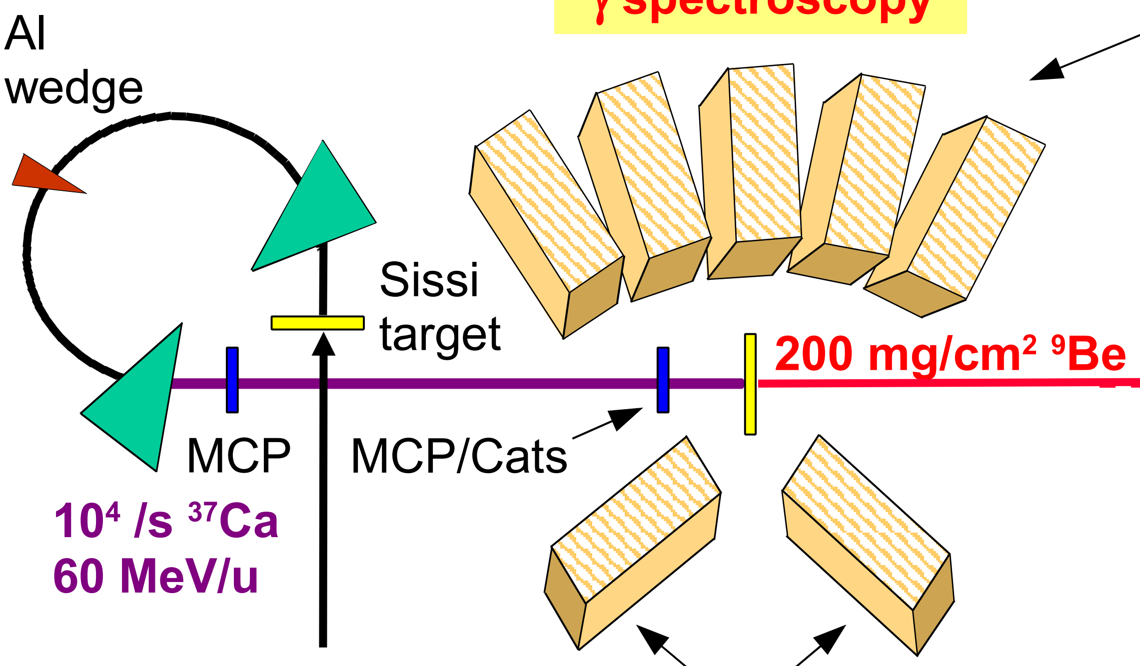
Knock out at Ganil

In-beam γ spectroscopy at Speg
one-neutron removal from radioactive ^{37}Ca beam

L. Bianchi et al., Nucl. Instr. Meth. A 276, 509 (1989)
E. Sauvan et al., PLB 491, 1 (2000)



γ spectroscopy



Al wedge

Sissi target

MCP

MCP/Cats

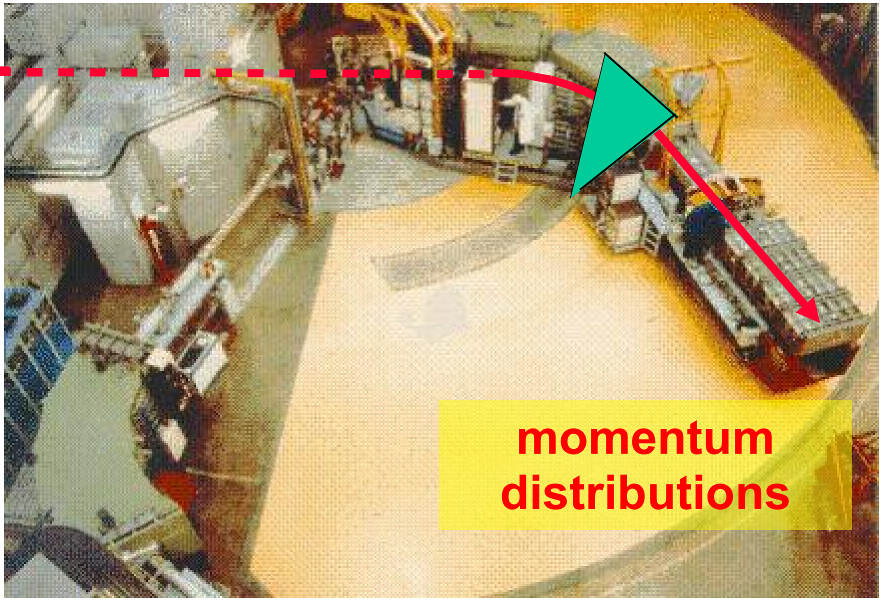
200 mg/cm² ^{9}Be

10^4 /s ^{37}Ca
60 MeV/u

^{40}Ca
95 MeV/u

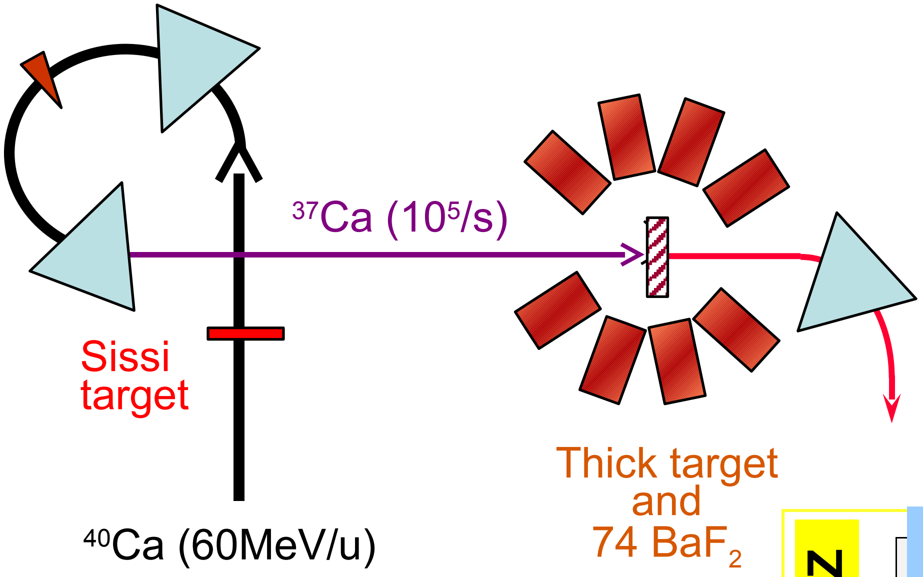
74 BaF_2 detectors
Château de Cristal

Speg spectrometer

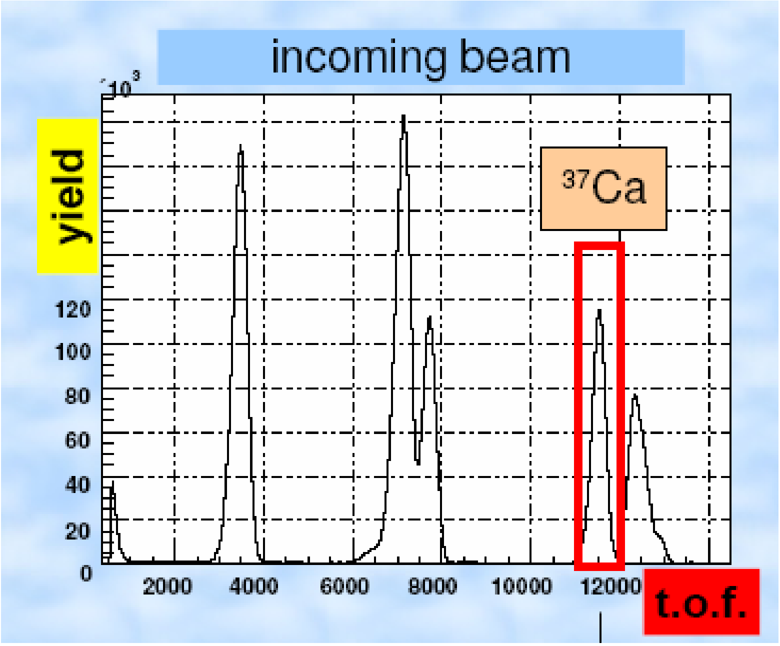


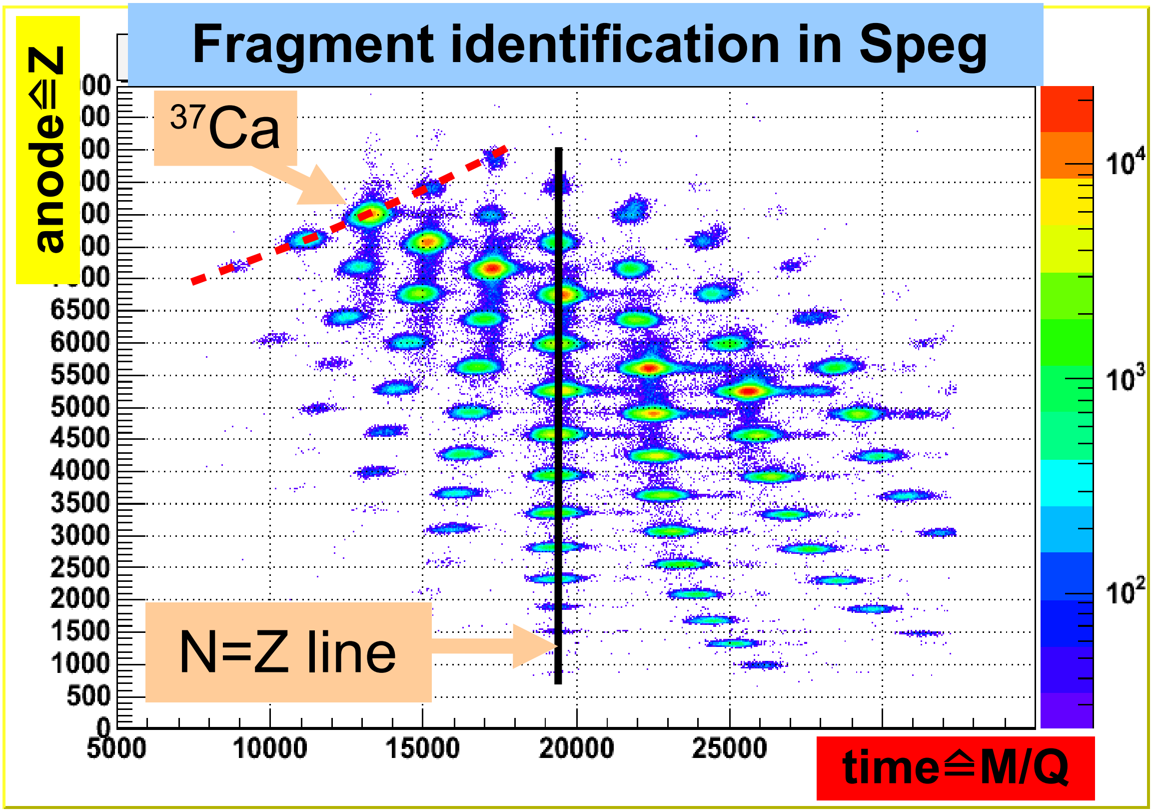
momentum distributions

Knock out at Ganil



γ spectroscopy with one-neutron knock-out reactions from ^{37}Ca RNB

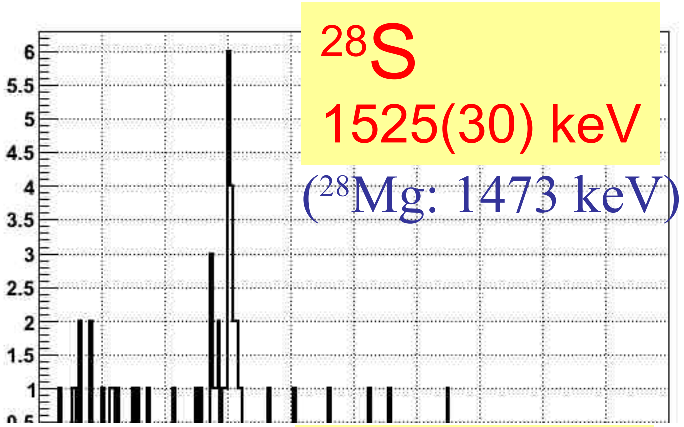




γ spectroscopy at the proton drip line

Systematics of T=2 and T=3/2 mirrors

A Bürger et al, in preparation



^{28}S

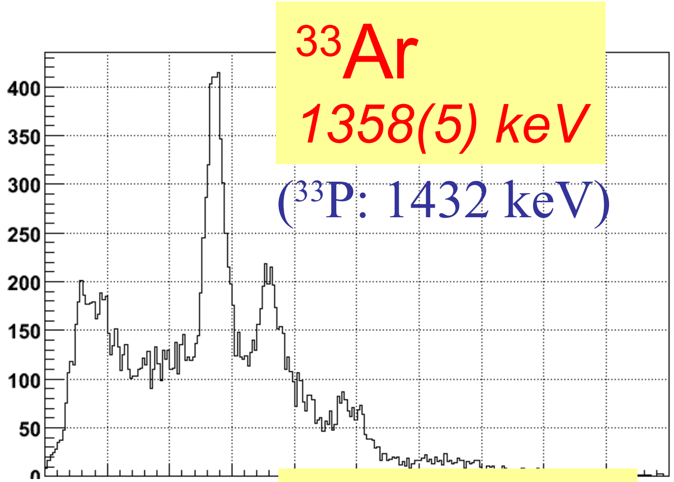
1525(30) keV

(^{28}Mg: 1473 keV)

^{32}Ar

1873(20) keV

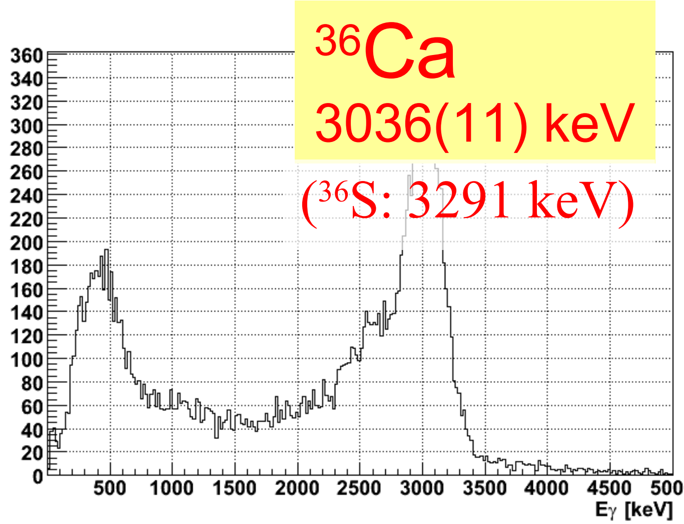
(^{32}Si: 1942 keV)



^{33}Ar

1358(5) keV

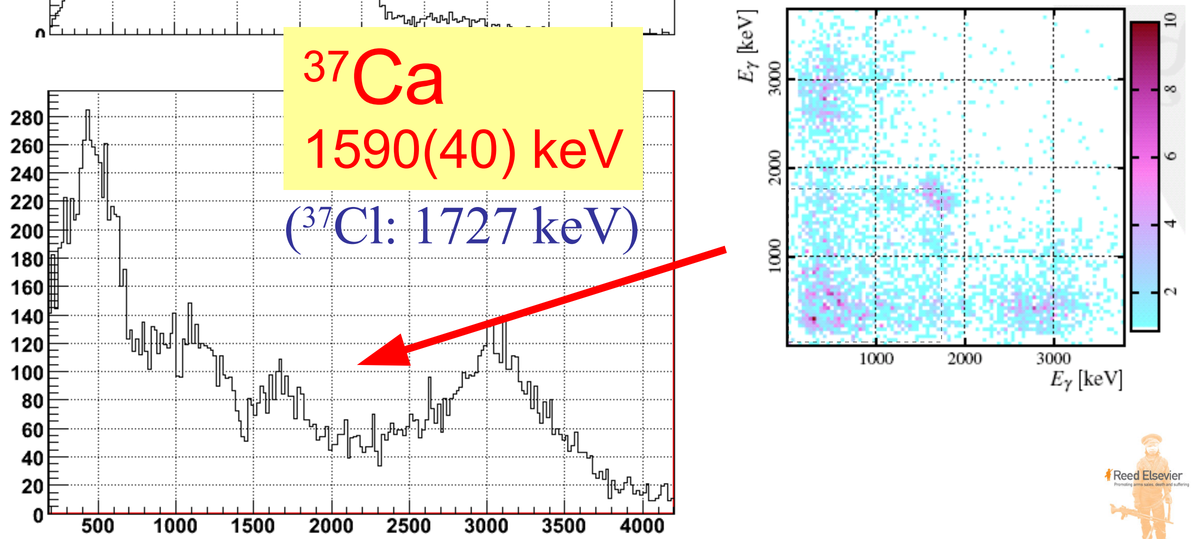
(^{33}P: 1432 keV)



^{36}Ca

3036(11) keV

(^{36}S: 3291 keV)

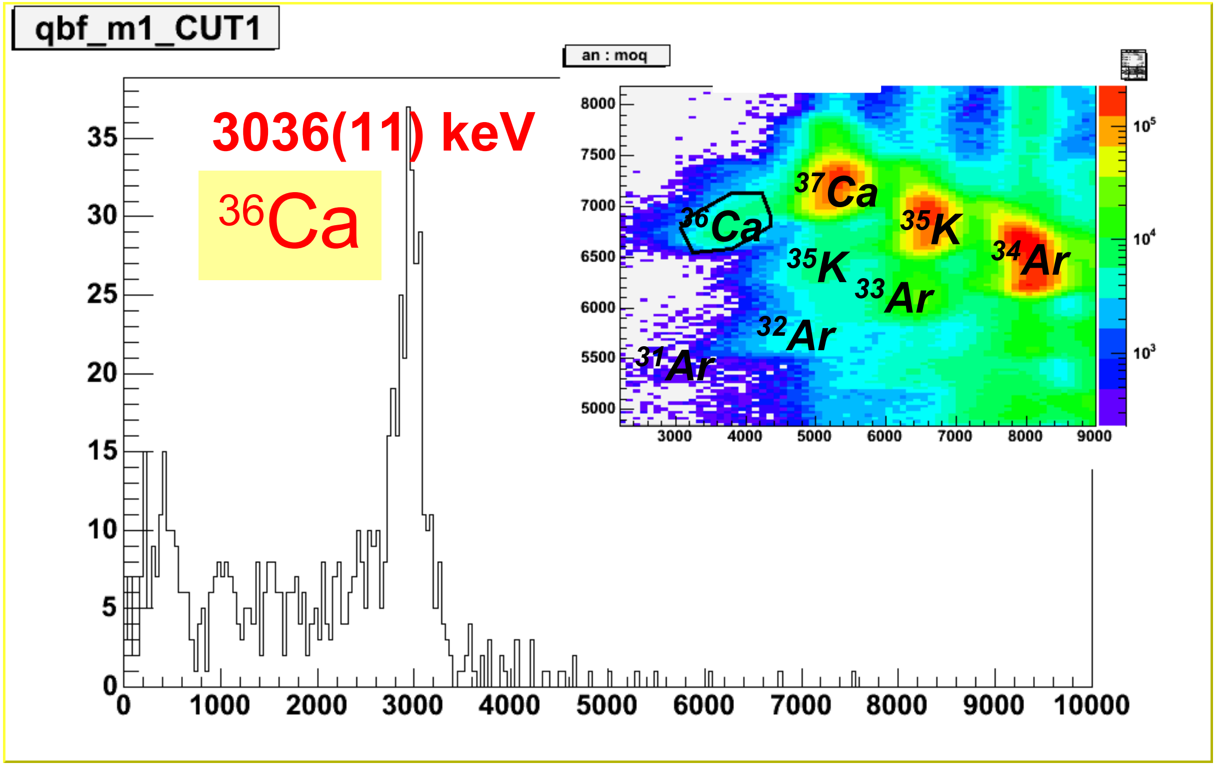


^{37}Ca

1590(40) keV

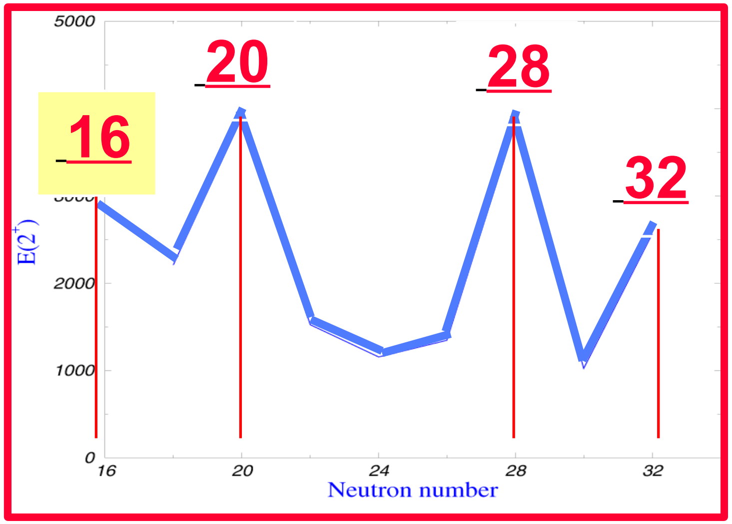
(^{37}Cl: 1727 keV)

γ spectroscopy at the proton drip line



γ decay from 2^+ in ^{36}Ca above S_p = 2560 keV

$\Gamma_\gamma > \Gamma_p \Rightarrow$ proton SF small



Well reproduced by only 1 γ ray

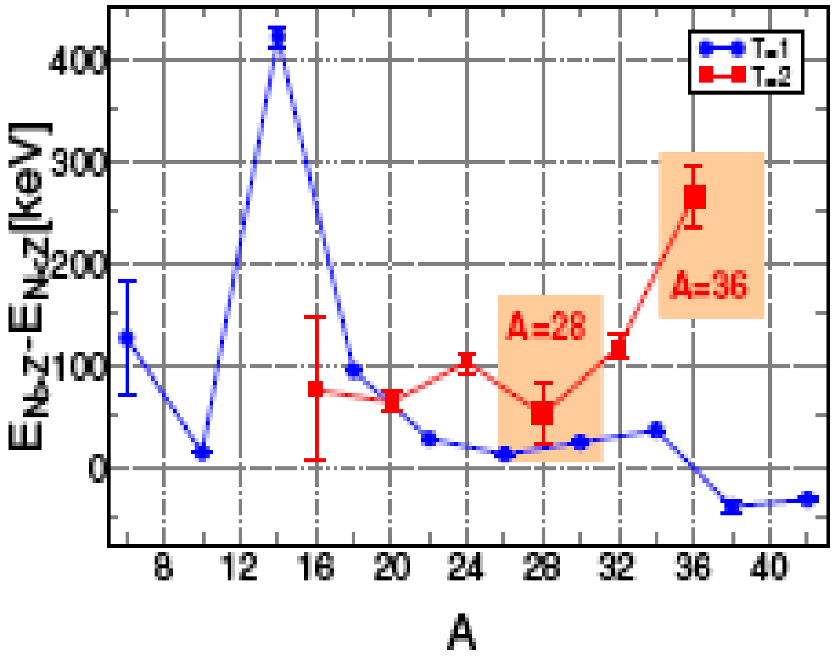
N=16 gap ⇒ ^{36}Ca doubly magic !

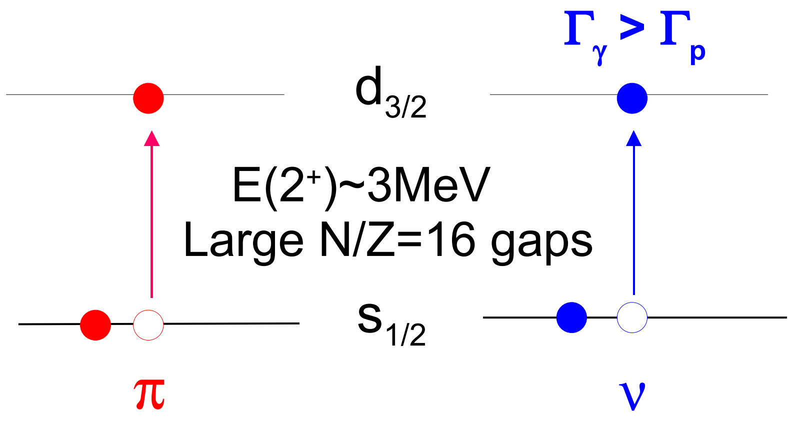
A Bürger et al, in preparation

S. Franchoo, EGP, Paris, May 2008

γ spectroscopy at the proton drip line

Mirror energy differences





$E(2^+)$~3MeV
Large N/Z=16 gaps

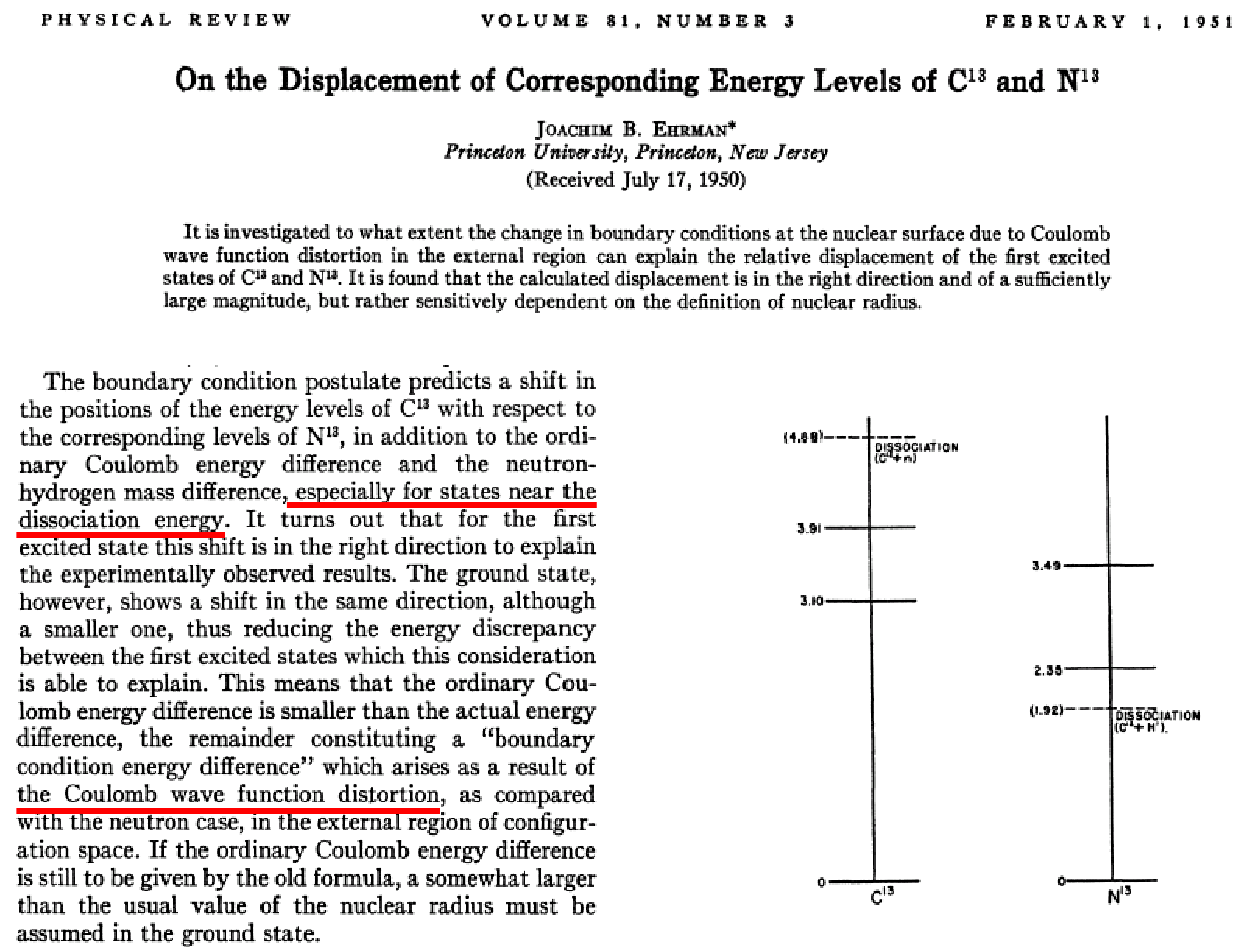
$2^+(^{36}S, N=20)$
well bound:
no TES

$2^+(^{36}Ca, Z=20)$
neutron state:
no TES

$\Delta E_{Coulomb}(2s_{1/2}-1d_{3/2})$ = 50 keV (SLy4) and 150 keV (SkI3)
HFB, M Grasso IPN Orsay

- **purity of the neutron (proton) configuration in ^{36}Ca (^{36}S)**
- **depends critically on density of s wavefunction**

A Bürger et al, in preparation



PHYSICAL REVIEW VOLUME 81, NUMBER 3 FEBRUARY 1, 1951

On the Displacement of Corresponding Energy Levels of C^{13} and N^{13}

JOACHIM B. EHRMAN*
Princeton University, Princeton, New Jersey

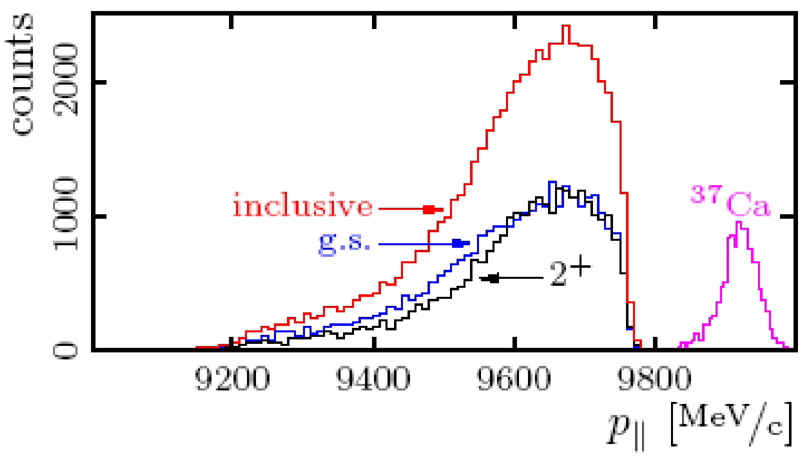
(Received July 17, 1950)

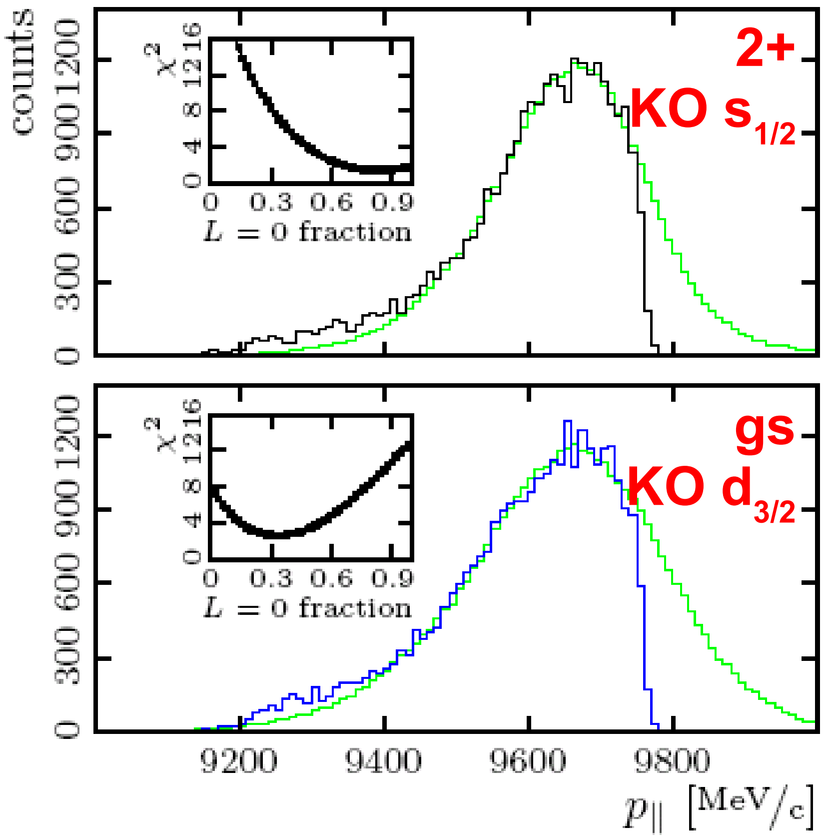
It is investigated to what extent the change in boundary conditions at the nuclear surface due to Coulomb wave function distortion in the external region can explain the relative displacement of the first excited states of C^{13} and N^{13}. It is found that the calculated displacement is in the right direction and of a sufficiently large magnitude, but rather sensitively dependent on the definition of nuclear radius.

The boundary condition postulate predicts a shift in the positions of the energy levels of C^{13} with respect to the corresponding levels of N^{13}, in addition to the ordinary Coulomb energy difference and the neutron-hydrogen mass difference, especially for states near the dissociation energy. It turns out that for the first excited state this shift is in the right direction to explain the experimentally observed results. The ground state, however, shows a shift in the same direction, although a smaller one, thus reducing the energy discrepancy between the first excited states which this consideration is able to explain. This means that the ordinary Coulomb energy difference is smaller than the actual energy difference, the remainder constituting a "boundary condition energy difference" which arises as a result of the Coulomb wave function distortion, as compared with the neutron case, in the external region of configuration space. If the ordinary Coulomb energy difference is still to be given by the old formula, a somewhat larger than the usual value of the nuclear radius must be assumed in the ground state.

J. Ehrman, Phys. Rev. 81(1951) 412

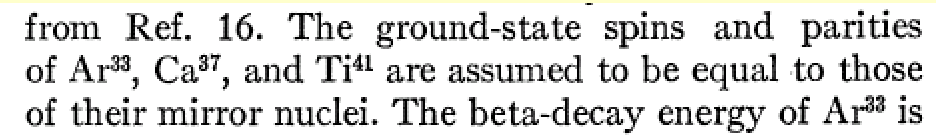
Momentum distributions





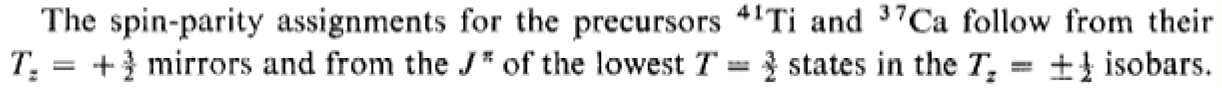
- thick target ⇒ reaction takes place at any depth (Geant4)
- minimize χ^2 for $\alpha(\ell=0) + \beta(\ell=2)$

⇒ $3/2^+$ ^{37}Ca ground state



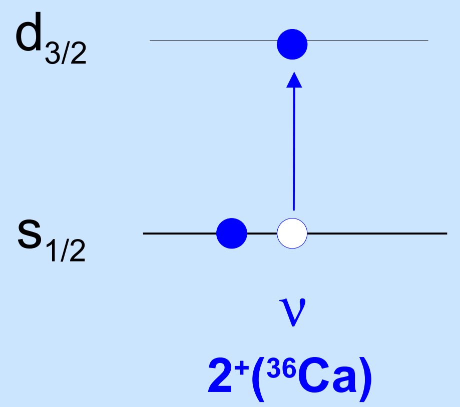
from Ref. 16. The ground-state spins and parities of Ar^{33}, Ca^{37}, and Ti^{41} are assumed to be equal to those of their mirror nuclei. The beta-decay energy of Ar^{33} is

A.M.Poskanzer et al, Phys.Rev. 152, 995 (1966)



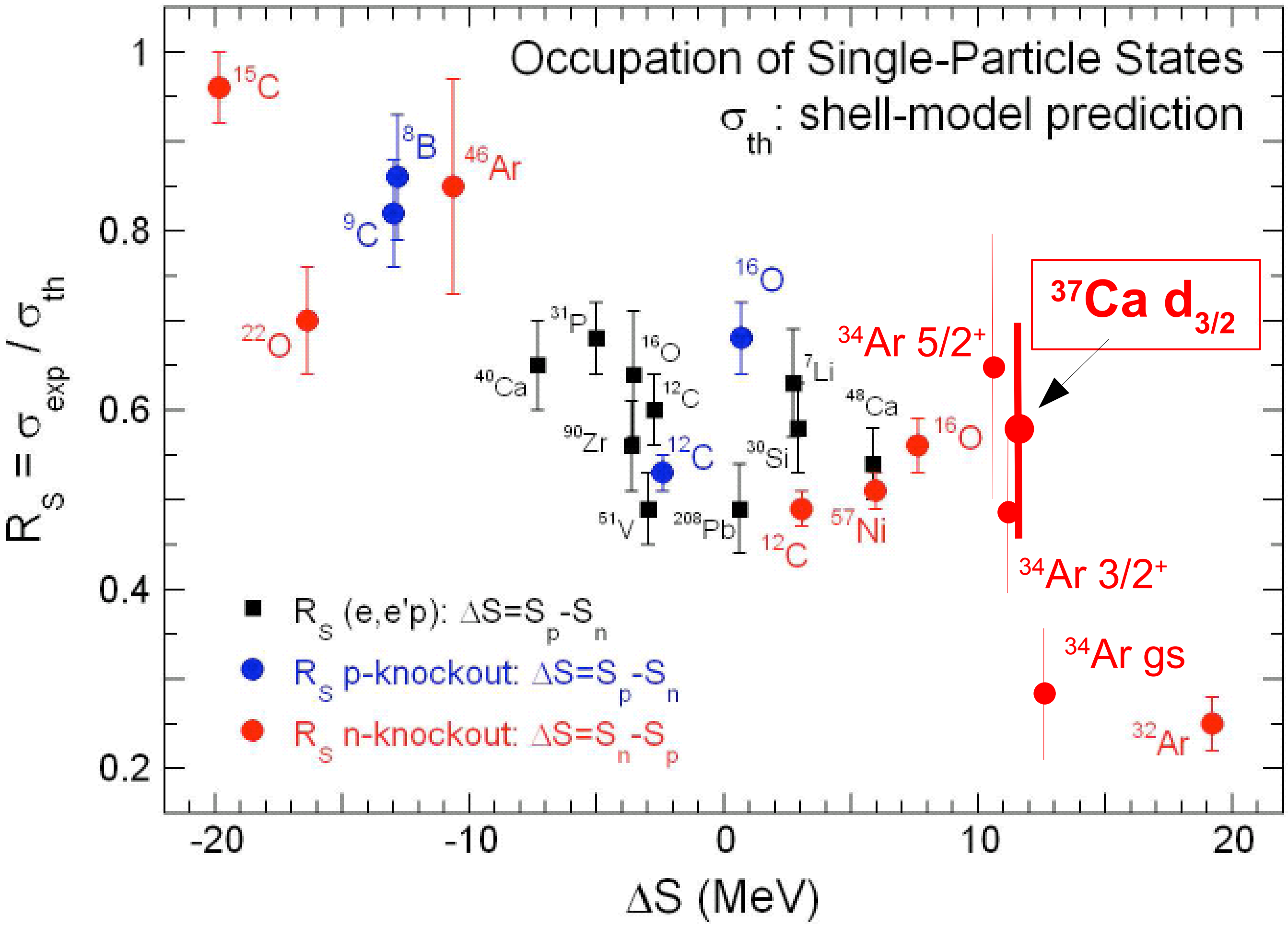
The spin-parity assignments for the precursors ^{41}Ti and ^{37}Ca follow from their $T_z = +\frac{3}{2}$ mirrors and from the J^π of the lowest $T = \frac{3}{2}$ states in the $T_z = \pm\frac{1}{2}$ isobars.

Sextro et al, NPA 234, 130 (1974)



Momentum distributions

	σ_{exp}		σ_{momdis}	C^2S_{USD}	σ_{th}	R_S
gs	3.2(7)	d3/2	5.80	0.92	5.64	**0.57(12)**
2+	2.4(6)	s1/2	6.87	1.13	8.20	**>0.29(8)**



proton branch ?!

$\tau(^{40}$Ca,2+) = 49 fs
Γ_γ = 1.34 10^{-2} eV

Γ_p = 2-4 10^{-1} eV x SF

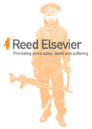
for SF = 4%
Γ_p/Γ_γ = 0.90
⇒ R_S = 0.55

but HFB
$\tau(^{36}$Ca,2+) = 400 fs !

A Bürger, in preparation

Conclusions

- tensor effect creates N=16 gap in ^{36}Ca
- large MED for A=36 of 255 keV
- normal KO reduction factor for pure configuration



Conclusions

- tensor effect creates N=16 gap in ^{36}Ca
- unexplained MED for A=36 of 255 keV
- normal KO reduction factor for pure configuration
- measure B(E2) ^{36}Ca... at Riken ?!
- ありがとうございます！

S. Franchoo, Gamma-08, Riken, April 2008

E450

Normal occupancy of deeply bound valence neutrons in ^{37}Ca

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The ground state and first excited 2+ state in proton-rich ^{36}Ca have been studied at Ganil by γ-ray spectroscopy of one-neutron knock-out reactions from deeply bound states in ^{37}Ca at intermediate energy. Partial cross-sections and momentum distributions of the knock-out reactions to both the ground state and the first excited 2+ state have been measured and the angular momentum of the two populated states identified. In contrast with previously reported cases, the extracted spectroscopic factors and their comparison to shell-model spectroscopic factors are found to be consistent with the trend observed for stable and near-magic nuclei. The gamma-ray spectroscopy in ^{36}Ca as well as in neighbouring T=2 proton drip-line nuclei has also revealed abnormal MED

ABrown: 36Ca SF(s1/2)= 0.0095. With a single particle scattering width of 22eV
this would give a proton width of 0.31eV (meant: 0.21??).

Q=0.7 MeV	22 eV
0.6	3.8
0.5	0.42
0.4	0.019

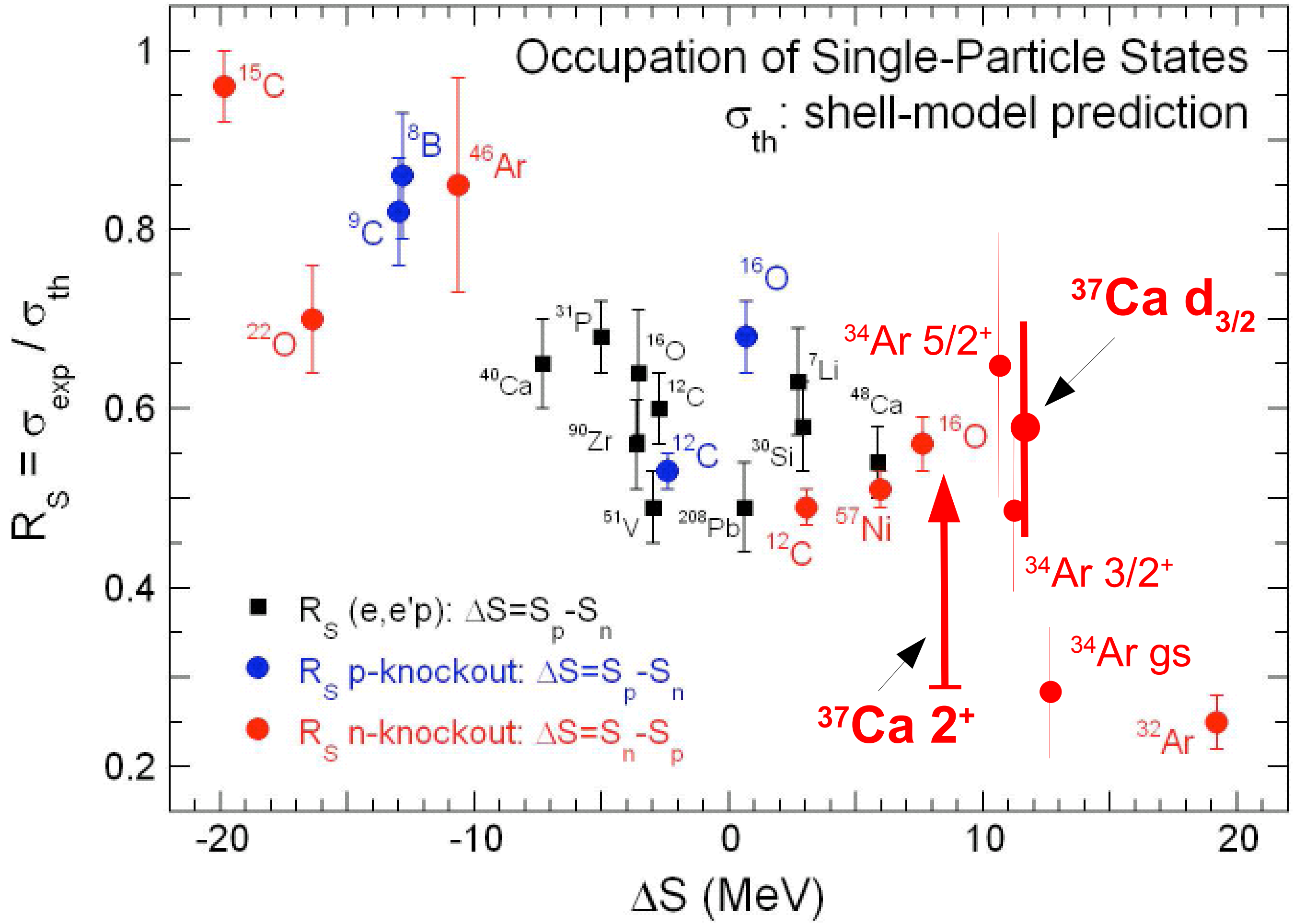
FA: proton separation energy Ex-Sp=470keV
=> Q=0.5, proton width=0.42 x SF= 4e-3eV

Differences could come from the radius taken for 36Ca! Iulian HF radius = 3.4 fm;
Should be the same as momdis ie r=3.312 as calculated by E. Khan ??

Validity of ‘the independent particle’ concept for deeply bound nuclear systems. MSU work shows a dramatic decrease of the s.p strength for deeply bound states. Other effects (deformation, coupling to vibrations…) could be responsible of the fragmentation of the s.p strength and therefore could also explain the very small s.p strength observed. Therefore one needs to measure a deeply bound system close to closed shells (the S.P nature is better fulfilled in doubly magic + or – one nucleon). The knock-out of one neutron from 37Ca is unique as 36Ca is doubly magic. The result is that the quenching of the s.p strength is ‘normal’ and that up to 60% of the full strength is observed, just like around doubly magic nuclei at the valley of stability.

B(E2)= $|M_n e_n + M_p e_p|^2/(2j+1)$
small BE2 for C14,16,18,20 & O20:
2+ is neutron excitation, n do not polarise core
would this also be true for Ca36 since proton gap large?

Hubert B(E2)=1.4e2fm4 avec oxbash et deux différentes interactions USD modifiées. C'est loin des calculs QRPA... SM uses effective charges for p and n (effective charges are the effect of truncation in the valence space). Mean field does not have this problem (it is self consistent within the effective force that is used; QRPA uses wave functions from HFB, for Bruyeres the effective force is Gogny) but suffers from correlations unless one is going 'beyond mean field'



for Ca37
S_n=14790, S_p=3025
=> S_n-S_p=11765

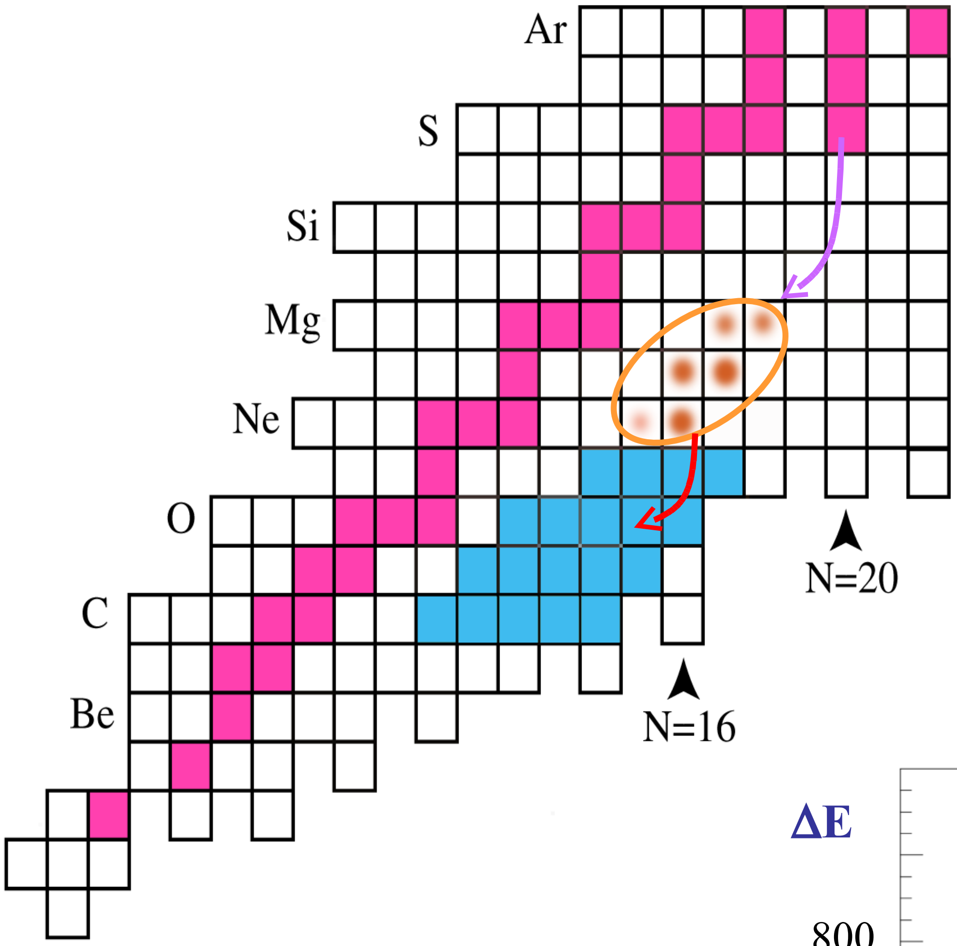
for Ar34
Sn= 17064, Sp =4663
=> Sn-Sp = 12401
3/2 at 1358 so DS = 11043
5/2 at 1795 so DS = 10606

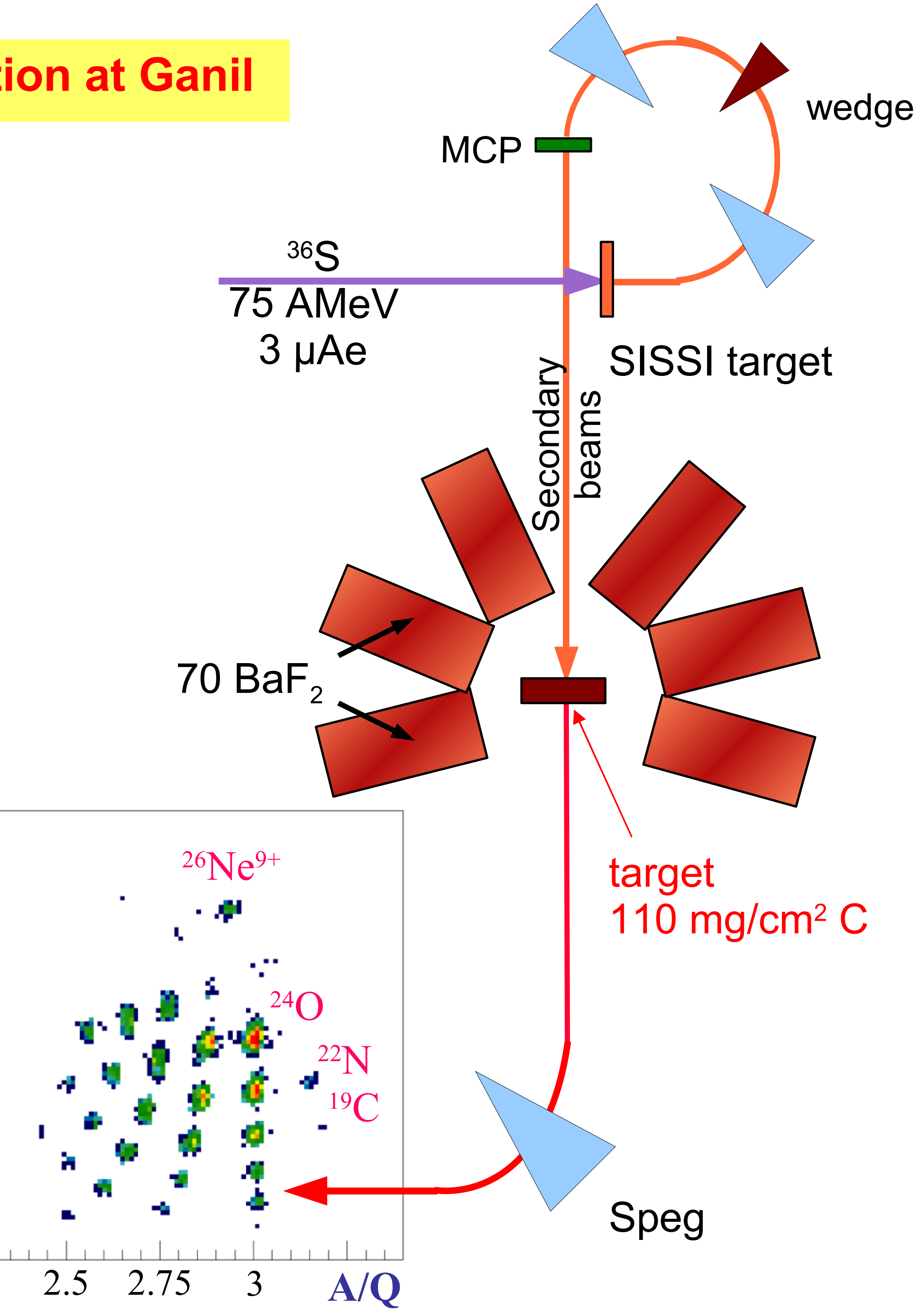
Antoine + USD for C^2Stheo
pure wvf for gs & 2+, large gap
how compare N/Z=16 considering Ex?

proton emission from 2+ in ^{36}Ca
for r(^{36}Ca) = 3.4fm, Γ_p = SF x 0.190eV

TES in 36S not relevant since well bound
USD interaction, eikonal model (straight rays)

double step in-beam fragmentation at Ganil





- **Production rate x10 for ^{24}O**
- **Better signal/noise for γ spectra**
- **Excited states fed by different projectiles**