Neutron-deficient sd-shell nuclei and mirror symmetry at the proton drip line

First fast-beam PRESPEC proposals

- **Motivation**
  structure of exotic sd-shell nuclei

- **Mirror symmetry at the proton drip line**
  results of 36Ca experiments, sd-shell modification, T=-3/2

- **Proposed experiment: ^{25}Si, ^{29}S and ^{33}Ar**
  PRESPEC-Array, LYCCA ToF-ΔE-E-Telescope

- **Coulomb excitation of ^{104}Sn**
  Proposal by M. Gorska, J. Cederkall

- **Mixed-symmetry states and Coulex of ^{88}Kr**
  Proposal by J. Jolie, N. Marginean

FRS users meeting, GSI, October 29, 2009

Collaboration

GSI Experimental Proposal S377 – a PRESPEC Proposal

Neutron-deficient sd-shell nuclei and mirror symmetry at the proton drip line

P. Reiter, A. Wendt, A. Blazhev, B. Bruyneel, A. Dewald, K. Geibel, J. Jolie, M. Seidlitz, B. Siebeck, N. Warr
Institut für Kernphysik, Universität zu Köln, D–50937 Köln, Germany
H. Grawe, J. Gerl, M. Gorska, I. Kojouharov, N. Kurz, S.Pietri, H. Schaffner, H.J. Wollersheim
Gesellschaft für Schwerionenforschung mbH, D-64291 Darmstadt, Germany
M.A.Bentley, R.Wadsworth, T. Brock, I. Paterson, B.S. Nara Singh, L. Scruton, S.P. Fox, M.J.Taylor
Department of Physics, University of York, Heslington, York YO10 5DD, U.K.
C. Fahlander, P.Golubev, R.Hoischen, D.Rudolph
Department of Physics, Lund University, S-22100 Lund, Sweden
N. Pietralla, J. Leske, O. Möller
Institut für Kernphysik, Technische Universität Darmstadt, D–69289 Darmstadt, Germany
N. V. Zamfir
National Institute of Physics and Nuclear Engineering, P.O. Box MG-6, Bucharest-Magurele,Romania
S.M.Lenzi, F. Recchia
Dipartimento di Fisica dell'Universita and INFN, Sezione di Padova, I-35131 Padova, Italy
D.R. Napoli
INFN, Laboratori Nazionali di Legnaro, Italy
A. Algora, A.Gadea
Instituto de Fisica Corpuscular. Universitat de Valencia. E- 46071 Valencia. Spain

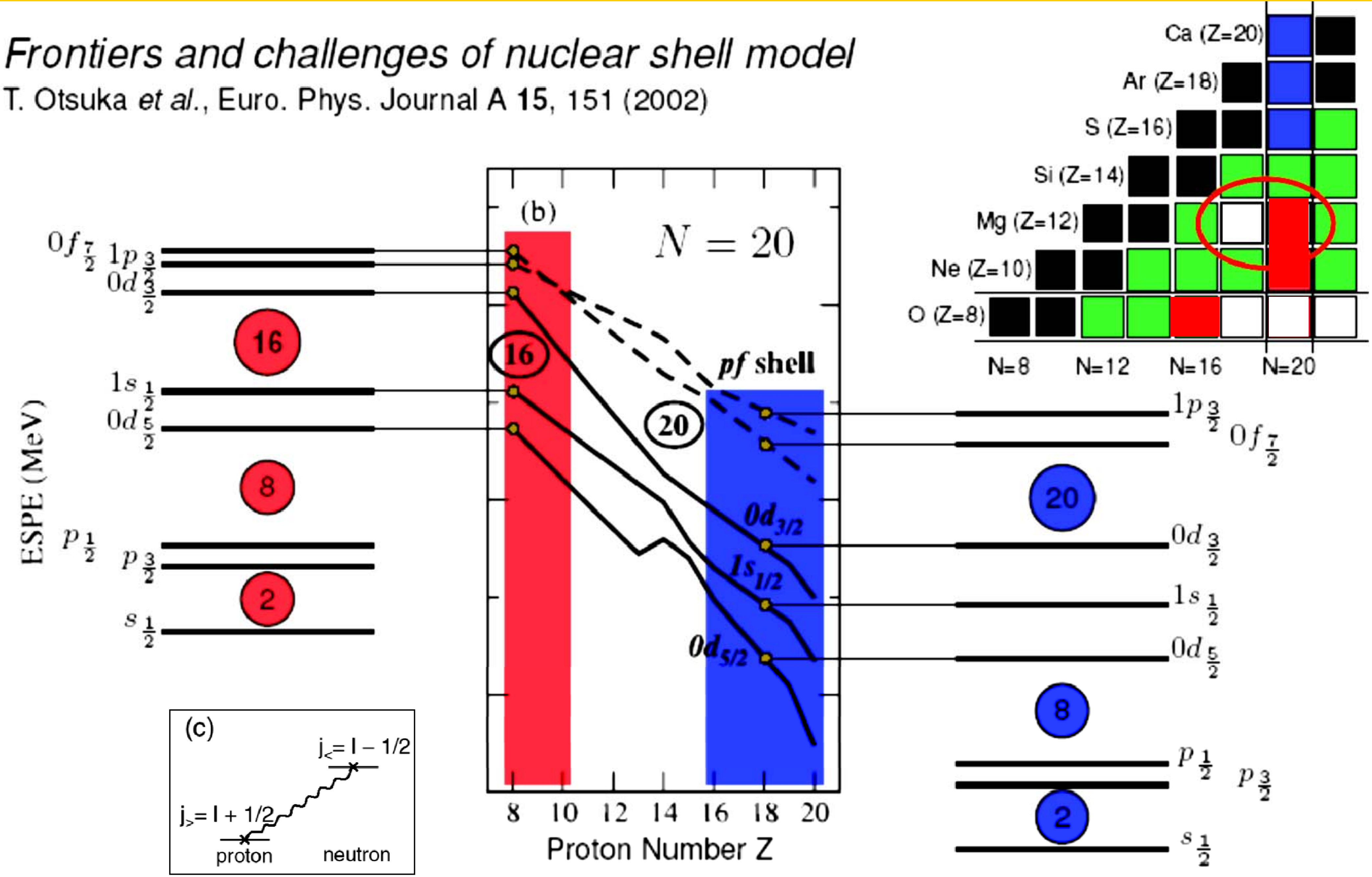
and the PRESPEC Collaboration

Spokesperson: P. Reiter PhD thesis project: A. Wendt

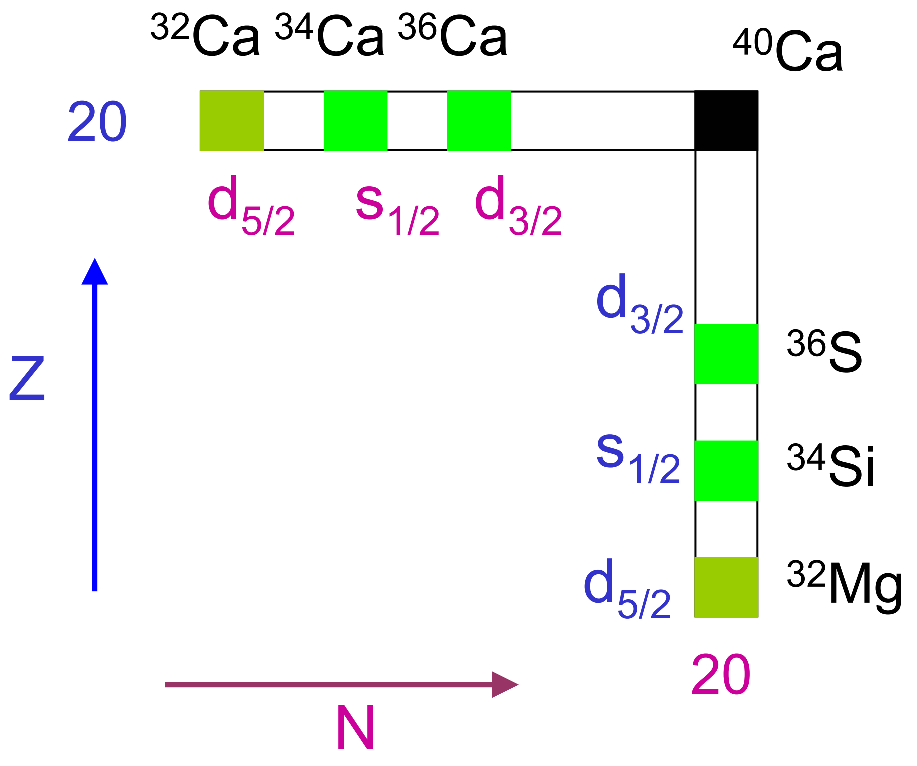
Deviations from classical shell model in sd-shell

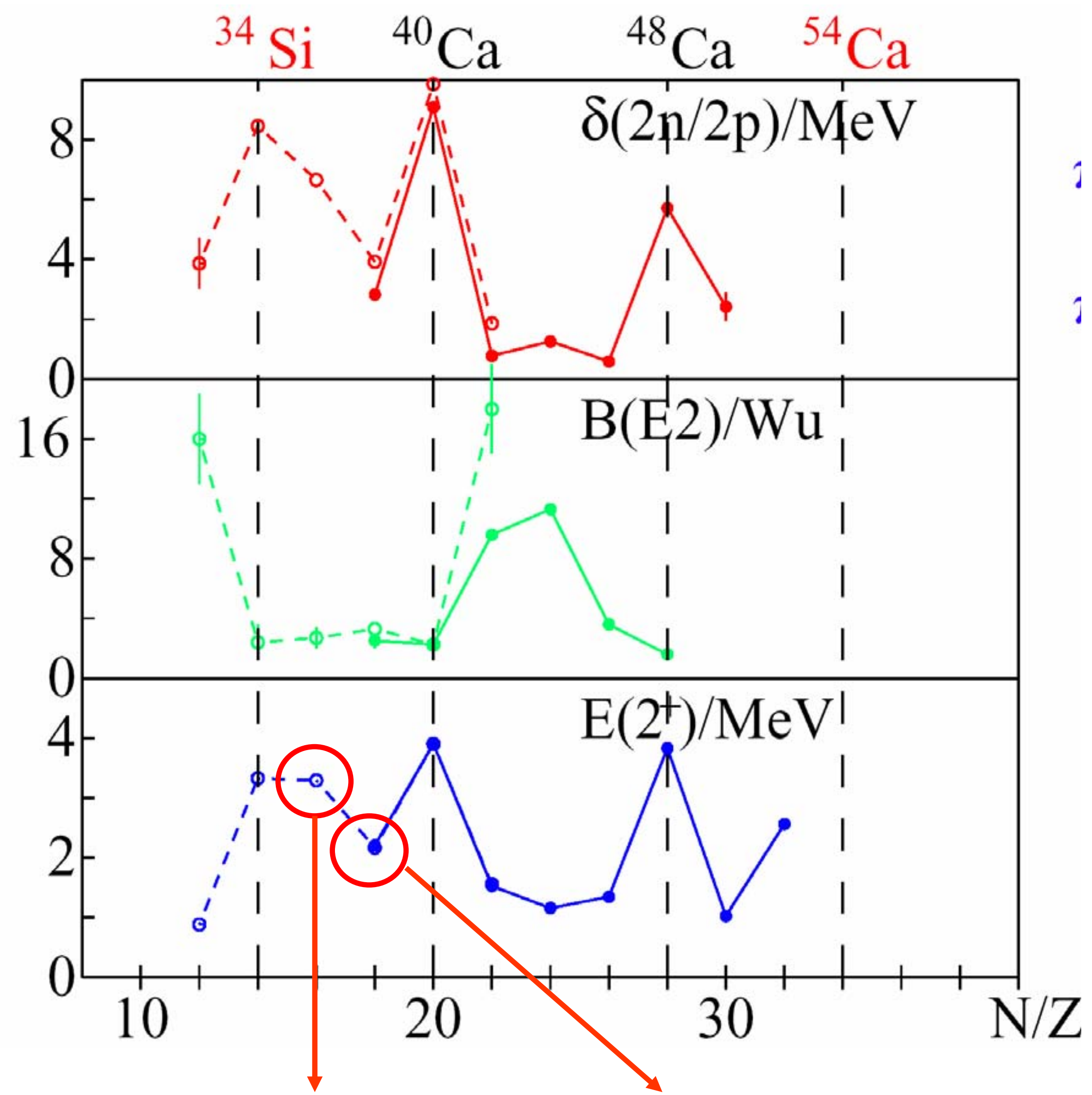
Frontiers and challenges of nuclear shell model

T. Otsuka *et al.*, Euro. Phys. Journal A **15**, 151 (2002)



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

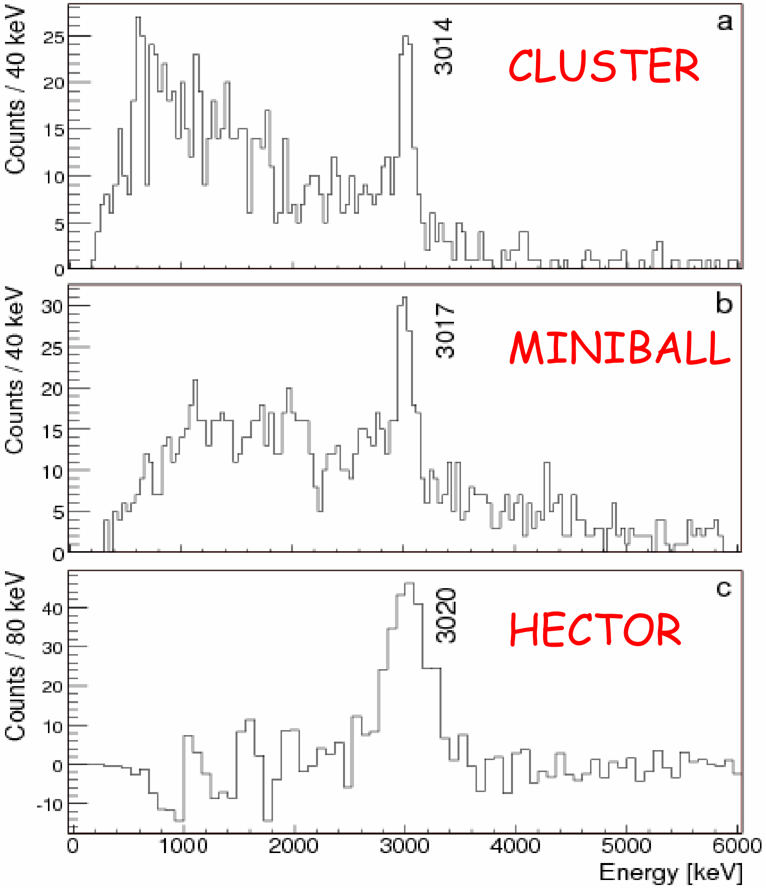




Isospin symmetric scenario?
- Shell stabilization at N,Z = 14(16)
- Vanishing shell closure at $^{32}Mg_{20}$

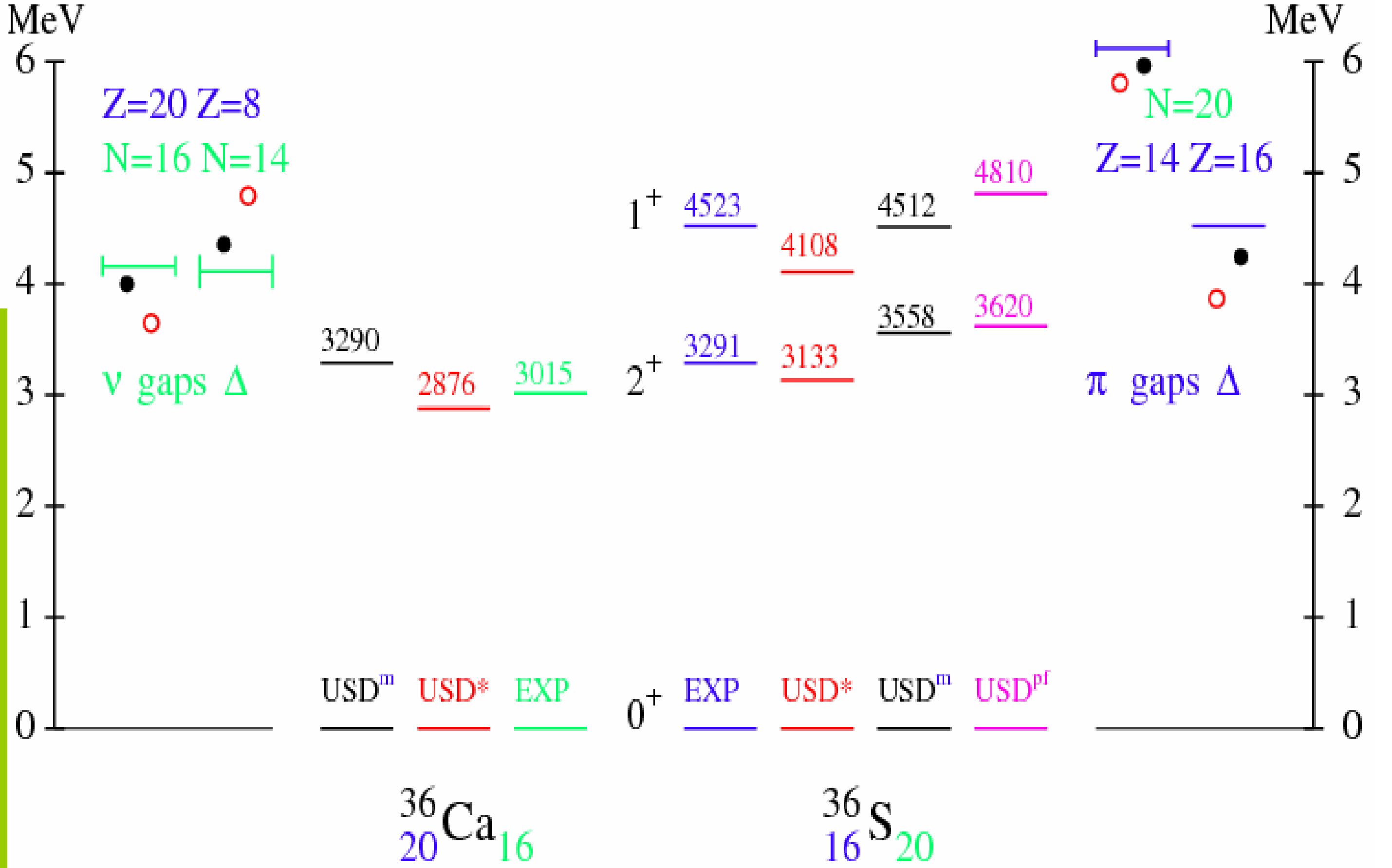
$$^{36}\mathrm{S};2^{+} = 3291\,\mathrm{keV}$$

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



Shell model calculations:

- 2s1d shell; ^{16}O core; USD
B.A.Brown, B.H.Wildenthal, Ann.Rev.Nucl.Sci. 38,29 (1988)
- USD* : USD with experimental single particle energies (SPE) from ^{17}O and ^{17}F
- USD^{m} : monopole modification
- USD^{pf}: sd,pf MCSM Utsuno et al. PRC 60, 054315 (1999)

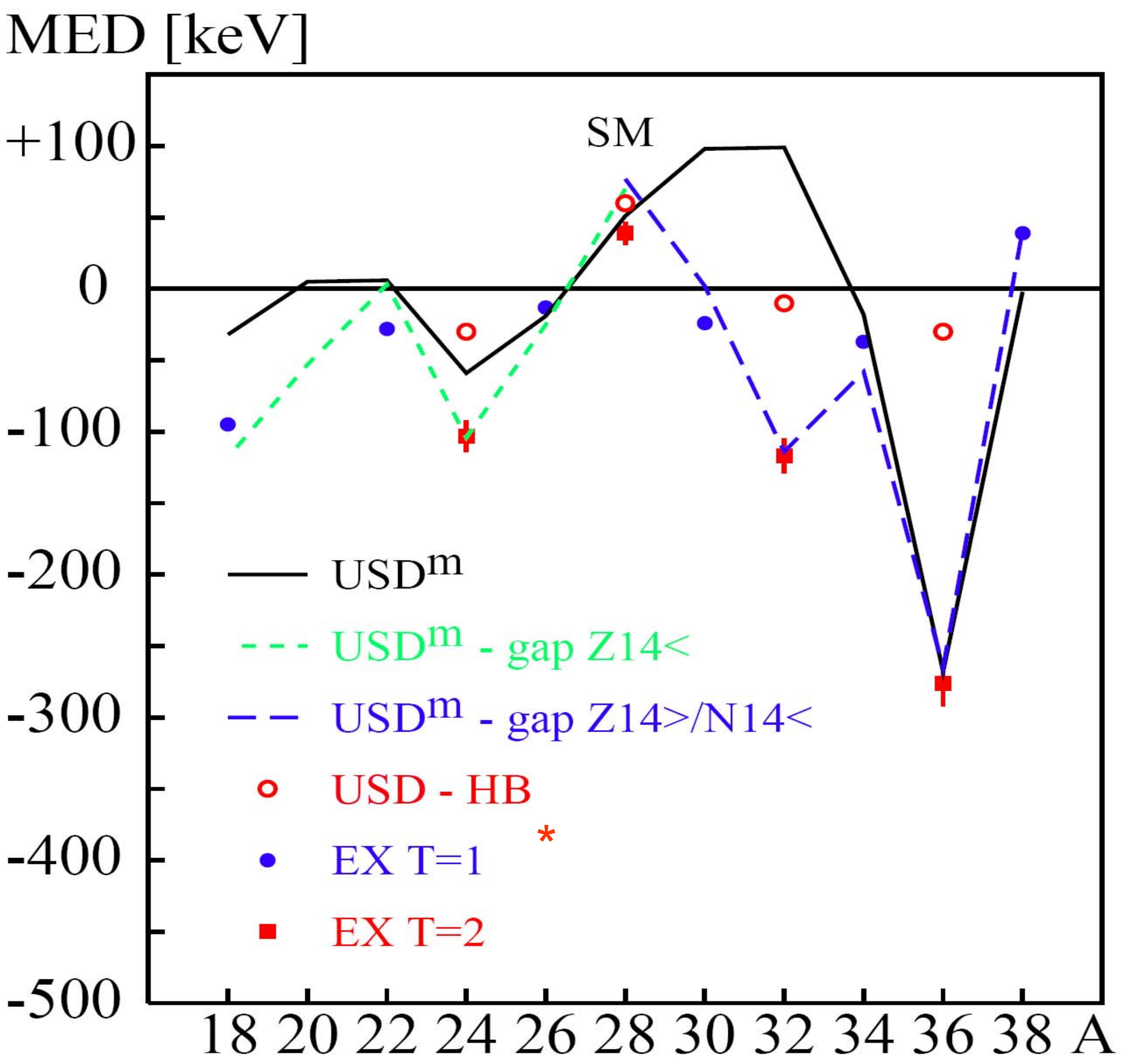


Experiment:

Primary: ^{40}Ca, 420 A·MeV, $3\cdot10^{8}$ ions/s, 4 mg/cm^{2} ^{9}Be
Secondary: ^{37}Ca, 196·A MeV, $2\cdot10^{3}$ ions/s, 0.7 mg/cm^{2} ^{9}Be

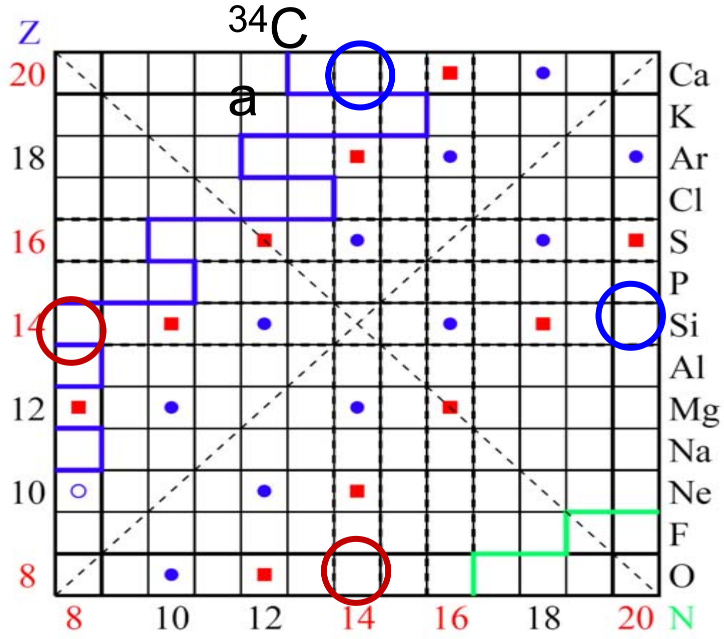
15 EUROBALL Ge CLUSTER (x7)
7 MINIBALL Ge (x3), 6-fold segmented
8 HECTOR BaF$_2$

Shell model calculation for T=1,2 nuclei in *sd*-shell



<u>Ad hoc modification introduced</u>

- For A = 16 – 28 increased $\pi 0d_{5/2}$ SPE by 200 keV
- For A = 28 – 40 reduced $\pi 0d_{5/2}$ SPE by 300 keV $\nu 0d_{5/2}$ SPE by 900 keV



Empirical shell gap (*G*) reduction :

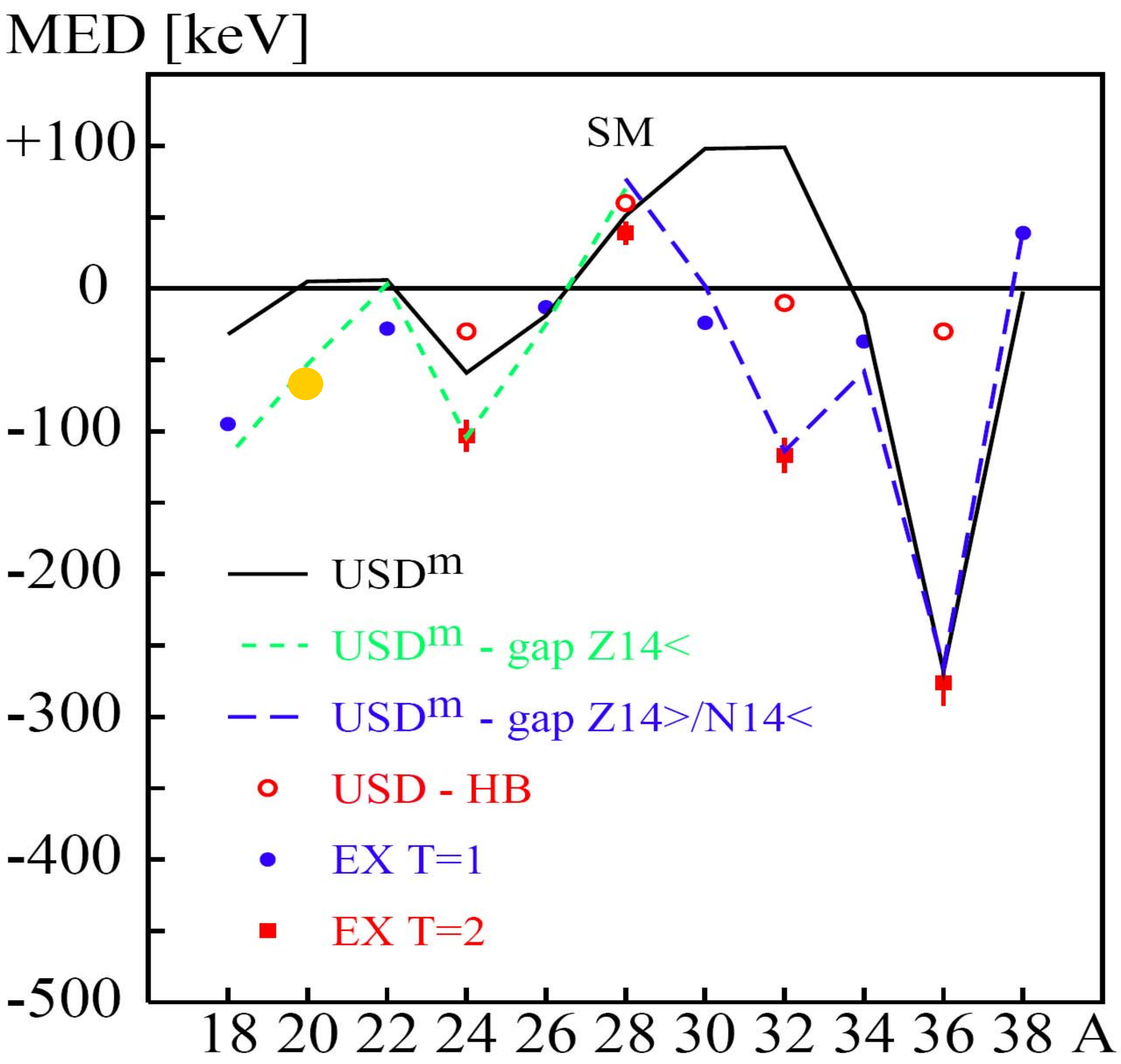
$\Delta = G(N=8, Z=14) - G(Z=8, N=14) = -0.32$ MeV

$\Delta = G(Z=20, N=14) - G(Z=14, N=20) = -0.74$ MeV

=> reduced neutronen gap in ^{34}Ca (Δ_ν = 5.498 MeV) with respect to protonen gap in ^{34}Si (Δ_π = 6.241 MeV)

*H. Herndl et al., Phys. Rev. C 52 (1995) 1078
P. Doornenbal et al., Phys. Lett. B647, 237 (2007).

Shell model calculation for T=1,2 nuclei in *sd*-shell



*H. Herndl et al., Phys. Rev. C 52 (1995) 1078
P. Doornenbal et al., Phys. Lett. B647, 237 (2007).
A. Gade et al. Phys. Rev. C 76, 024317 (2007)

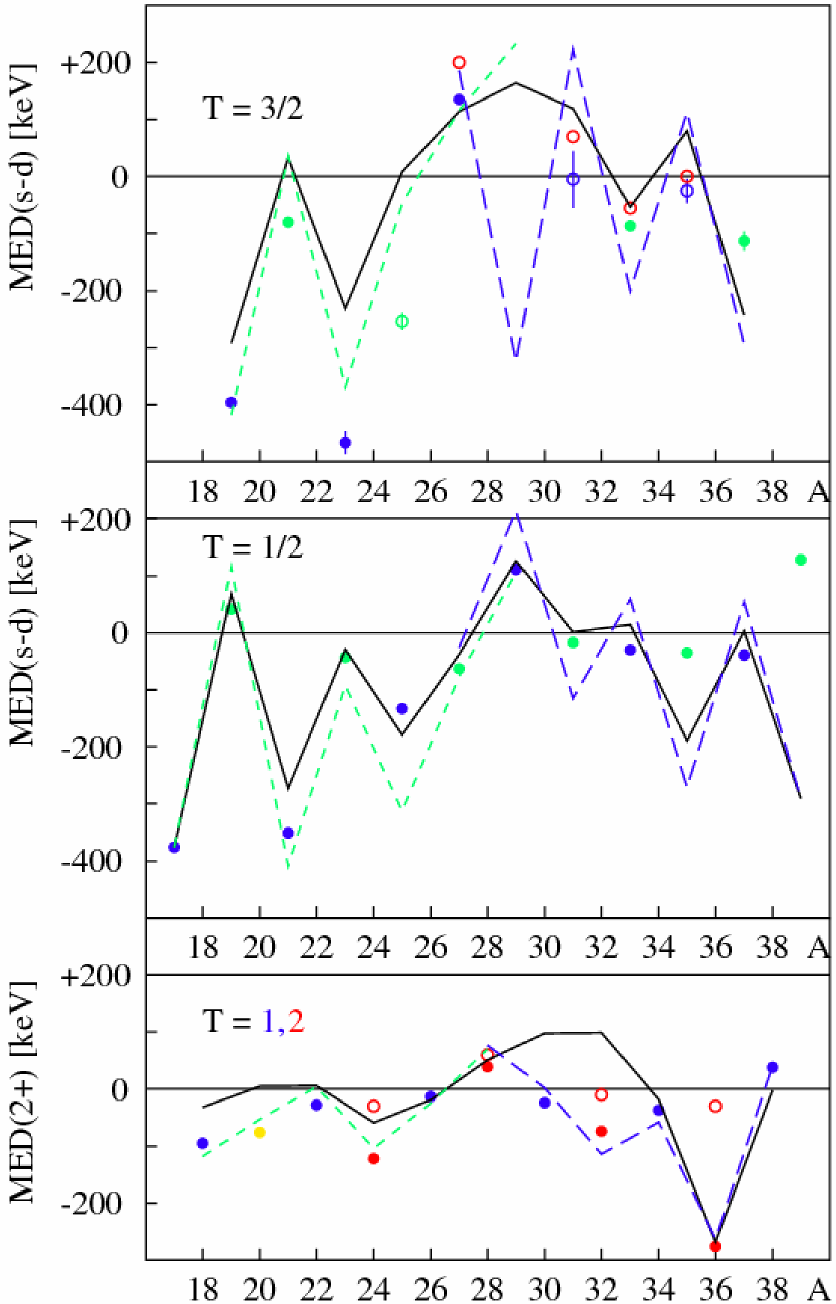
- Confirmation of modifications by recent result on last and missing 2^+ MED in sd-shell for ^{20}Mg and ^{20}O pair.

- Motivation for future work:

It is remarkable that the USD^m interaction presented in Ref. [9] that does not include the additional reduction of the Z = 14 proton subshell gap, predicts the mirror energy difference for ^{20}Mg and ^{20}O to be small and positive. This indicates predictive power of the modified interaction and underlines the sensitivity of MEDs to details of the nuclear shell structure.

From: *Phys. Rev. C 76, 024317 (2007)*

Experimental and shell model status MED T=1,2,1/2,3/2 nuclei in *sd*-shell



Experimental MED values for T=1/2, 3/2

full dots: firm spin-parity assign.,
open circles: spin-parity from systematic.

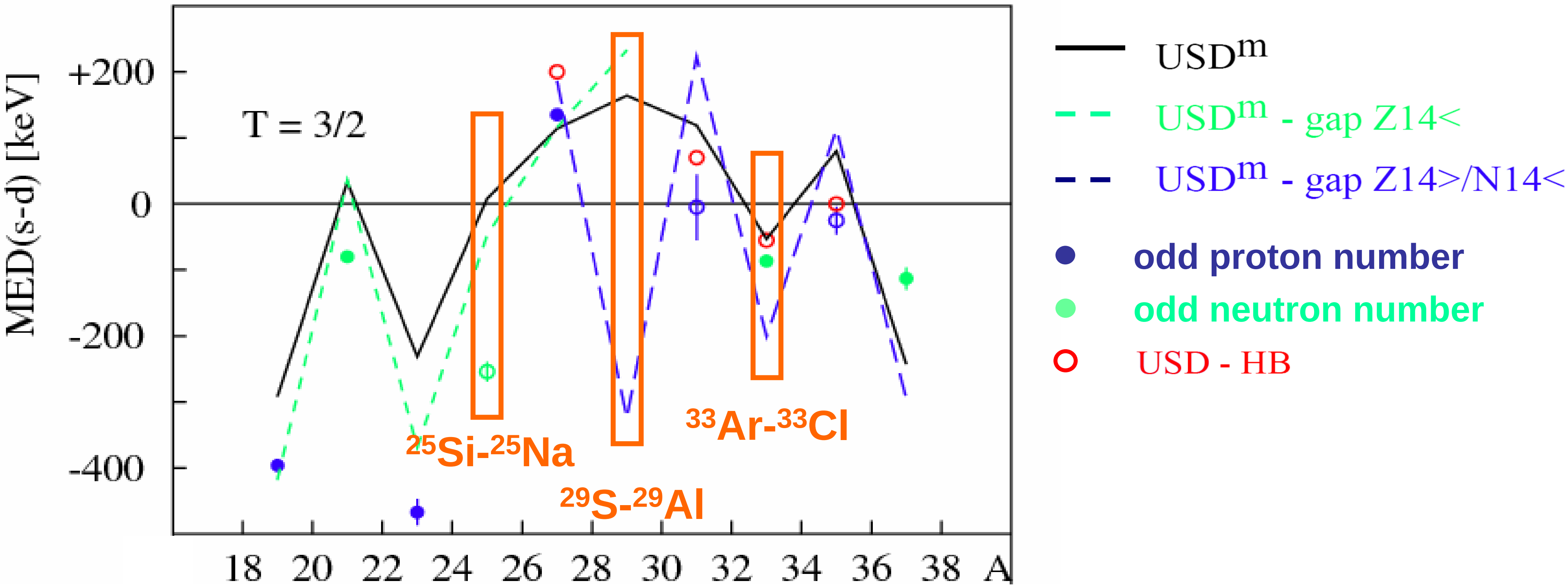
odd-proton state of T_z = -1/2, -3/2 partner

odd-neutron state of T_z = -1/2, -3/2 partner

Herndl, Brown T=3/2 panel
H. Herndl et al., Phys. Rev. C 52 (1995) 1078

T=1, 2 MED values
P. Doornenbal et al., Phys. Lett. B647, 237 (2007).

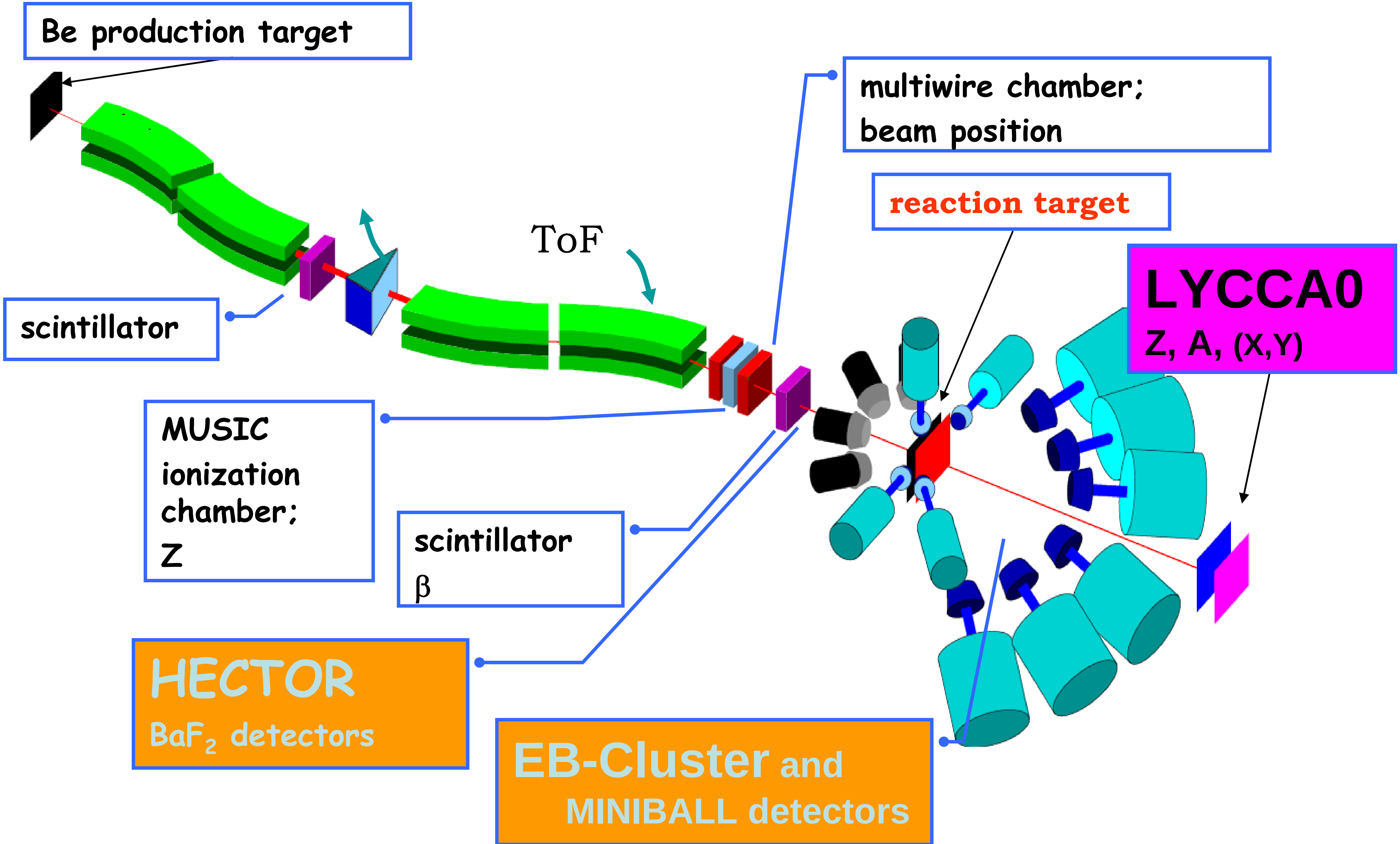
New PRESPEC proposal



in-beam-γ-spectroscopy of neutron-deficient, sd-nuclei:

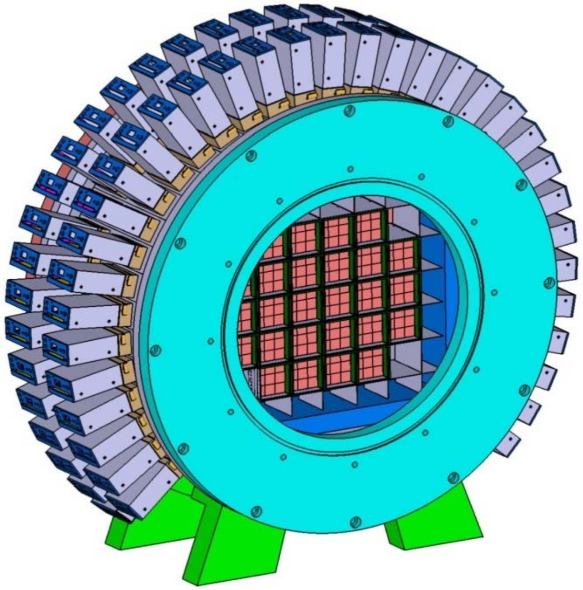
^{25}Si, ^{29}S, ^{33}Ar

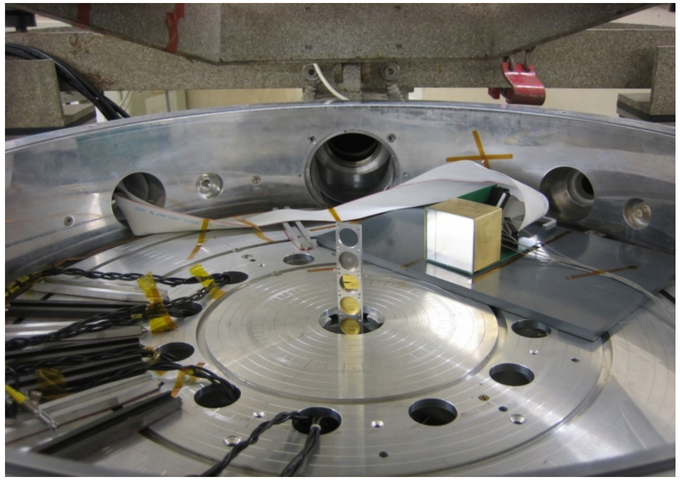
PRESPEC fast beam set-up



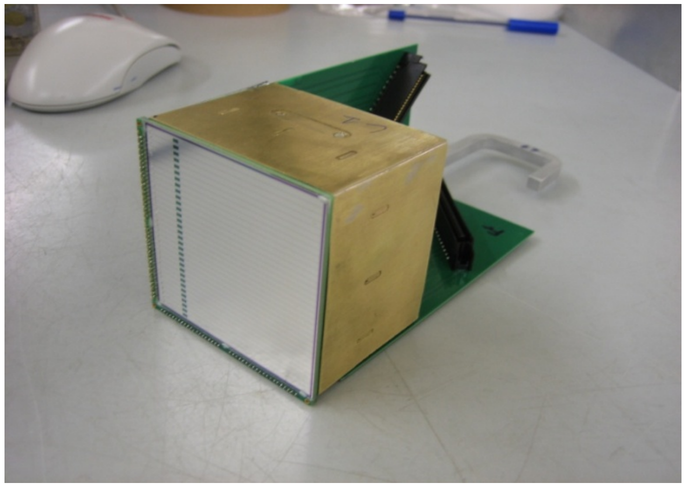
LYCCA Secondary beam particle identification

vaccum chamber



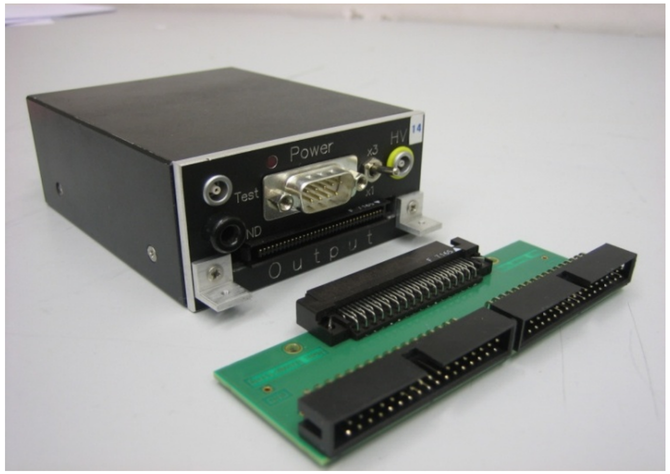


In beam test @ IKP



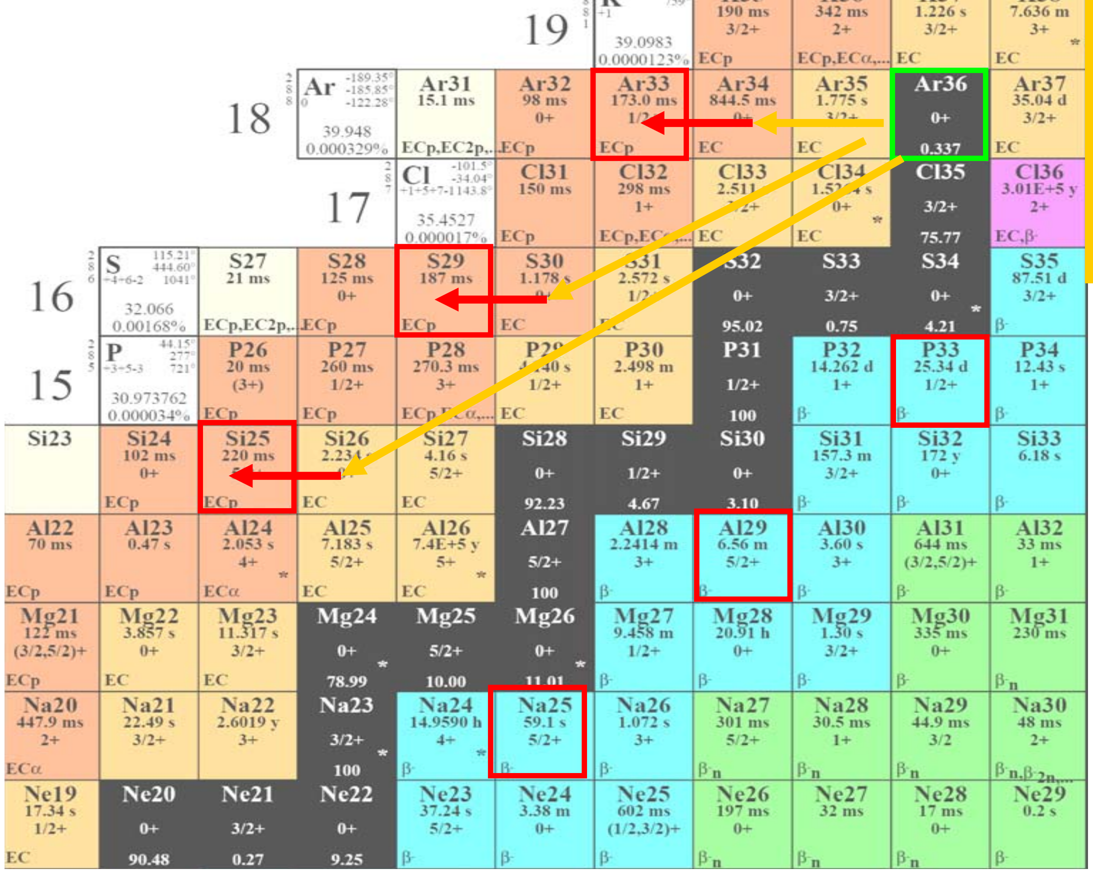
detector unit

detector support



pre-amps

Double fragmentation technique

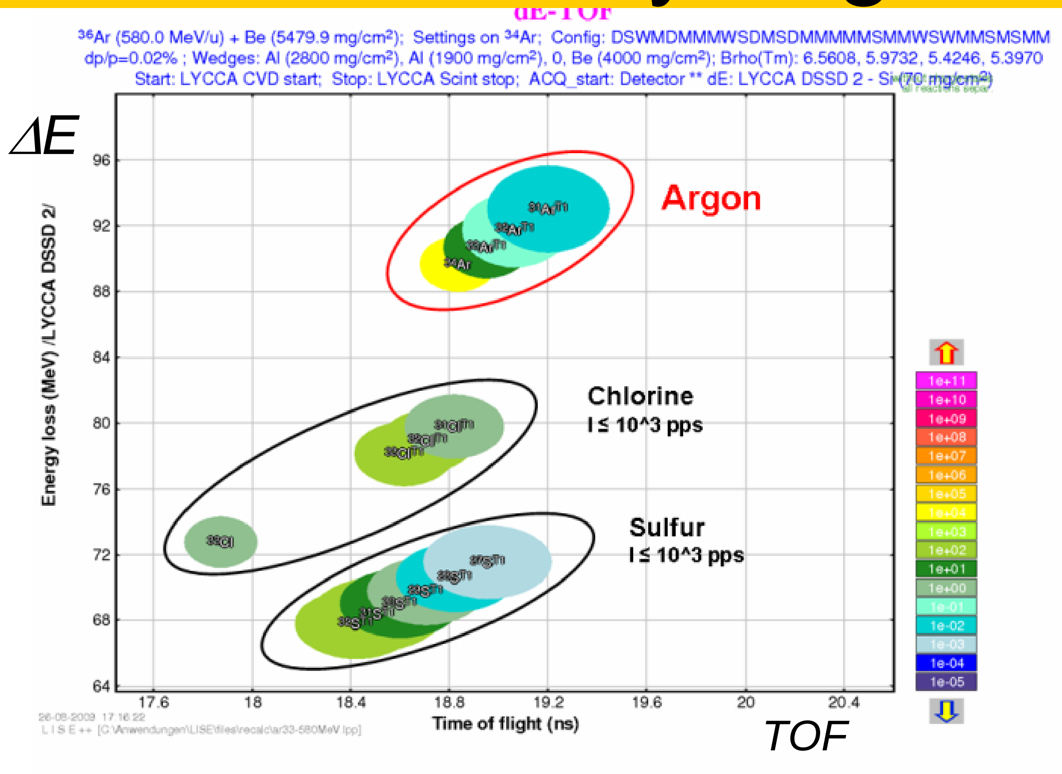


Secondary beam production rates based on LISE++ calculations.

*^{36}Ar primary SIS beam of 2*10^{+10} pps*

Nuclei of interest	primary beam / energy (MeV/u)	2nd beam	Prim. target g/cm²	S1 Deg g/cm²	S2 Deg g/cm²	all frags (kHz)	S2 2nd beam (kHz)	all frags @ MUSIC (kHz)	2nd beam @ MUSIC (kHz)	2nd beam on target (kHz)	Unreacted 2nd beam @ LYCCA (kHz)	2-frag-prod. @ LYCCA (pps)	Energy @ DSSD (MeV/u)
^{33}Ar	**^{36}Ar 580**	**^{34}Ar**	**1,0**	**4,0**	**1,9**	**350**	**350**	**60**	**60**	**57**	**40**	**51**	**311**
^{29}S	**^{36}Ar 580**	**^{30}S**	**3,5**	**3,8**	**1,9**	**350**	**344**	**60**	**60**	**57**	**39**	**51**	**252**
^{25}Si	**^{36}Ar 580**	**^{26}Si**	**3,0**	**4,5**	**1.9**	**138**	**132**	**38**	**38**	**36**	**23**	**28**	**210**

Reaction product identification after secondary target via ToF-ΔE-TKE in LYCCA



LYCCA

energy loss ΔE of secondary fragments vs. the TOF from the target position to the LYCCA array for the secondary beam ^{34}Ar.

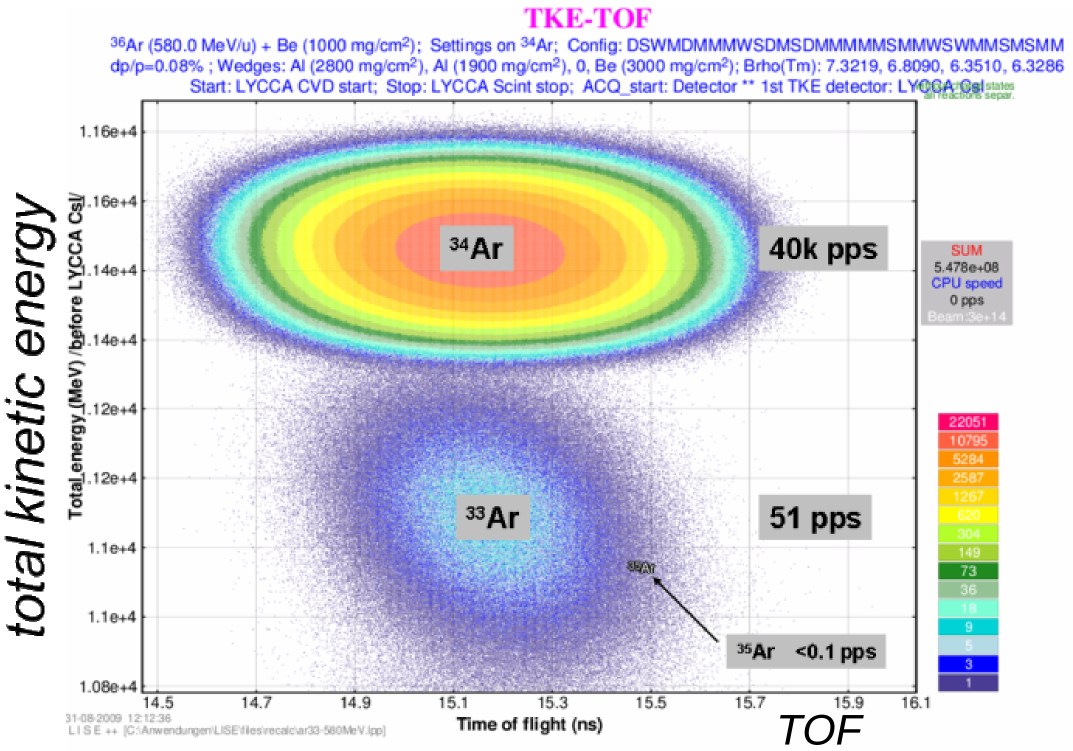
=> Isotope separation

LYCCA

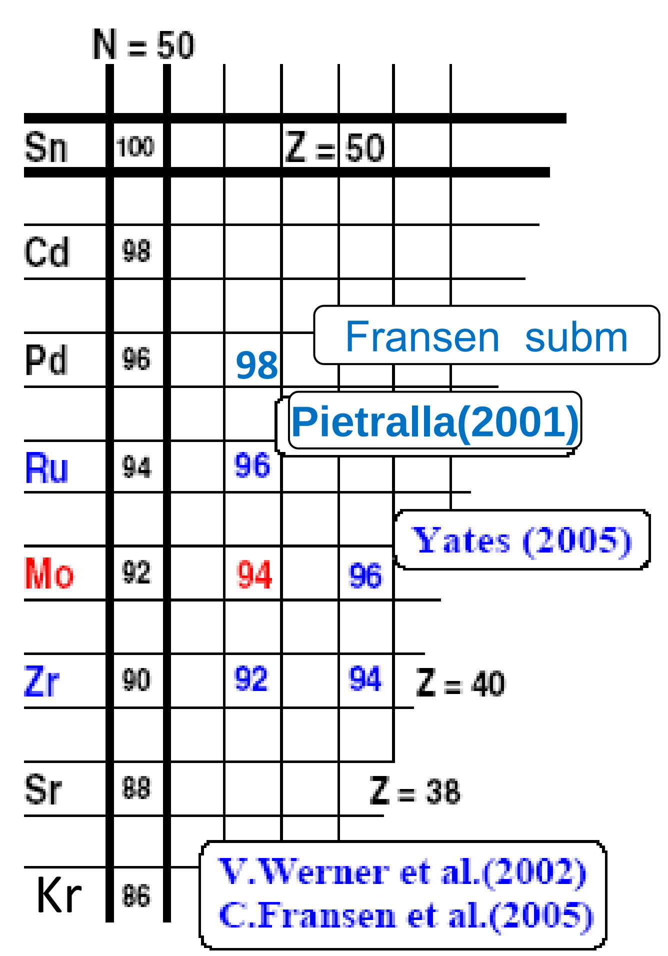
total kinetic energy, detected by the CsI detectors vs. TOF

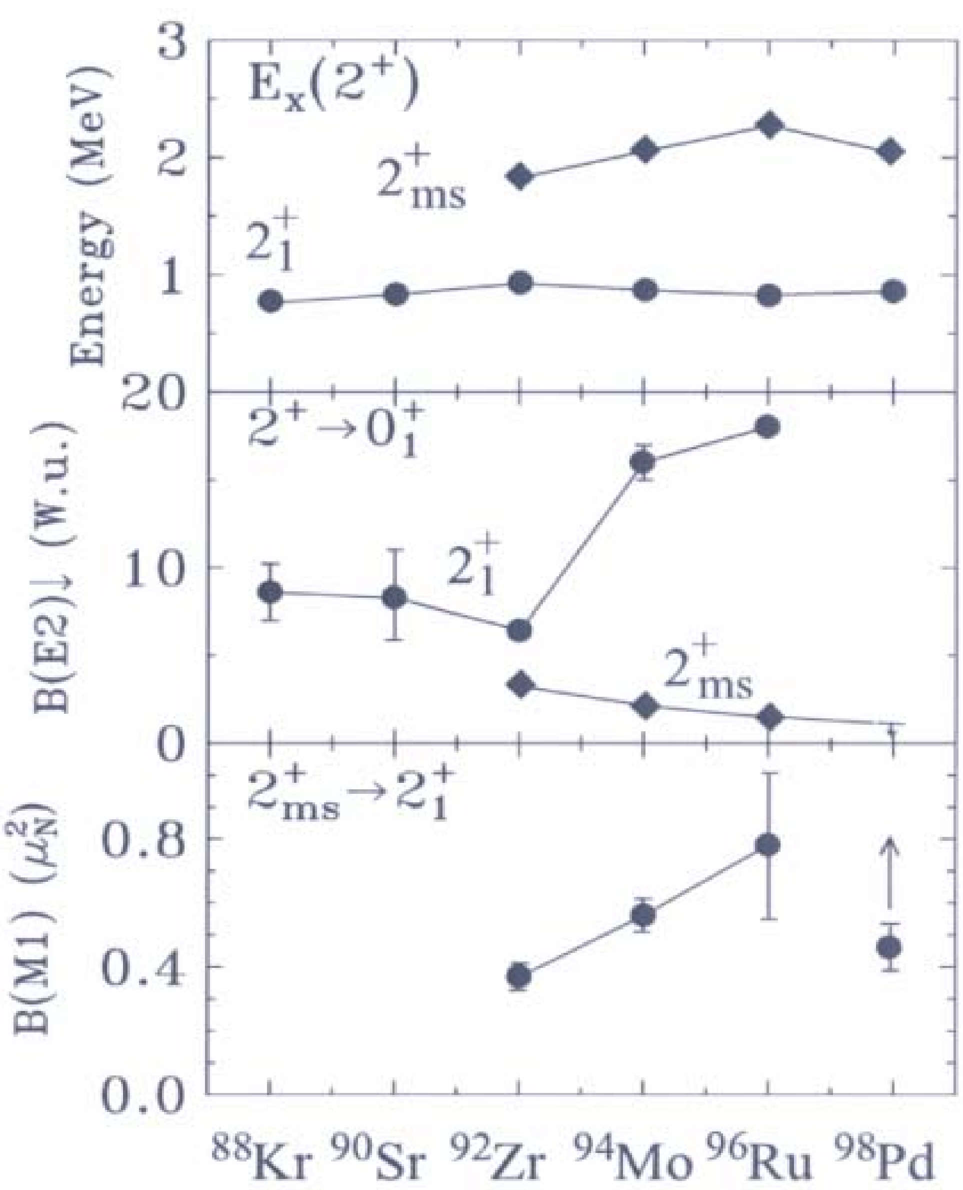
separation of the fragmentation product ^{33}Ar after the target

=> Mass separation



The 2^+ mixed-symmetry state in ^{88}Kr



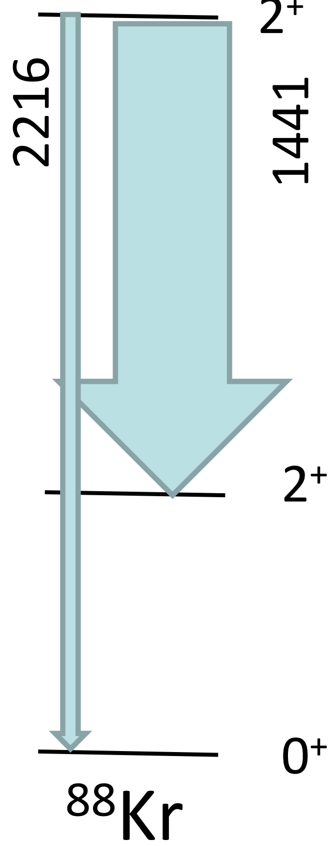


- Search for the MS state in ^{88}Kr
- First identification via RIB experiment
- Challenge: higher lying third 2^+ state
- Identification via strong M1 decay

Some experimental details

- Primary beam/target
650 MeV/A **^{238}U beam**
0.6 g/cm^2 ^{9}Be target

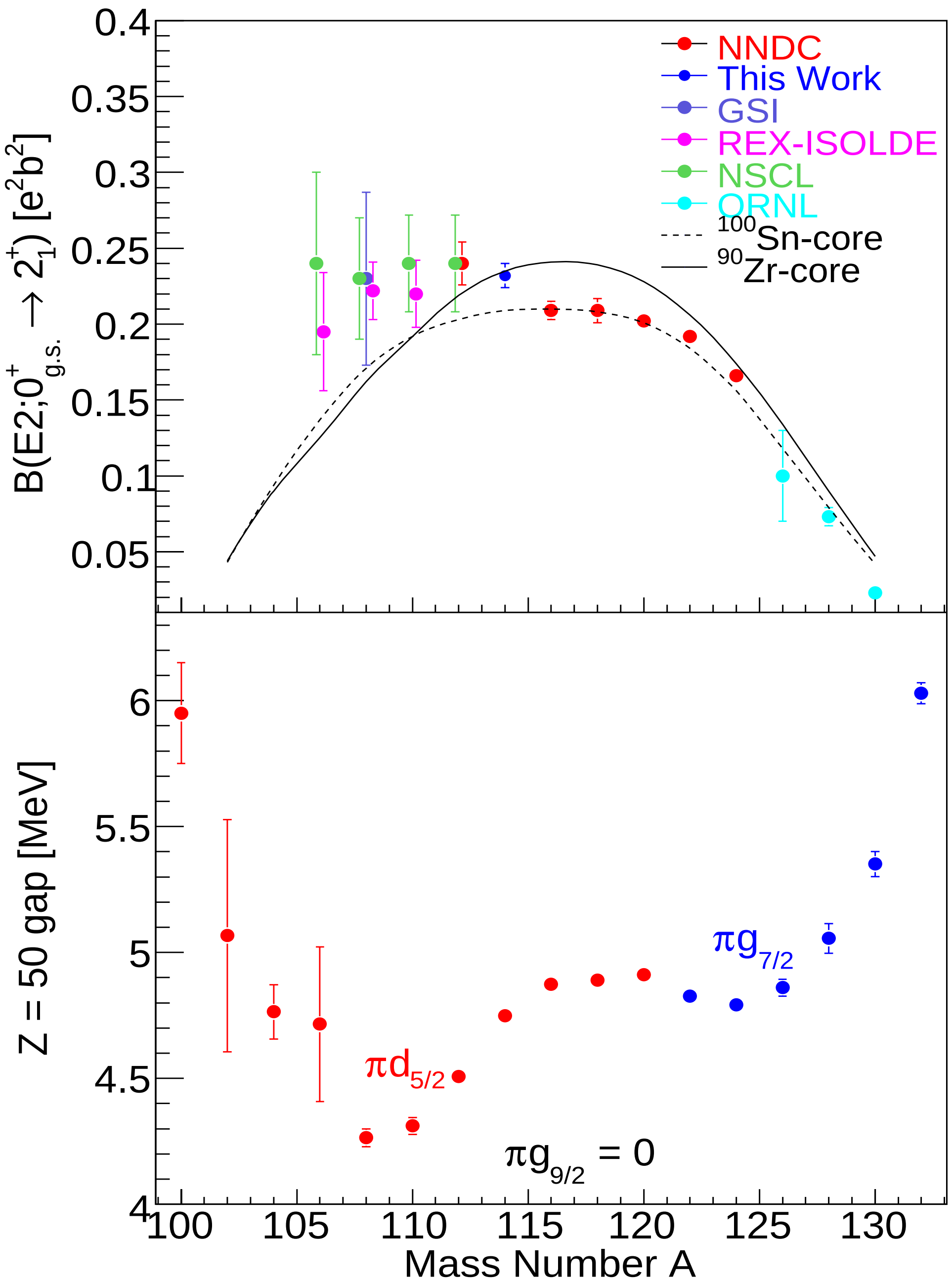
- Secondary beam/target
$^{84,88}Kr$ @ 120 MeV/A
0.4 g/cm^2 Pb target



	^{84}Kr	^{88}Kr	
	2_1^+	2_1^+	2_3^+
σ [mb]	4.95	3.34	
$S2$ rate [pps]	240000	170000	
RIB [pps]	1000	1000	
$B(E2)$ [W.u.]	11.5(2)	8.8(15)	~ 0.8
σ_{Coulex} [mb]	220	190	20
$N_{p\gamma}$ [per day]	660	570	30

Beam request
Set-up (parasitic)
1day+4days

Enhanced B(E2) values towards ^{100}Sn
next step: Coulombexcitation of ^{104}Sn



Shell Model: F. Nowacki et al.,

$\nu(d_{5/2}g_{7/2}s_{1/2}h_{11/2})$, $e_\nu = 0.5e$,

$\pi(g_{9/2}g_{7/2}d_{5/2}d_{3/2}s_{1/2})$, $e_\pi = 1.5e$

$\pi\nu$ monopoles tuned to

πESPEs and Z=50 shell gap

First RISING result ^{108}Sn:

A. Banu et al, Phys. Rev. C 72, 061305(R) (2005)

J. Cederkäll et al., Phys. Rev. Lett. 98,172501(2007)

A. Ekström et al., Phys. Rev. Lett. 101, 012502(2008)

C. Vaman et al., Phys. Rev. Lett. 99, 162501(2007),

GSI result:

P. Doornenbal et al., Phys. Rev. C 78, 031303(R) (2008)

Accepted proposal Coulombexciation of ^{104}Sn

Spokesperson: M. Gorska, J. Cederkall

Summary

First accepted PRESPEC proposals

- Mirror energy differences of T=3/2 nuclei will show enhanced sensitivity to isospin symmetry violation and shell gap evolution
- Experiment is crucial for new LYCCA detector
- Mixed symmetry state in ^{88}Kr
- Coulombexcitation of ^{104}Sn

- Mid-term perspective for in-beam spectroscopy AGATA demonstrator at FRS

- Long-term HISPEC/DESPEC with AGATA at NUSTAR/FAIR