Nuclear structure studies through in-flight measurements

Today

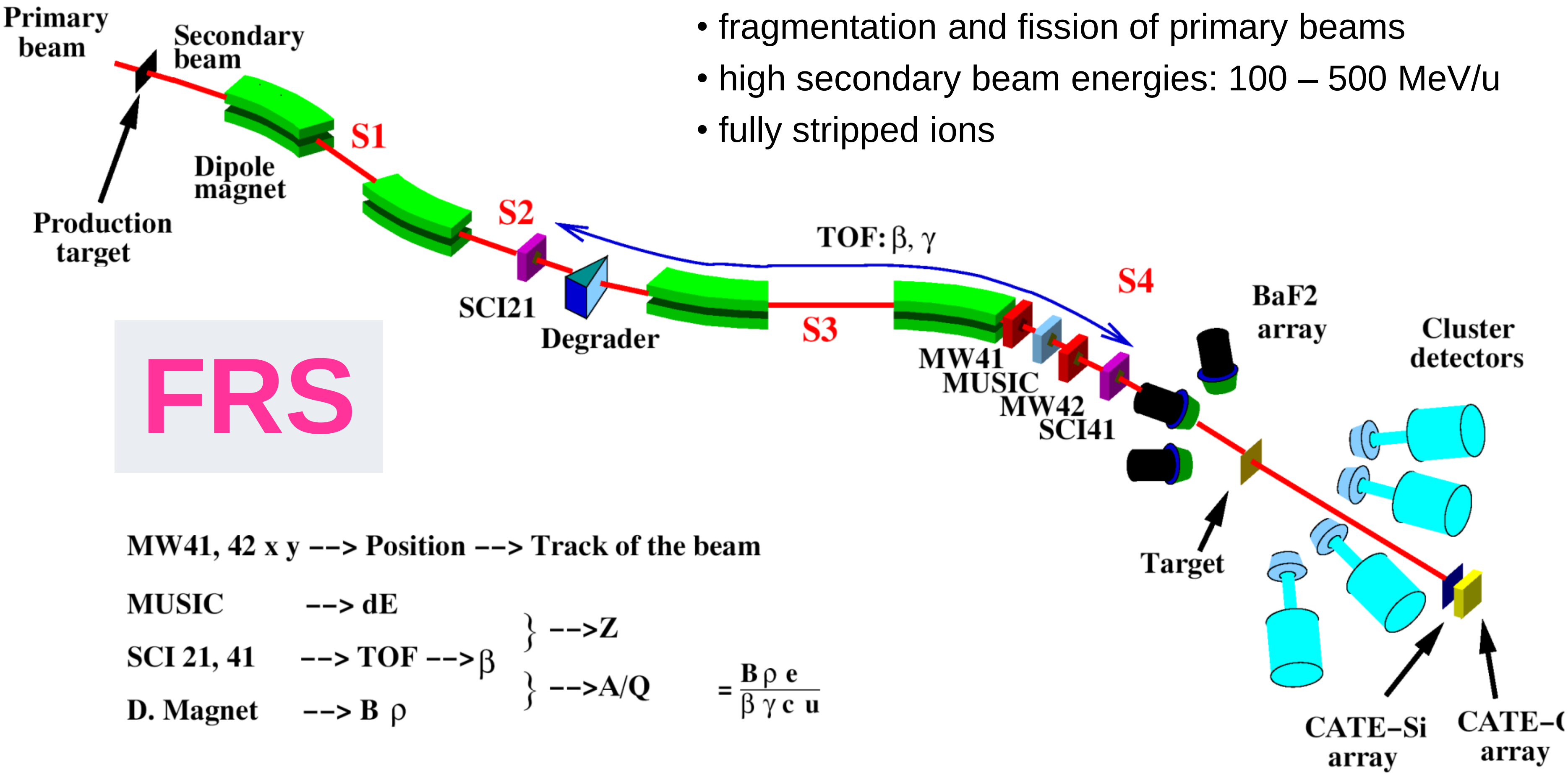
- 3. Physics case: ‚Shell model and isospin symmetry'
- 4. Physics case: ‚Neutron deficient Sn nuclei and the seniority scheme'

- γ-ray tracking Part I

High resolution γ-spectroscopy at the FRS

FRS provides secondary radioactive ion beams:

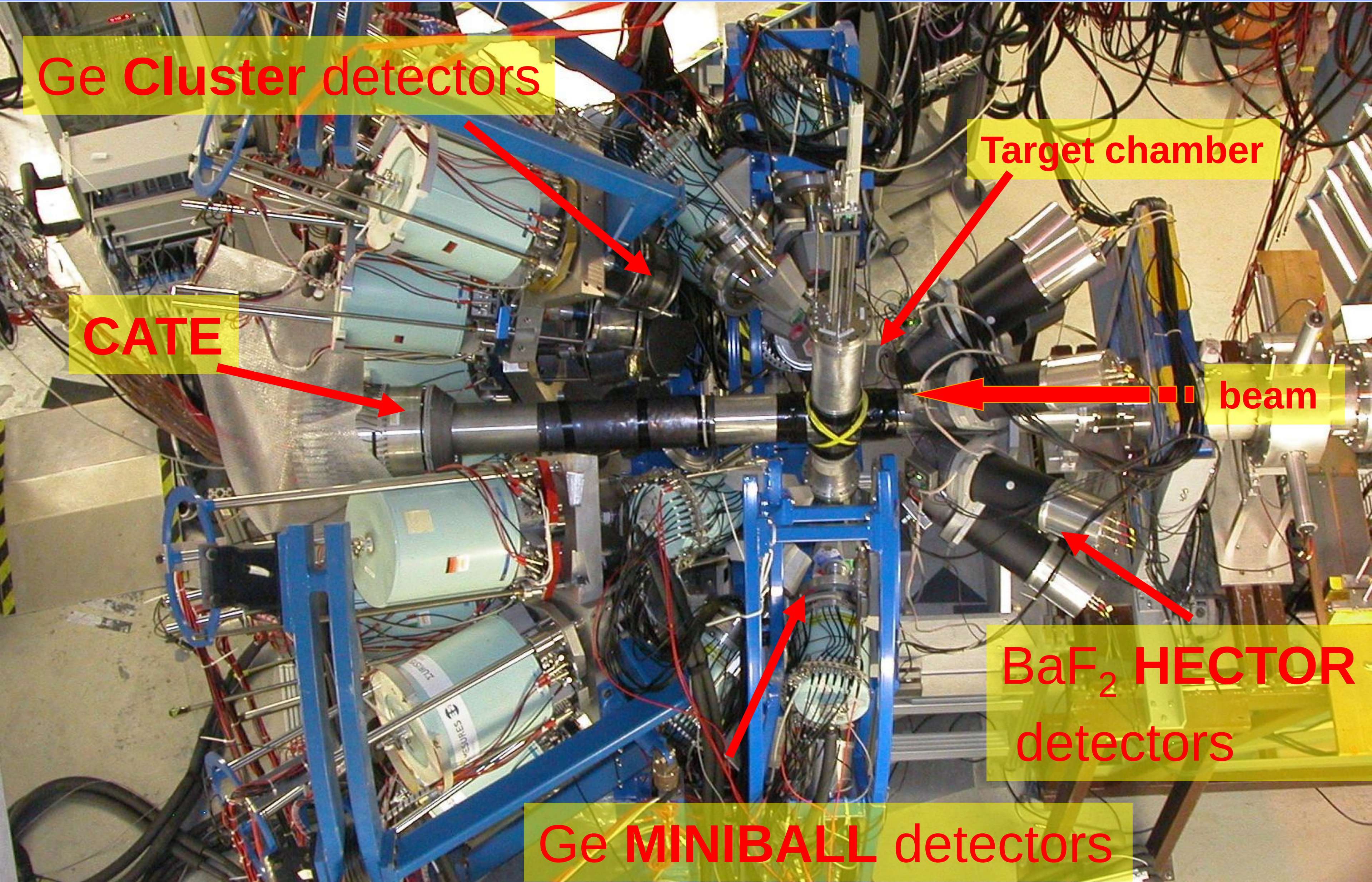
- fragmentation and fission of primary beams
- high secondary beam energies: 100 – 500 MeV/u
- fully stripped ions



FRS

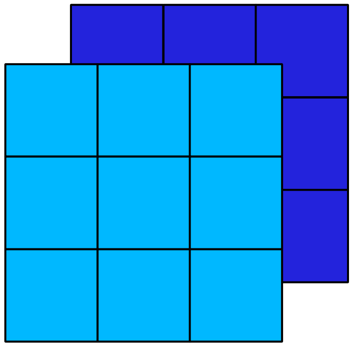
RISING

RISING experimental setup



CAlorimeter TElescope CATE
Particle Identification and Tracking after Target

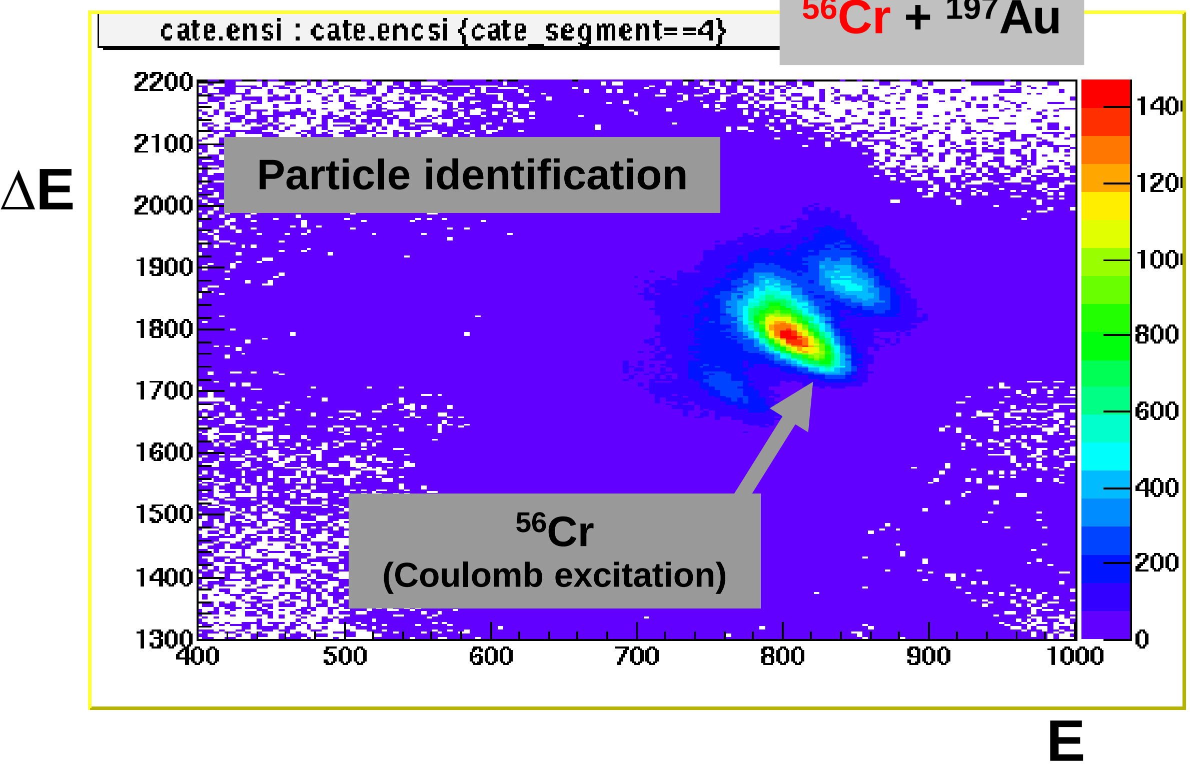
R. Lozeva et al, NIM B, *204 (2003) 678*



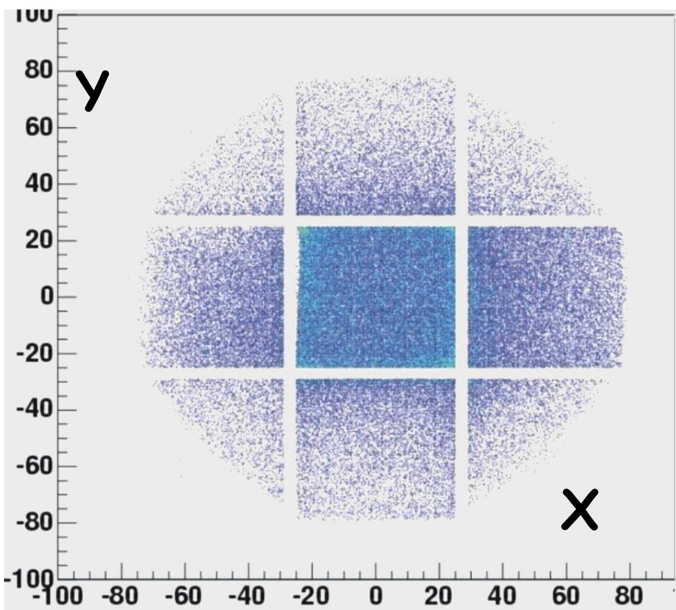
E
- **CsI detectors**
- **Z identification**

ΔE
- **0.3 mm thick Si detectors**
- **Z identification**
- **Position sensitive**

^{56}Cr + ^{197}Au



Tracking after target

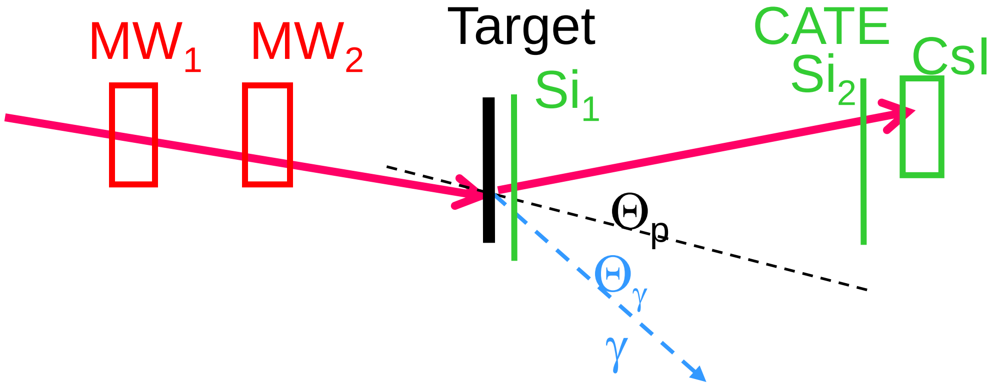


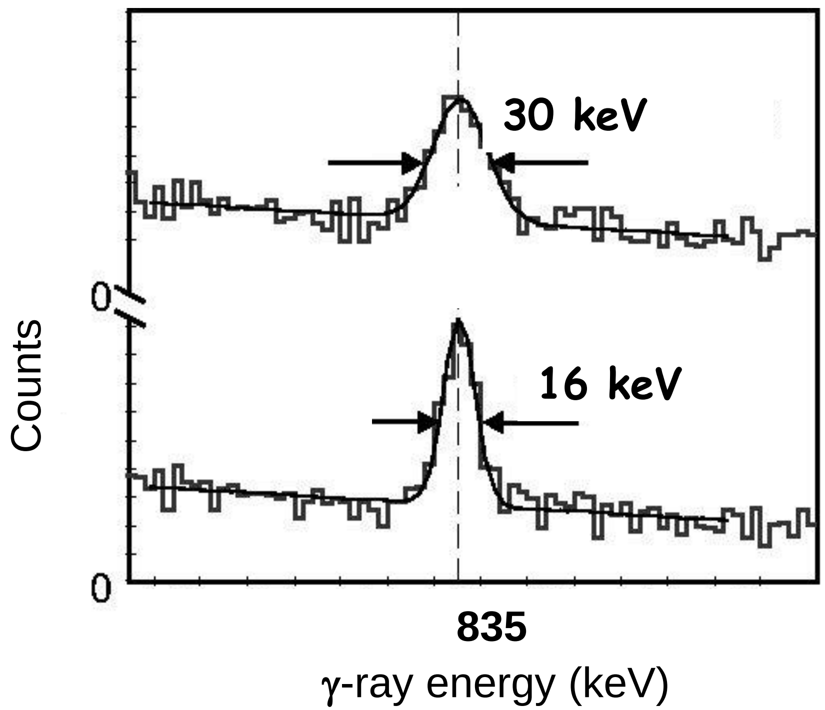
Tracking: - Doppler correction
- scattering angle

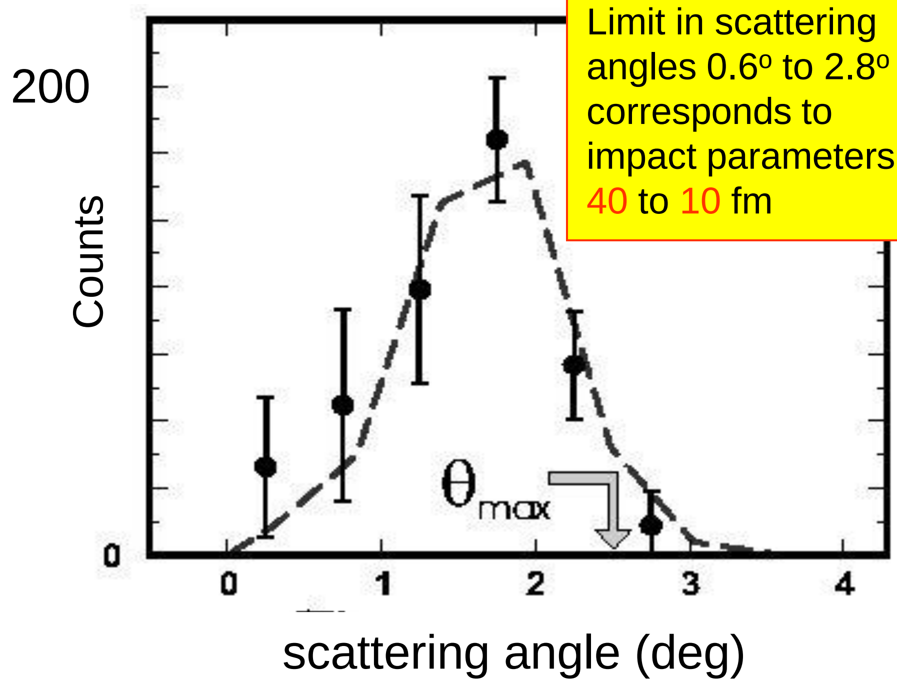
- velocity v/c from TOF (event-by-event)
- tracking of ions: γ-ray emission angle

⇨ γ-ray energy resolution

⇨ scattering angle

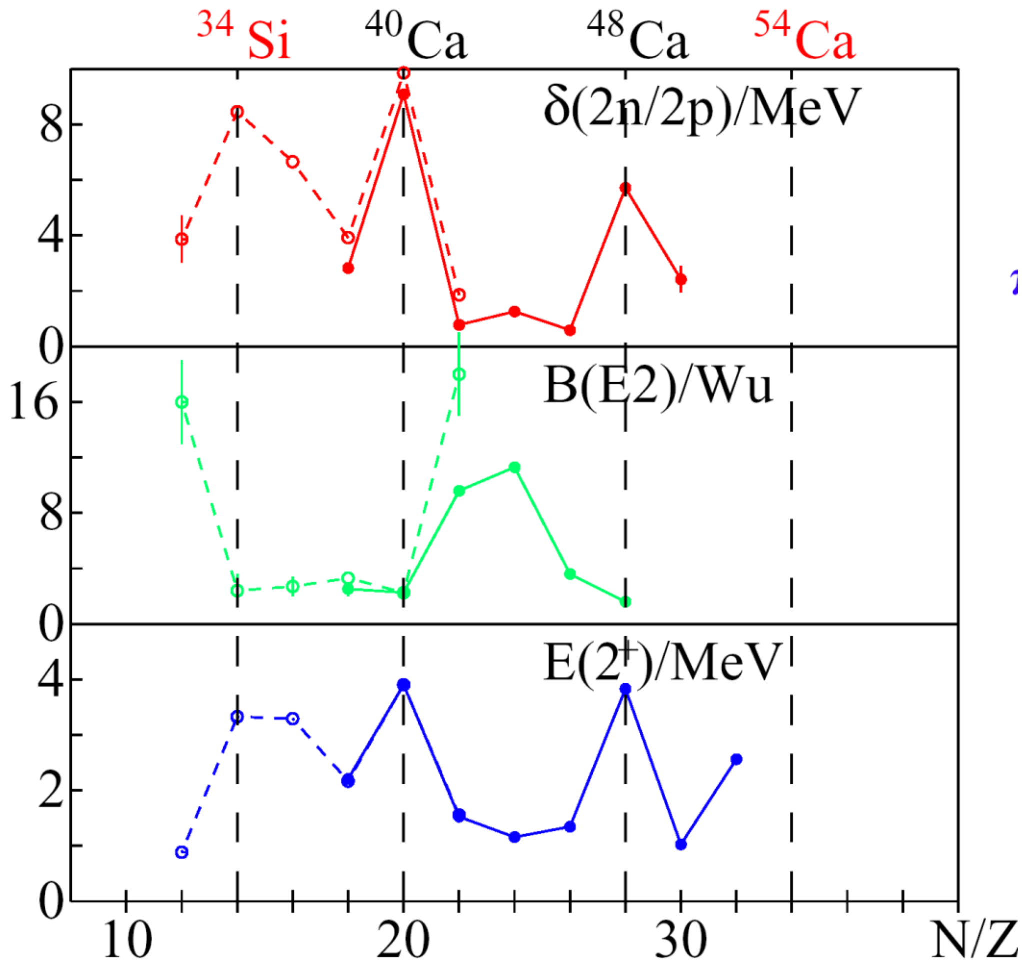


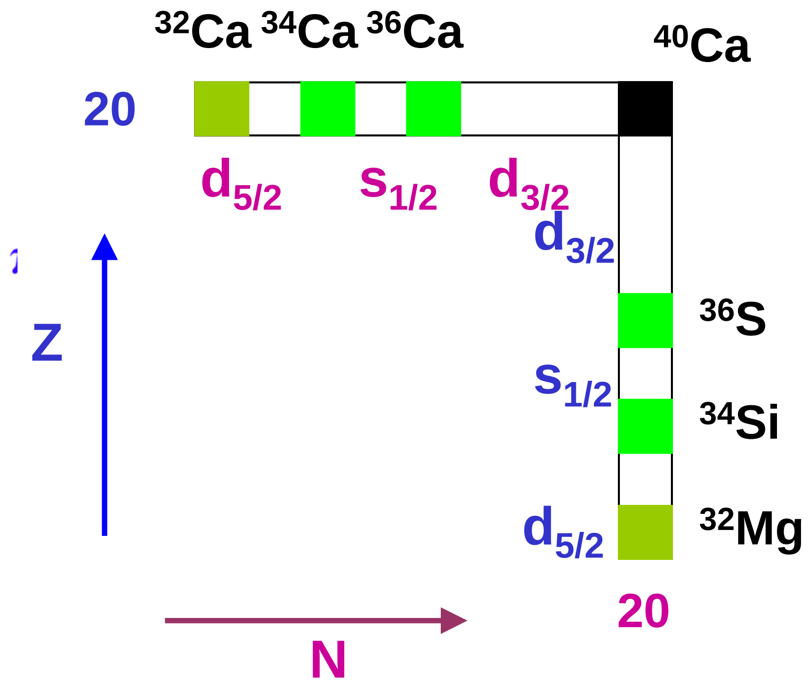




Limit in scattering angles 0.6º to 2.8º corresponds to impact parameters: 40 to 10 fm

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?

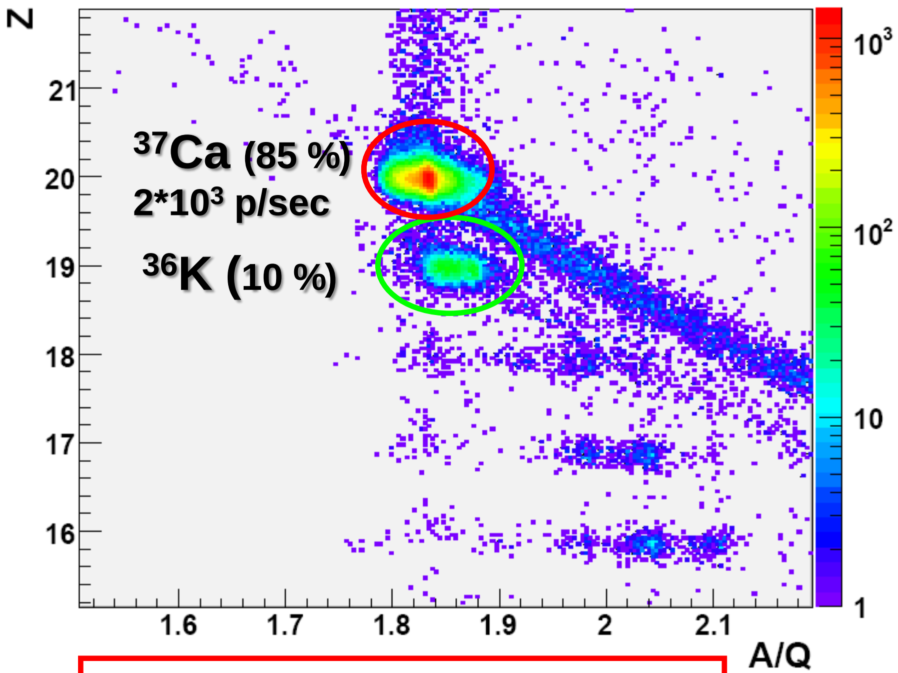
Isospin symmetry in Z=20 isotopes
- excited states in ^{36}Ca vs ^{36}S

Particle identification before and after the secondary target

Double fragmentation reaction:

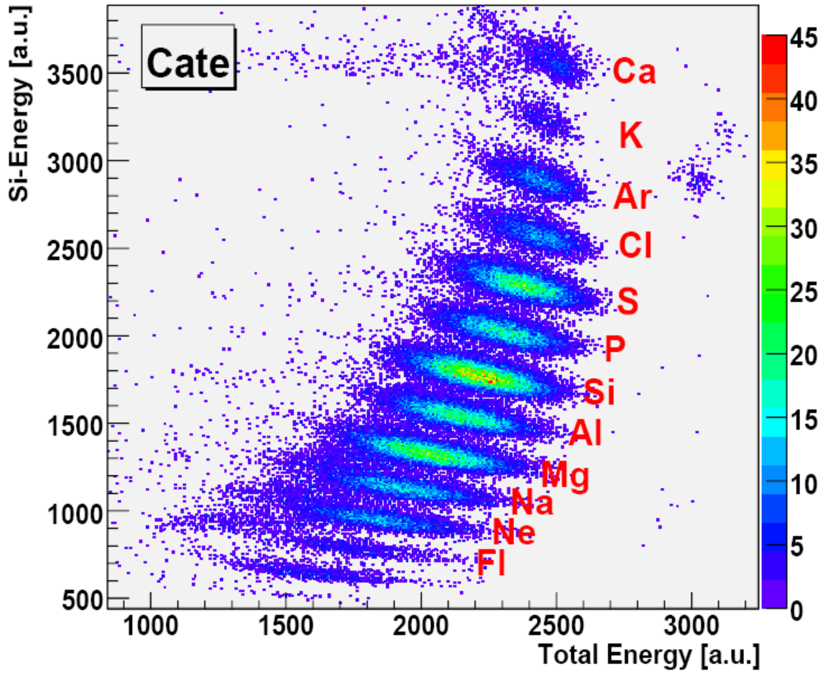
^{40}Ca (420 MeV/u) + ^{9}Be (4.0 g/cm^2) $\rightarrow$ ^{37}Ca (196 MeV/u) + ^{9}Be (0.7 g/cm^2)

Selection by FRS



$$\Delta E \sim Z^2; \frac{A}{Q} = \frac{e}{uc}\frac{B\rho}{\beta\gamma}$$

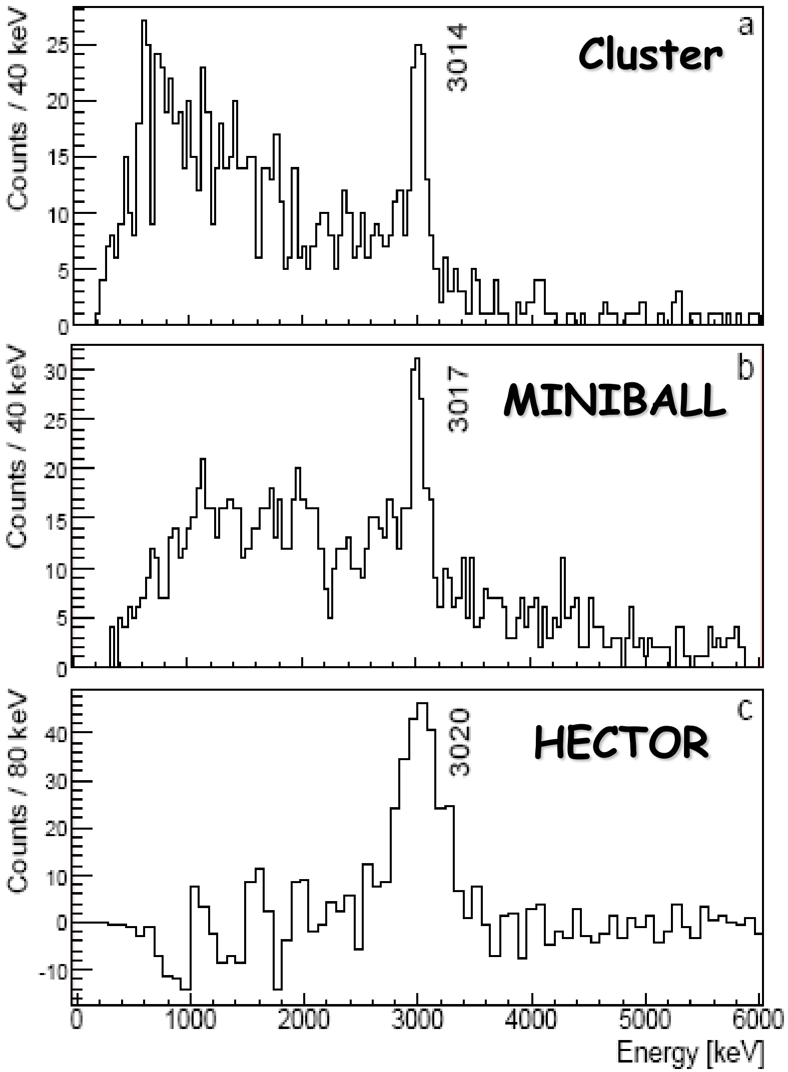
Selection by CATE



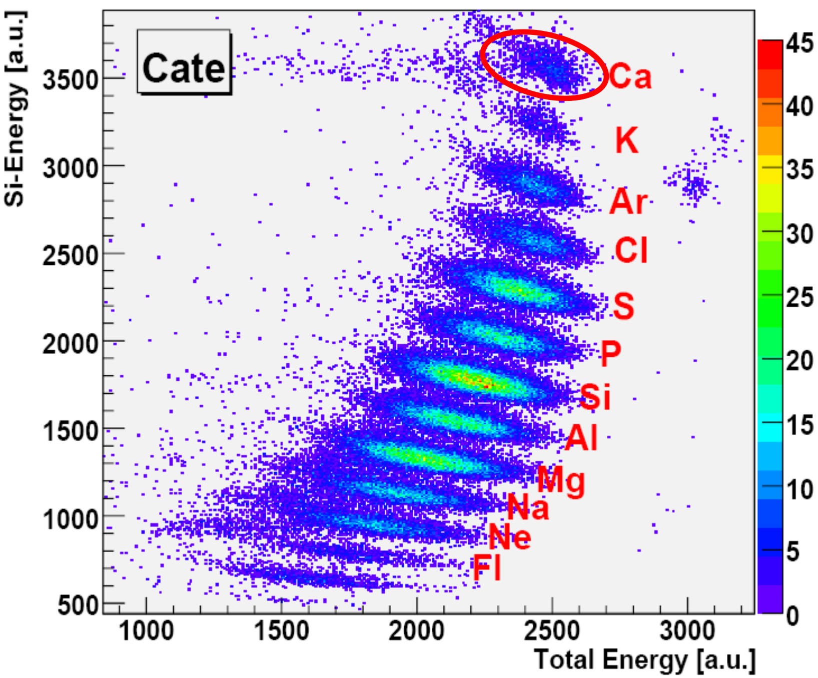
$$\Delta E \sim Z^2; E_{tot} \sim A$$

E(2⁺)-transition in ^{36}Ca

β = 0.545



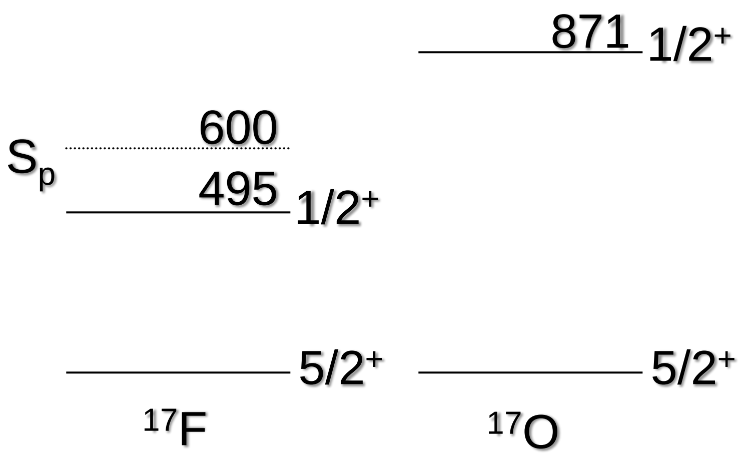
^{36}Ca E(2$^+$) = 3015(16) keV



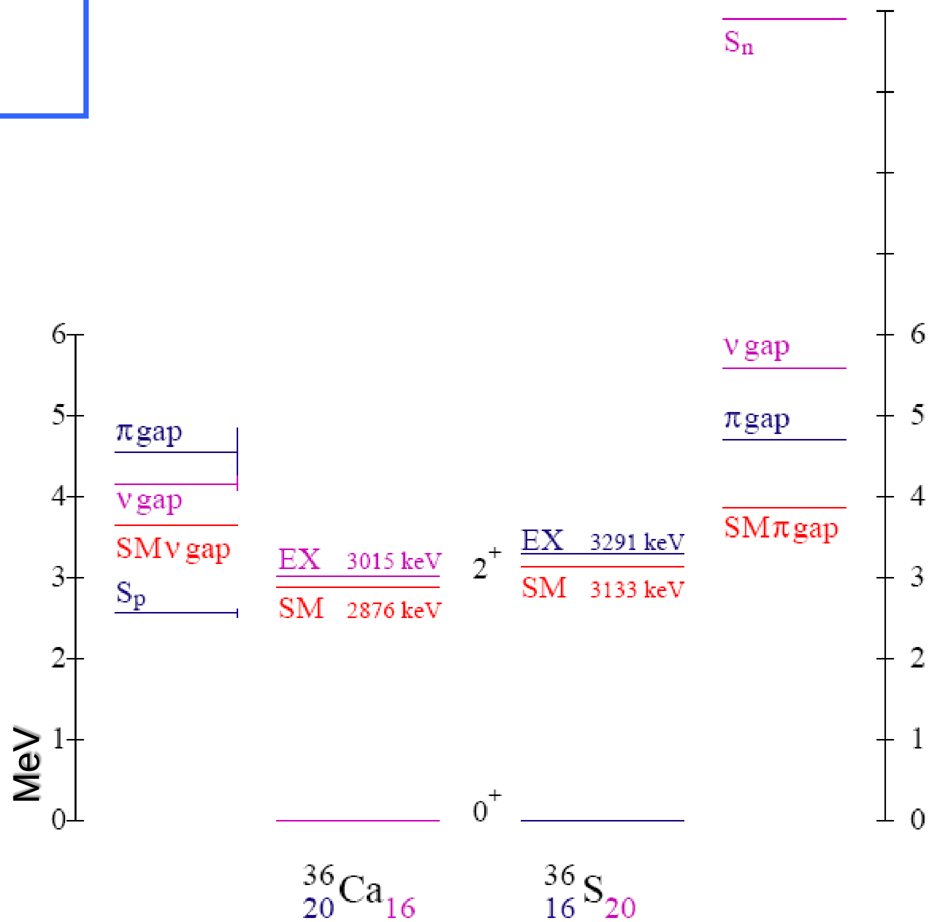
^{36}Ca E(2$^+$) - ^{36}S E(2$^+$) = -276(16) keV

Shell model calculation 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



→ MED = -257 keV



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

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

Monopol modification (USD$^{m}{}_{1}$), deduced from Utsuno *et al**.:

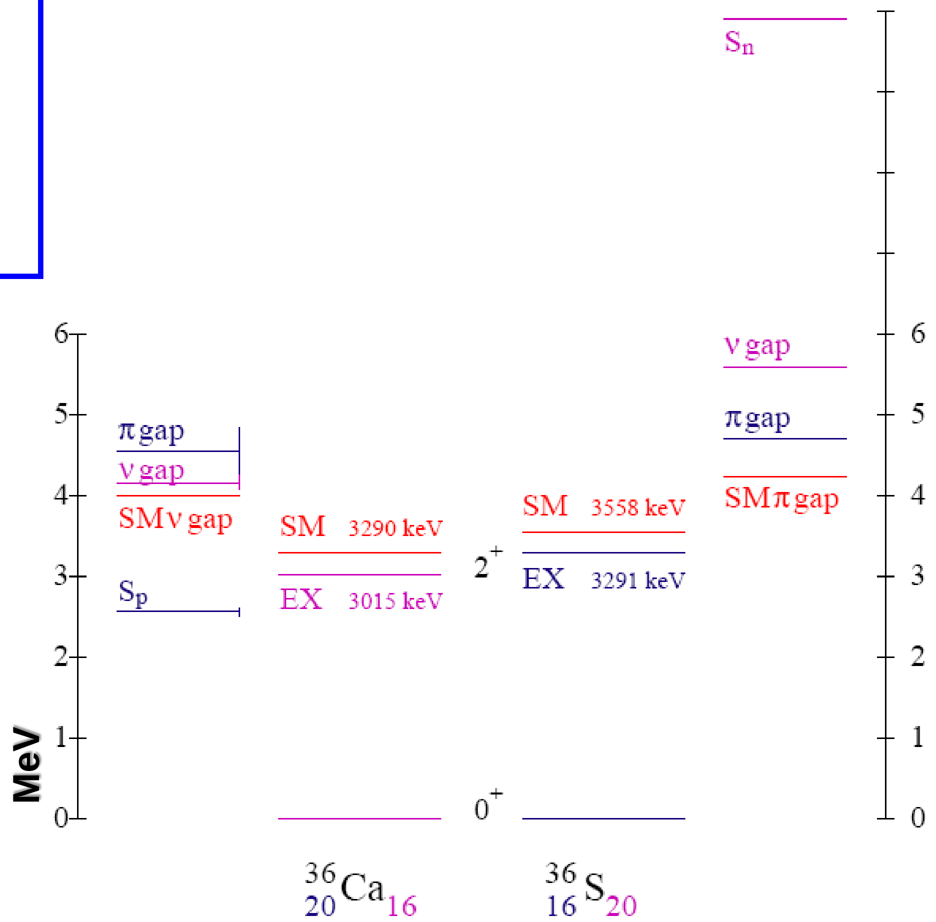
$$\delta V^{T=1,0}_{d_{5/2},d_{3/2}} = +0.20, -0.6\,\mathrm{MeV}$$

$$\delta V^{T=1,0}_{d_{5/2},s_{1/2}} = +0.10, +0.1\,\mathrm{MeV}$$

→ MED = -268 keV

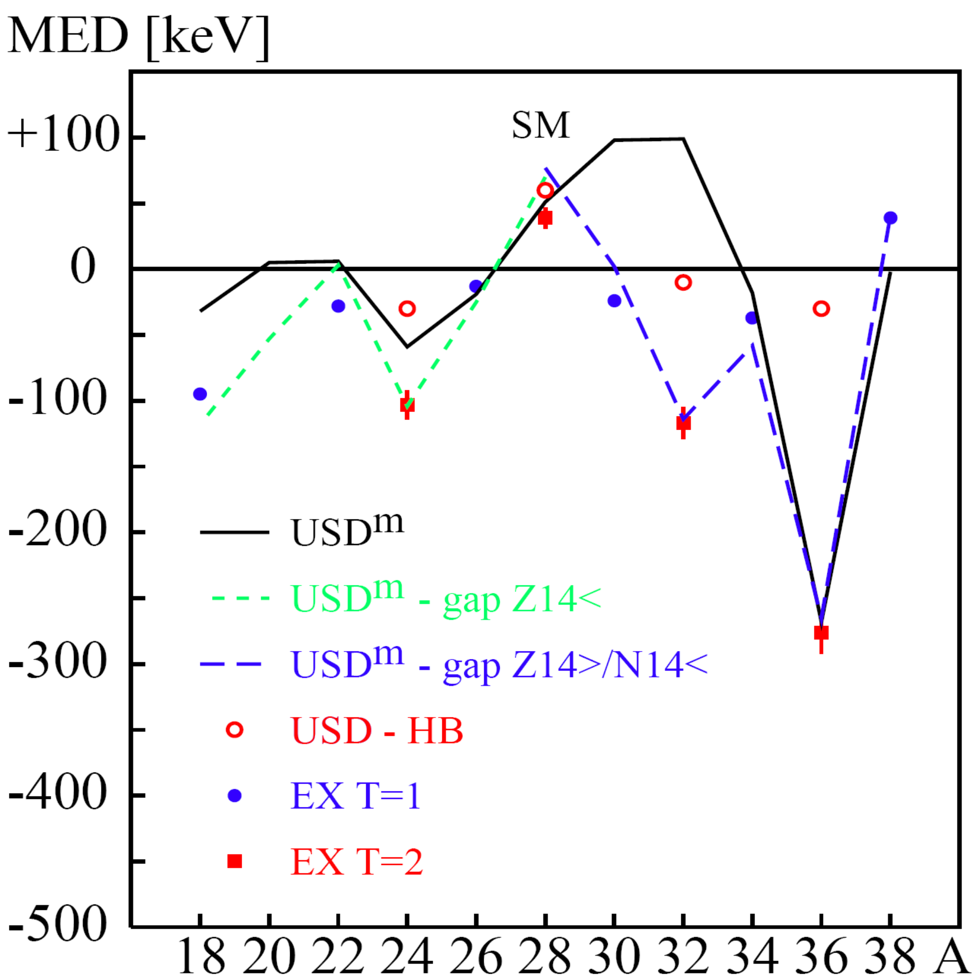
→ ν, π gaps better reproduced!

→ how does it fit for other cases in *sd*-shell?



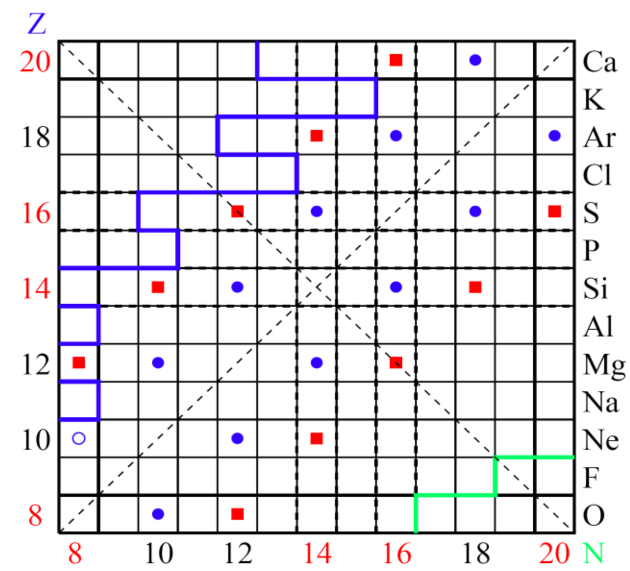
*Y. Utsuno et al., Phys. Rev. C 60 (1999) 054315

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



Ad hoc modifikation introduced H. Grawe

- 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

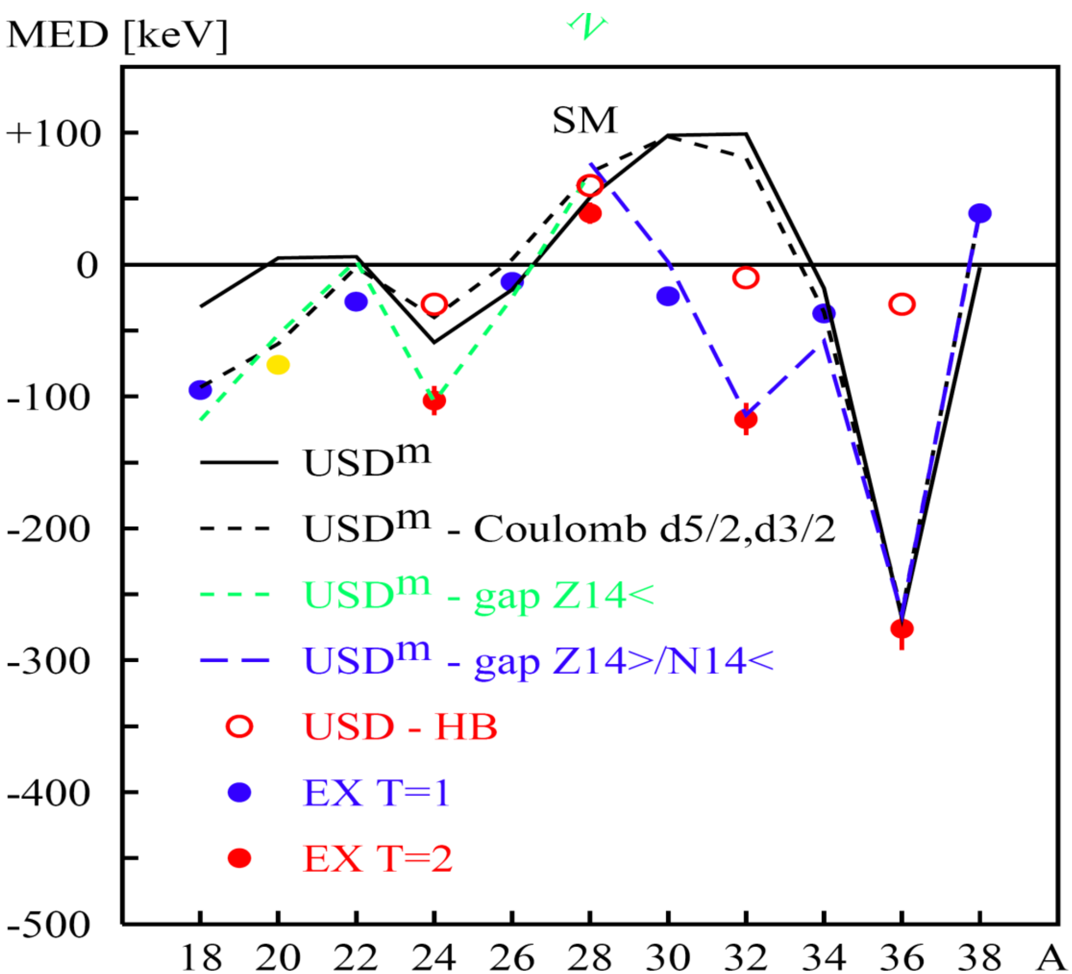


=> reduced neutronen gap in ^{34}Ca (Δ_ν = 5.498 MeV) with respect to protonen gap in ^{34}Si (Δ_π = 6.241 MeV)

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

Y. Utsuno et al., Phys. Rev. C 60 (1999) 054315

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

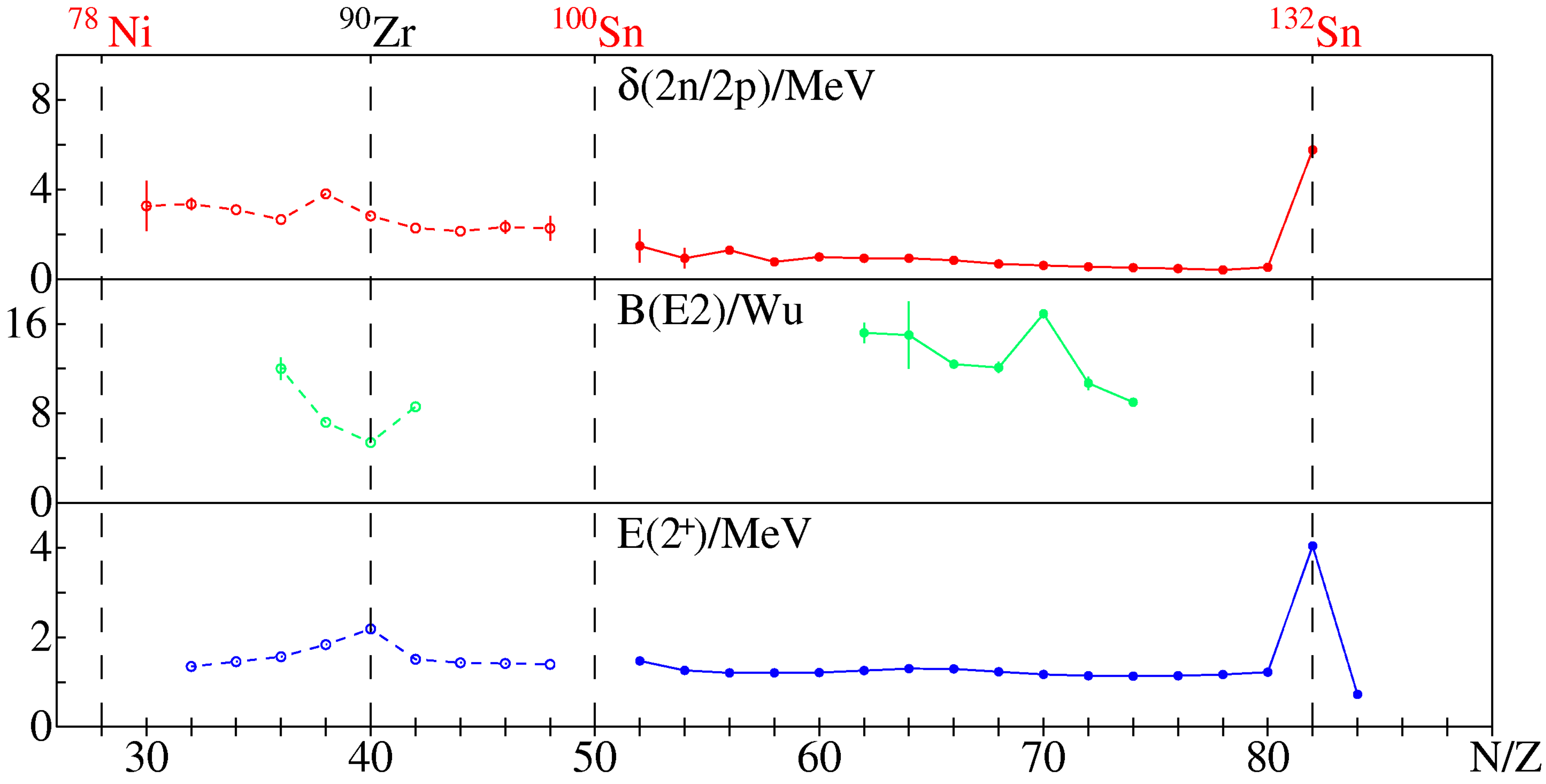


- Confirmation of modifications by MSU result on last and missing 2^+ MED in sd-shell for ^{20}Mg and ^{20}O pair.

- Motivation for future work:

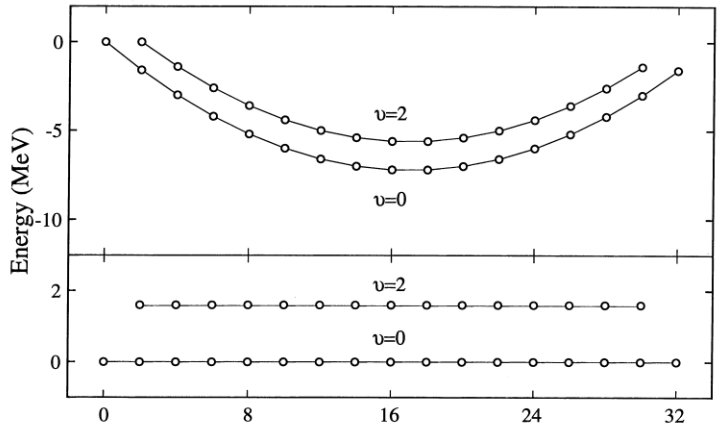
*H. Herndl et al., Phys. Rev. C 52 (1995) 1078
P. Doornenbal et al., Phys. Lett. B647, 237 (2007).
A. Gade et al. Phys. Rev. C 76, 024317 (2007)

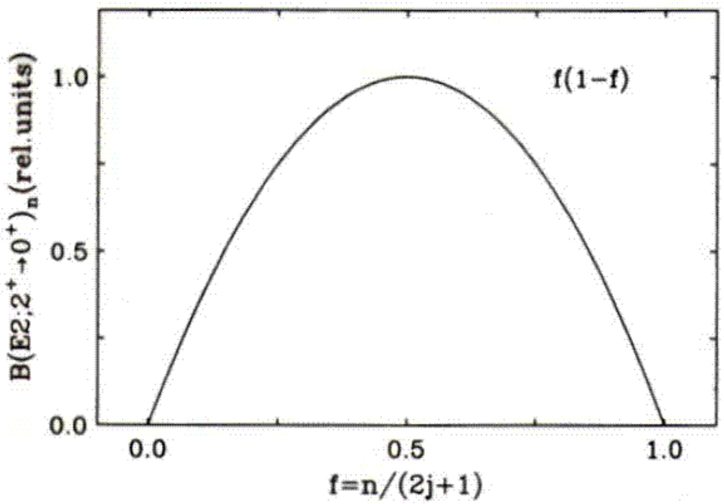
Relativistic Coulomb Excitation of Nuclei Near ^{100}Sn



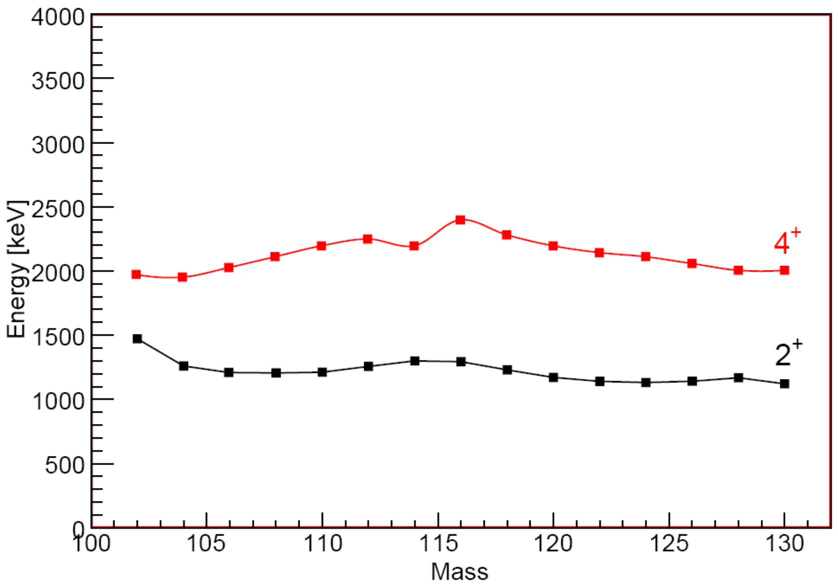
- B(E2, 2^+->0^+) values provide E2 correlations related to core polarization.
- Lifetime measurements hampered by isomeric 6^+ states in even Sn isotopes
- 2^+->0^+ decay too fast for electronic timing methods.
- Coulomb excitation of instable Sn isotopes

Seniority Scheme





$B(E2) \sim N_{particles} * N_{holes}$

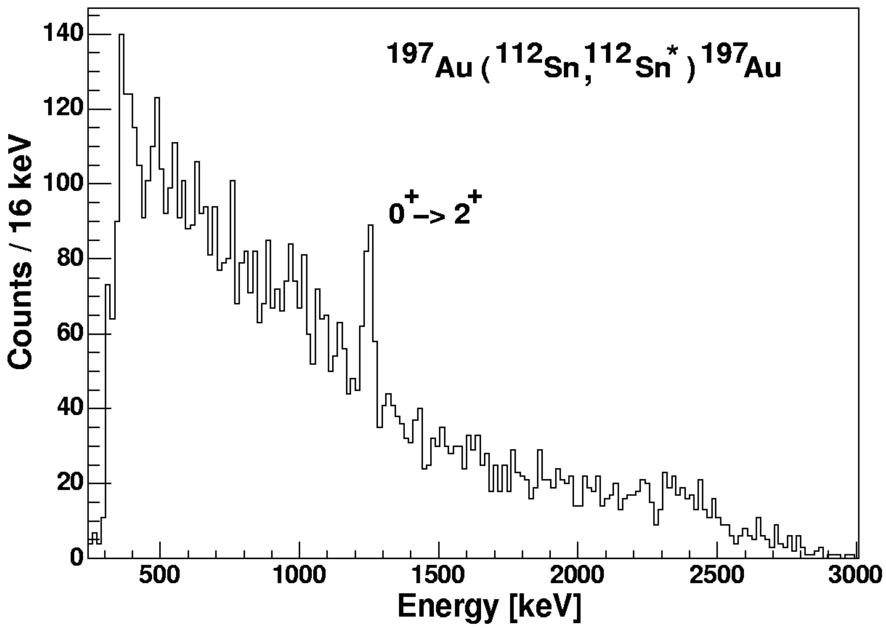


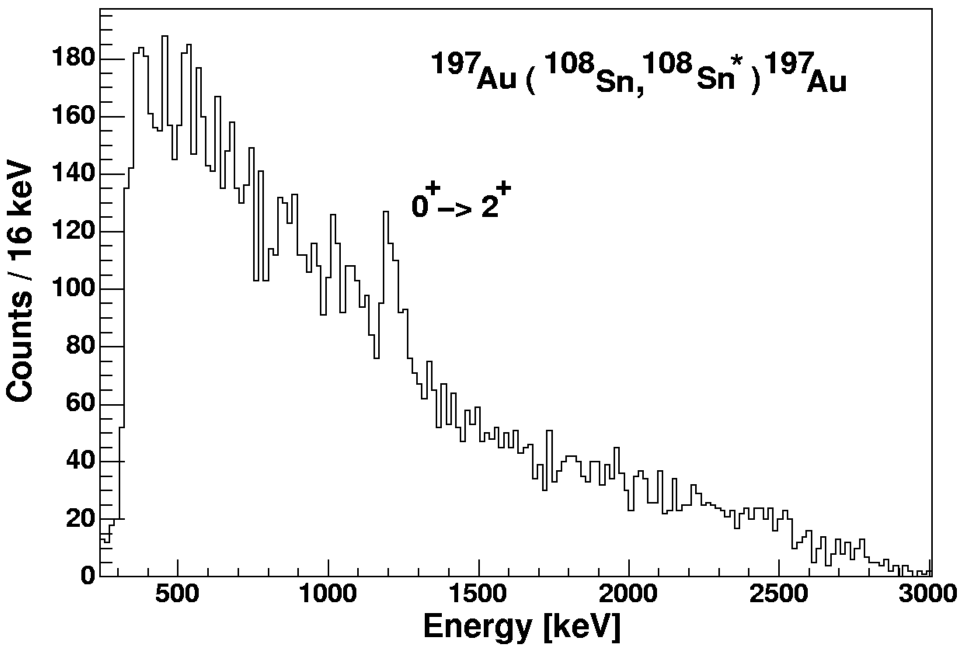
Experimental 2^+ and 4^+ Levels of Sn isotopes are text book examples.

How about the B(E2) values?

Relativistic Coulomb excitation of nuclei towards ^{100}Sn

- **$^{108,112}Sn$ secondary beam with 150MeV/u**
- **Au – Coulex target**





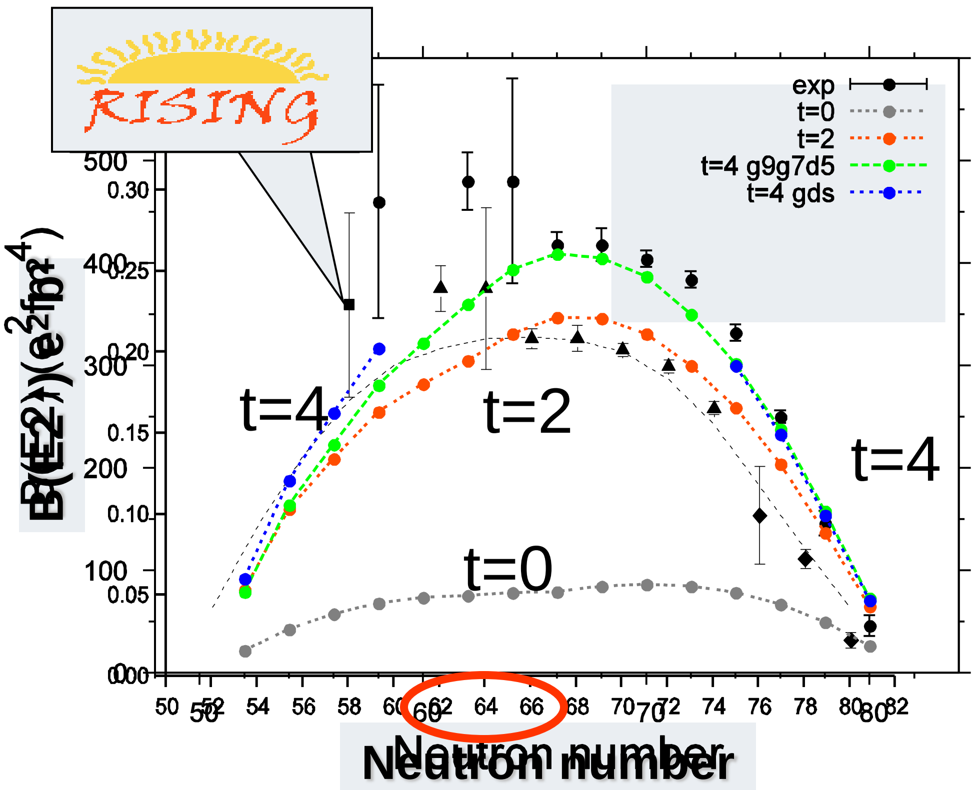
^{108}Sn $B(E2:2^+ \rightarrow 0^+)$ value:

EXP: 15.1 (3.3) W.u.
TH1: 11.2 W.u. Morten Hjorth-Jensen
TH2: 11.5 W.u. Frederic Nowacki

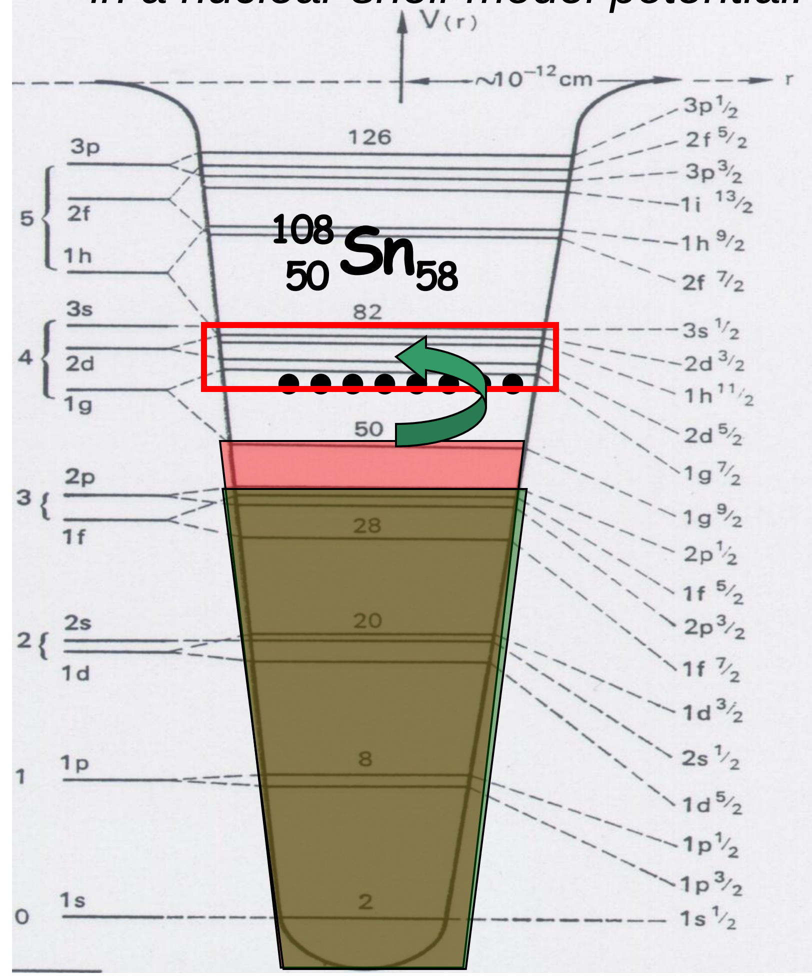
A. Banu, et al.; PRC 72, 061305(R) (2005)

Comparison with Shell Modell calculations

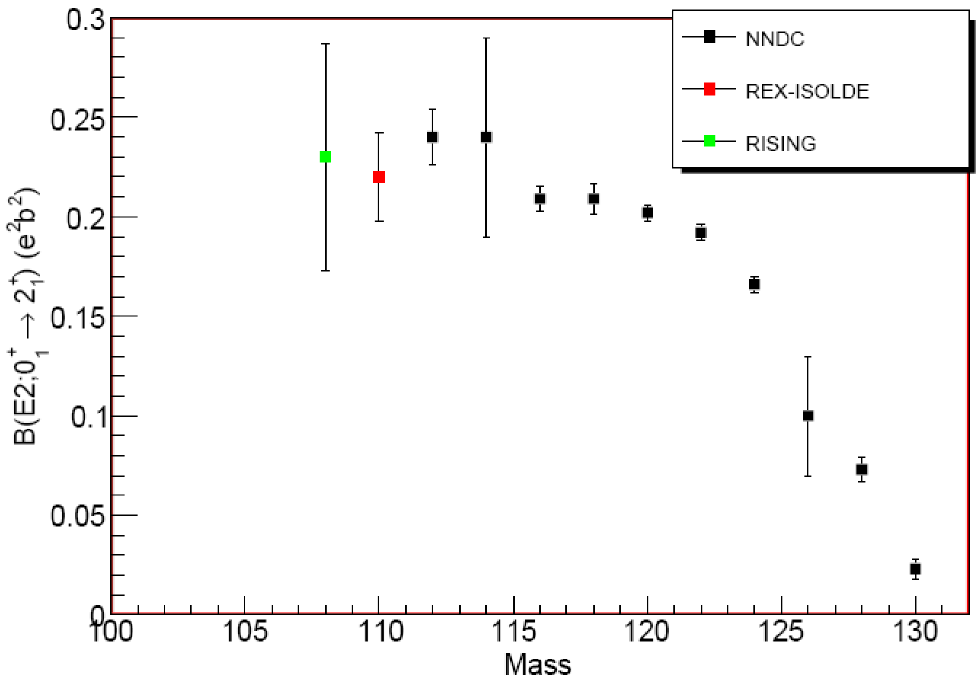
.... theory (neutron valence + proton core excitations and ^{90}Zr as closed-shell core)



Neutron/proton single-particle states in a nuclear shell-model potential:

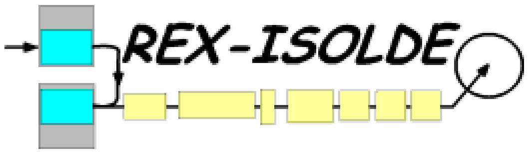


Experimental B(E2) values of Sn Isotopes



2 Methods applicable for neutron deficient Sn isotopes:

- Sub-barrier Coulex



^{110}Sn B(E2) = 0.220(22) e^2b^2

J. Cederkäll et al., PRL98, 172501(2007)

- Intermediate Energy Coulex

^{108}Sn B(E2) = 0.230(57) e^2b^2

A. Banu et al, PRC 72 061305(R) (2005)

An new measurement of ^{114}Sn would enlighten the picture!

Coulex Experiment with stable beams

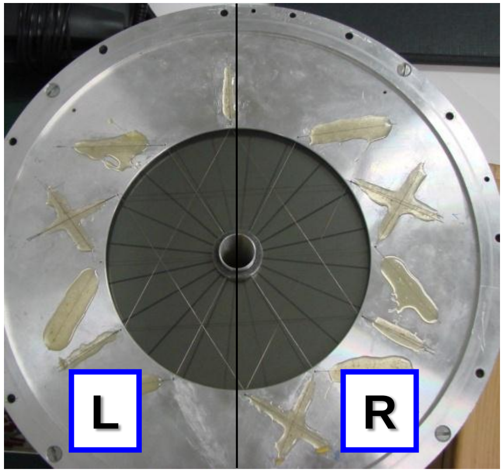
- Previous Coulex measurements were performed using ^{114}Sn as target material
- Natural abundance is only 0.65%
- Enriched materials have contaminations of other Sn isotopes, which cannot be separated, as the 2^+ levels have the same energy

→ **^{114}Sn used as beam and studied via inverse kinematics**

→ ^{116}Sn measured in addition to minimize systematic errors

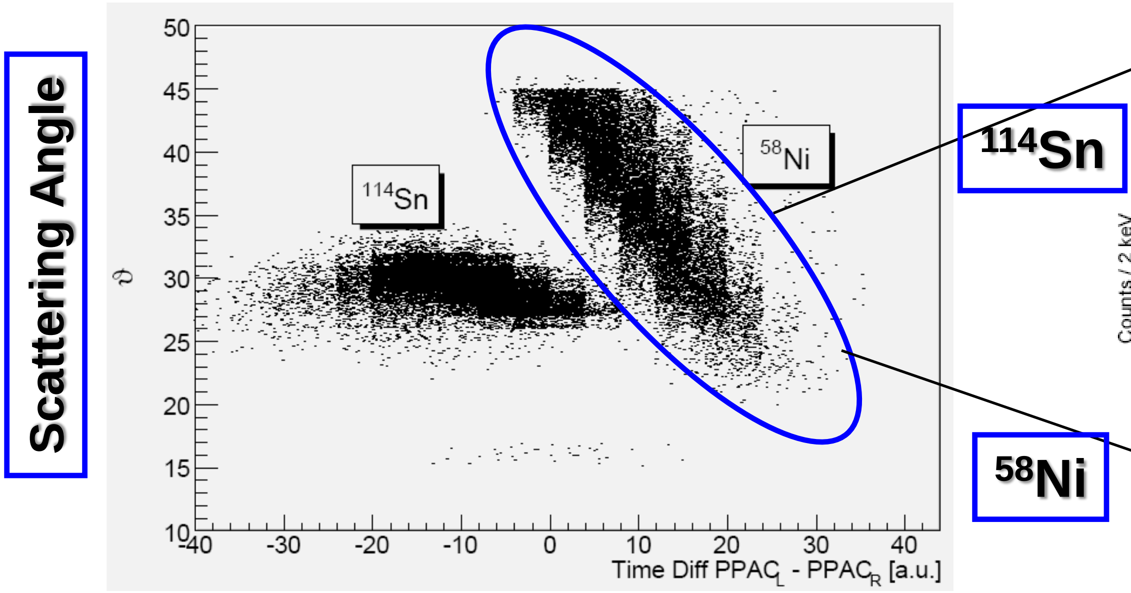
→ Sub-barrier beam energies of 3.4 A MeV provided by UNILAC at GSI

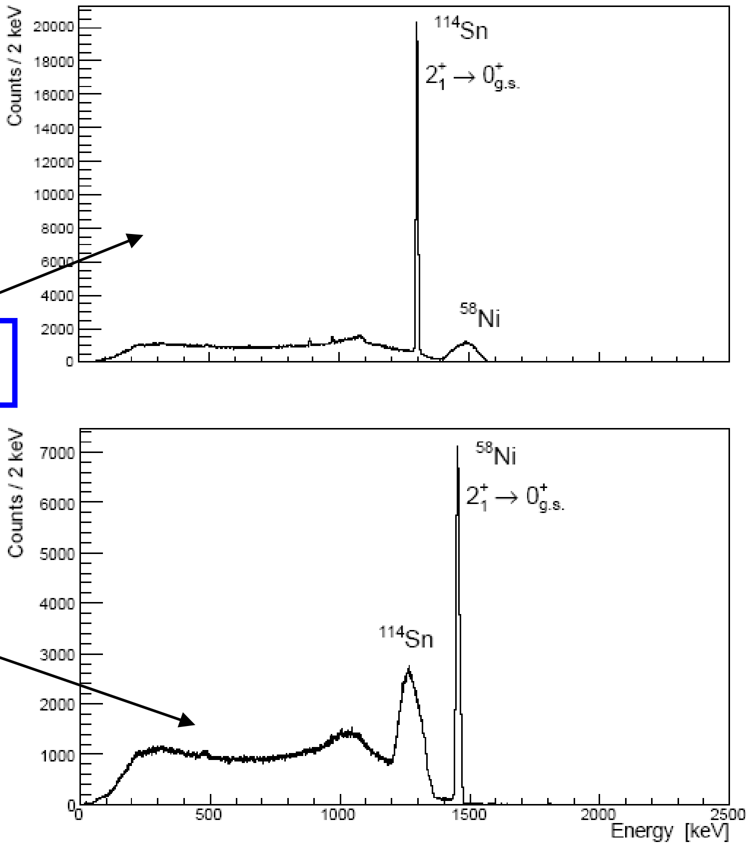
Particle Identification



Scattered particle identification with PPAC

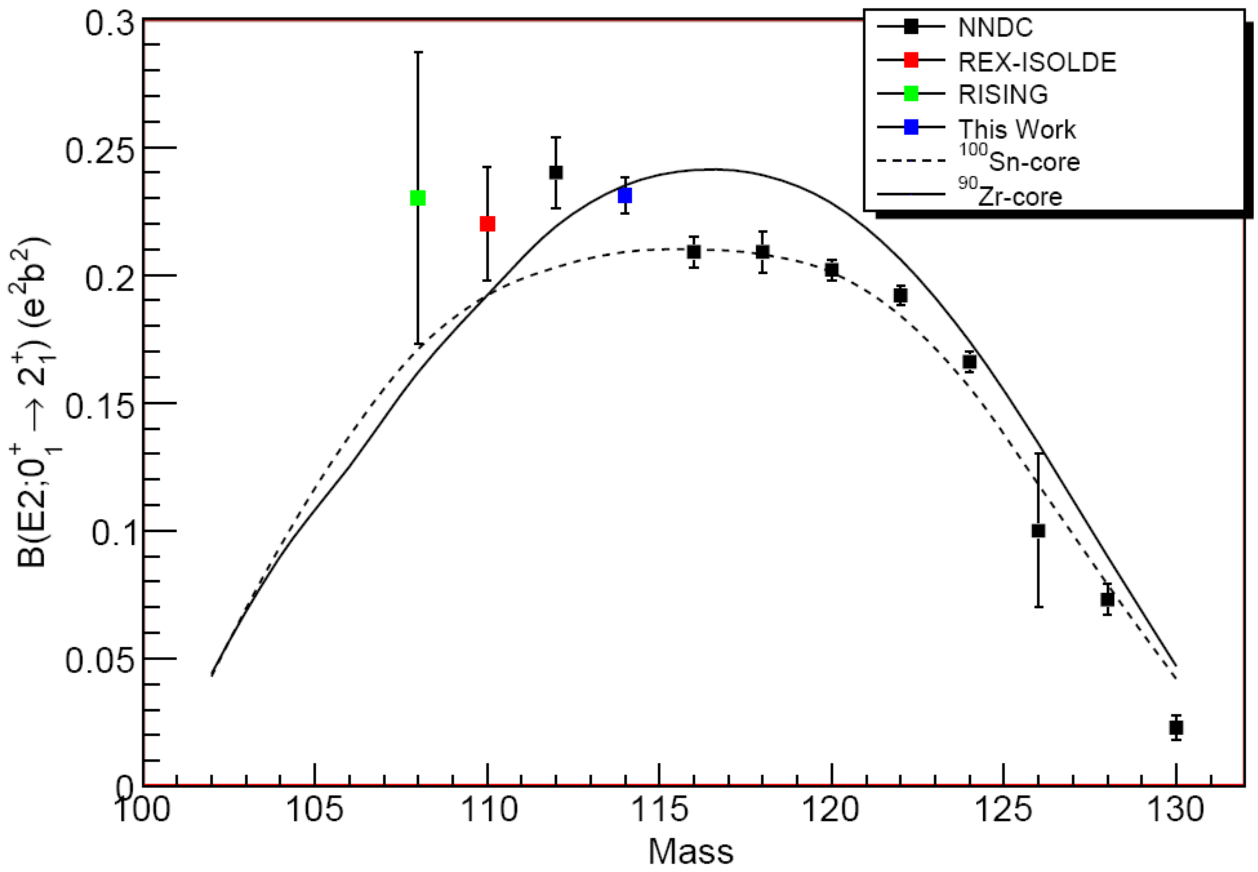
φ and θ determination





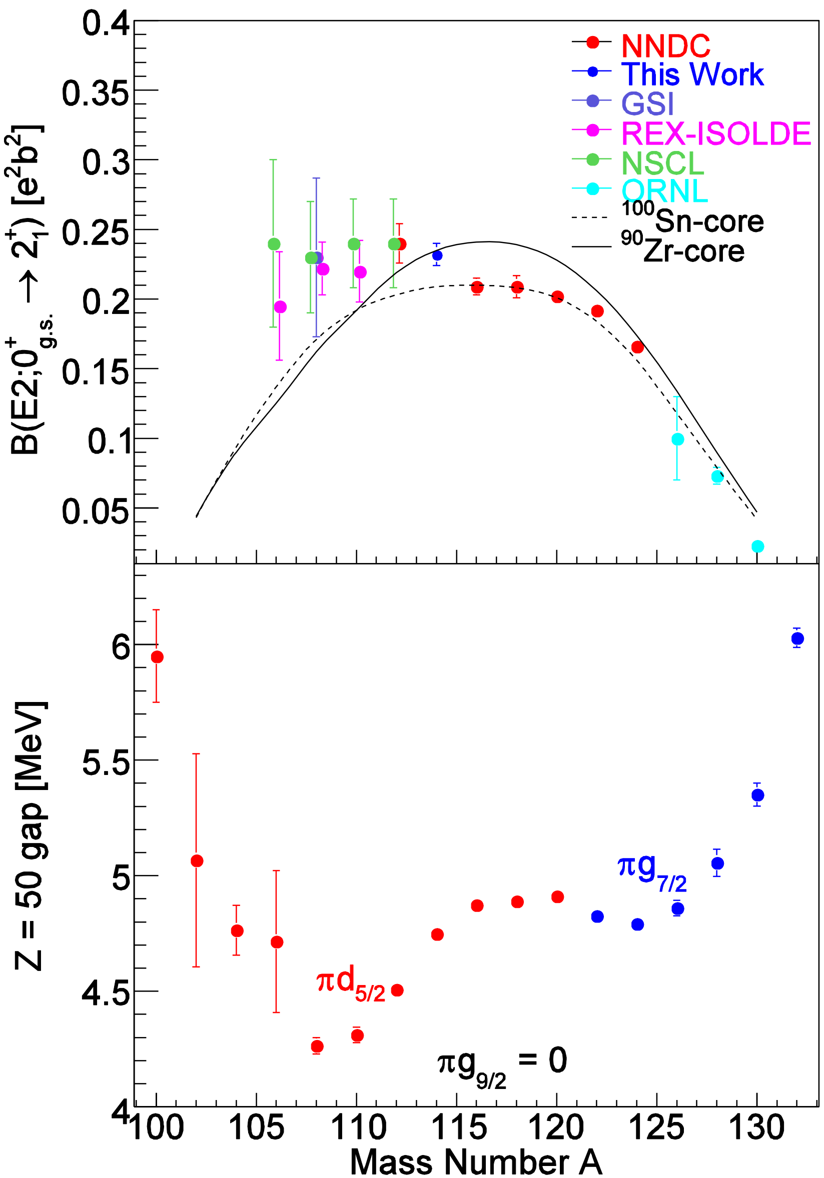
Doppler Correction

B(E2) Systematics for Sn isotopes



^{114}Sn B(E2) = 0.231(7) e^2b^2

Enhanced B(E2) values towards ^{100}Sn



^{100}Sn core

$\nu(d_{5/2}g_{7/2}s_{1/2}h_{11/2})$, $e_\nu = 1.0e$

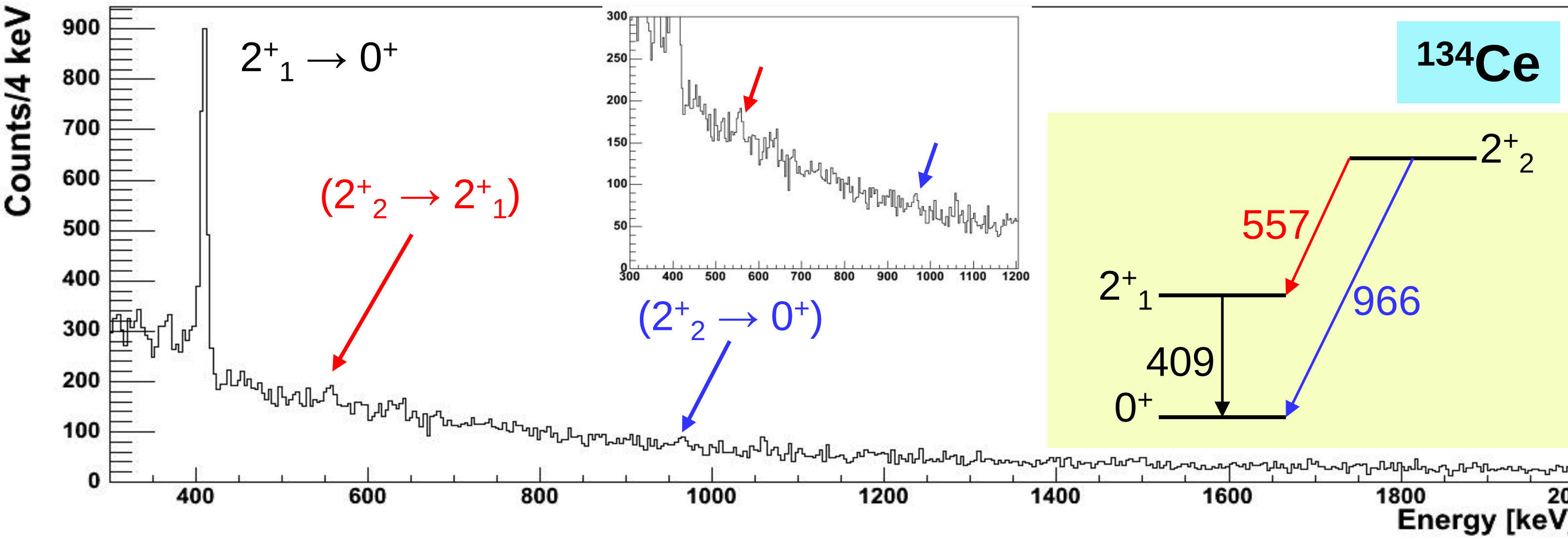
^{90}Zr core

$\nu(d_{5/2}g_{7/2}s_{1/2}h_{11/2})$, $e_\nu = 0.5e$,
$\pi(g_{9/2}g_{7/2}d_{5/2}d_{3/2}s_{1/2})$, $e_\pi = 1.5e$

πν monopoles tuned to
ESPEs and Z = 50 shell gap

A. Banu et al, PRC, 72 061305(R) (2005)
J. Cederkäll et al., PRL98, 172501 (2007)
A. Ekström et al., PRL 101, 012502 (2008)
C. Vaman et al., PRL 99, 162501 (2007),
P. Doornenbal et al., PRC 78, 031303 (R) (2008)

Triaxiality in even-even core nuclei of N=75 odd-odd isotones



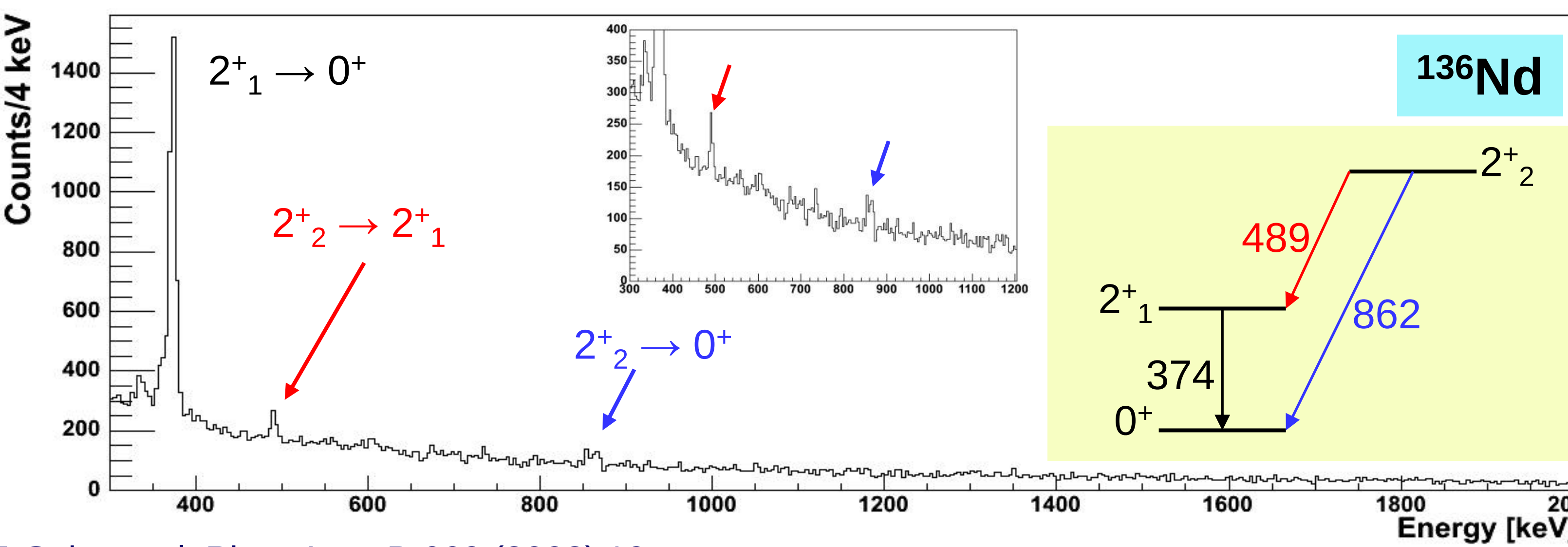
B(E2)

[W.U.]

53±5

< 12 *

< 206 *



B(E2)

[W.U.]

90±11

12±3 *

251±95 *

T. Saito et al. Phys. Lett. B 669 (2008) 19

RISING collaboration

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Summary

Coulomb excitation results from fast beam RISING

- Coulomb excitation at 130-150 MeV established
- Coulomb excitation of 2^+_1 in ^{108,112}Sn
  A. Banu et al., Phys. Rev. C 72, 061305(R) (2005)
- Coulomb excitation of 2^+_1 in ^{54,56,58}Cr
  A. Bürger et al., Phys. Lett. B 622, 29 (2005)
- RDDS results confirms B(E2) of ^{56}Cr
  M. Seidlitz et al., Phys. Rev. C 84, 034318 (2011)
- Collective modes and E1 strength distribution: ^{68}Ni
  O. Wieland et al., Phys. Rev.Lett. 102, 092502 (2009)
- Coulomb excitation of 2^+_1 and 2^+_2 in ^{134}Ce, ^{136}Nd
  T. Saito et al., Phys. Lett. B 669 (2008) 19
- Mirror symmetry in ^{36}Ca
  P. Doornenbal et al., Phys. Lett. B647, 237 (2007).

Future

fast beam experiments PRESPEC employing γ-ray tracking