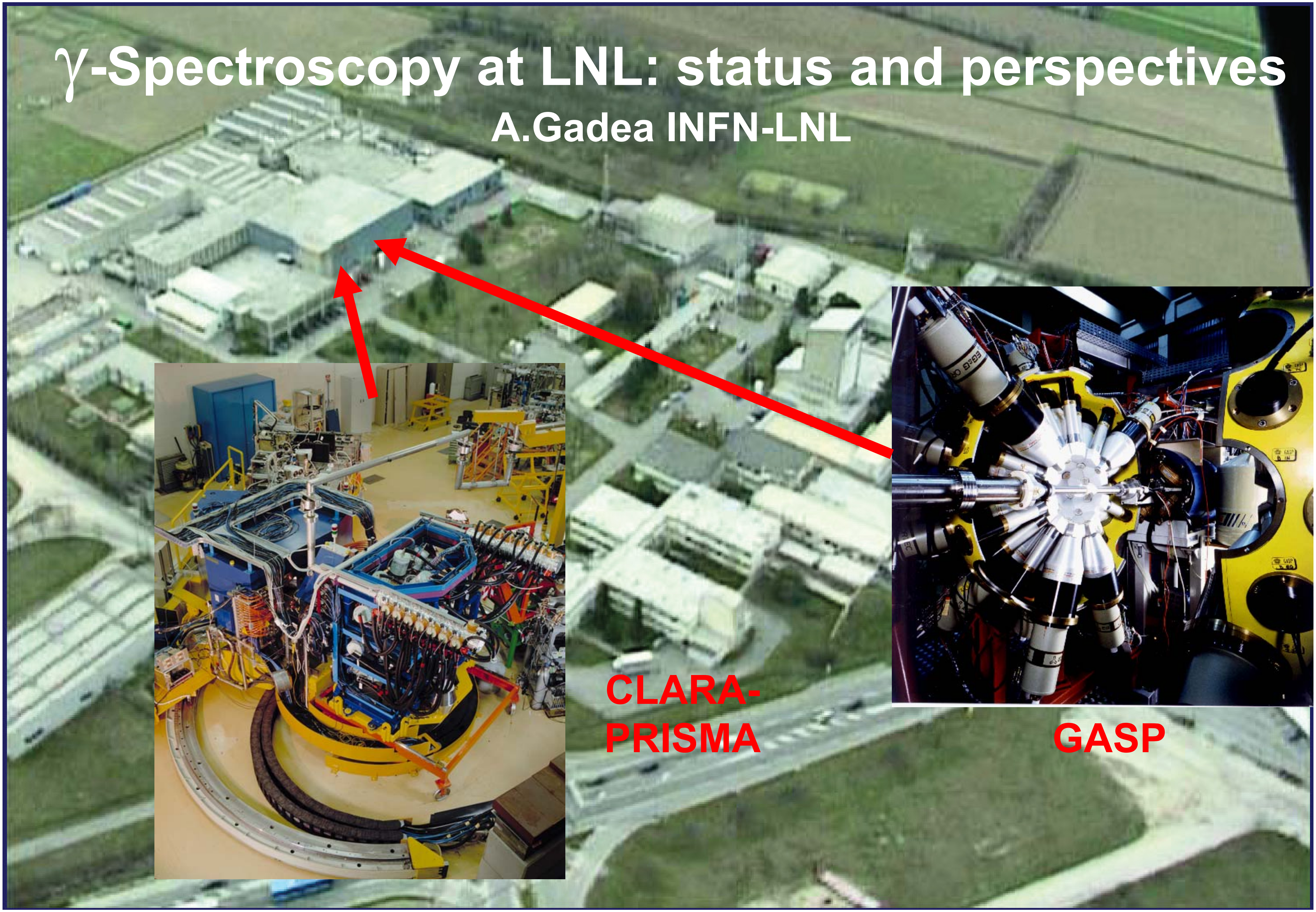
γ-Spectroscopy at LNL: status and perspectives

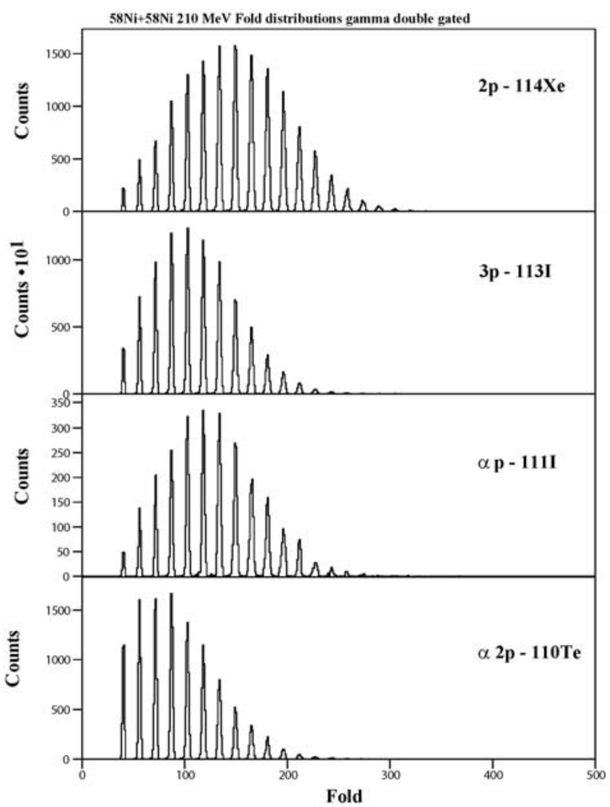
A.Gadea INFN-LNL

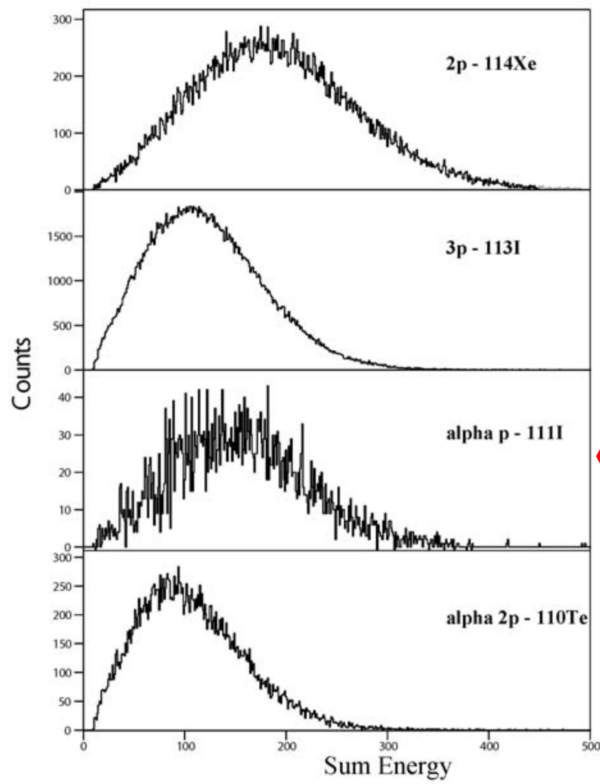


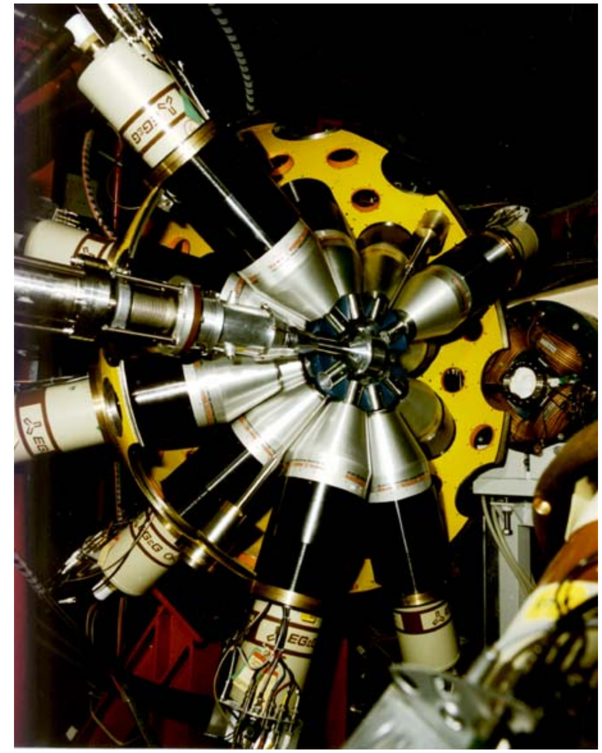
GASP:

4π array, 40 Ge detectors 70%
Designed for high spin studies in fusion-evaporation reactions Two configurations:

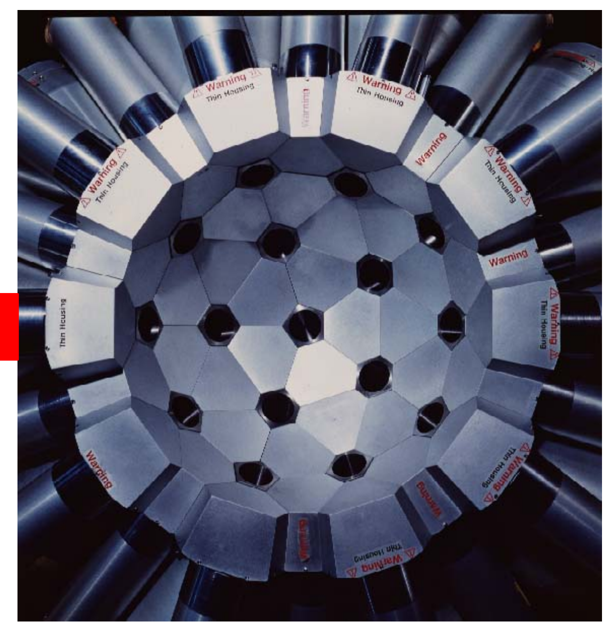
- **I Ge + inner BGO ball Eff~3% (1.3MeV)**
- **II Ge closer + collimator Eff~ 5%**



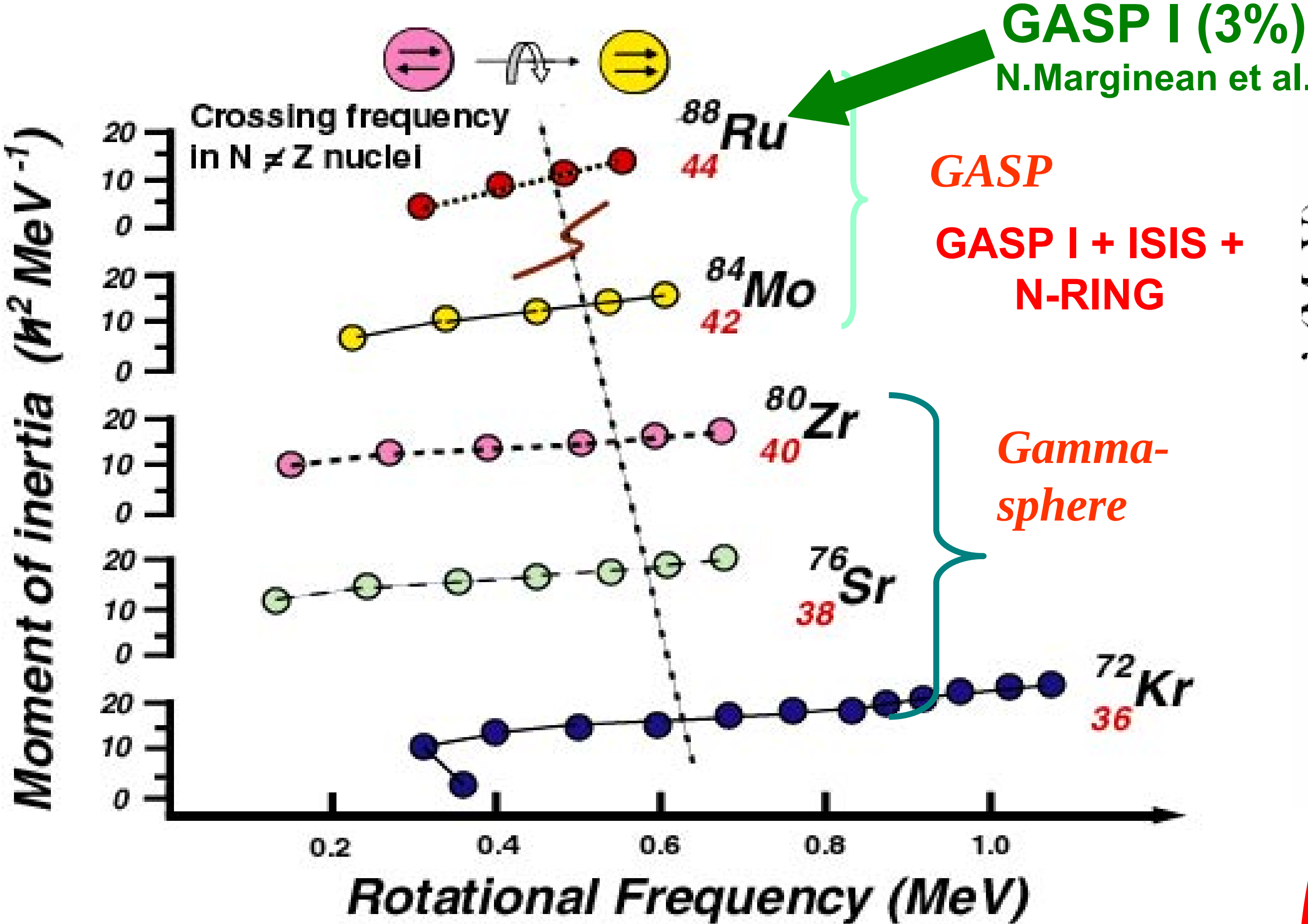


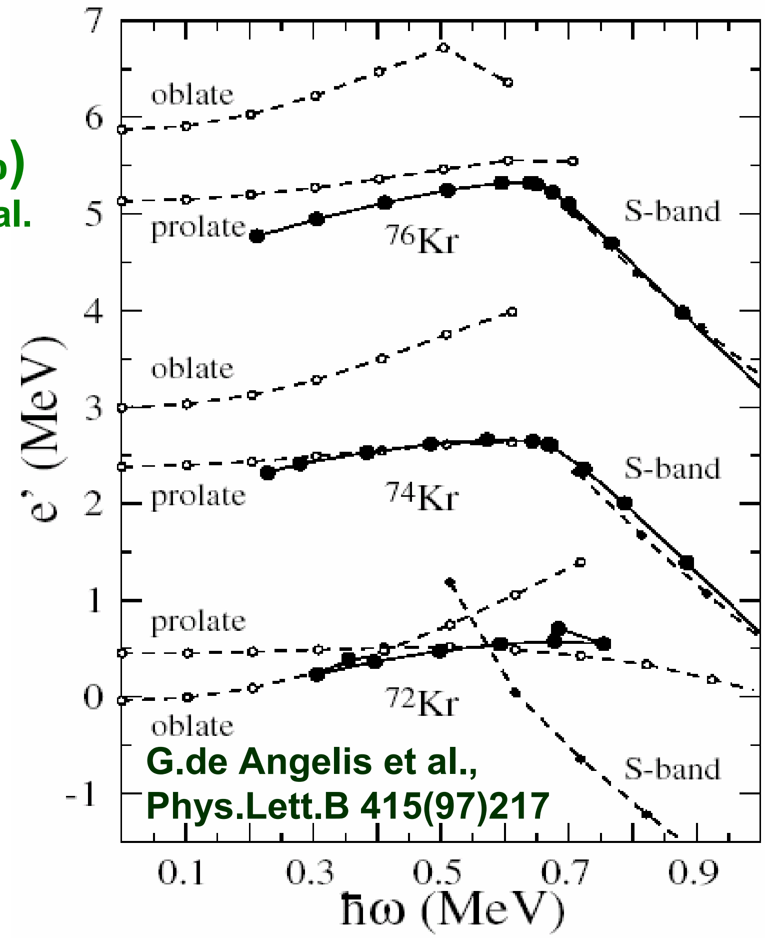


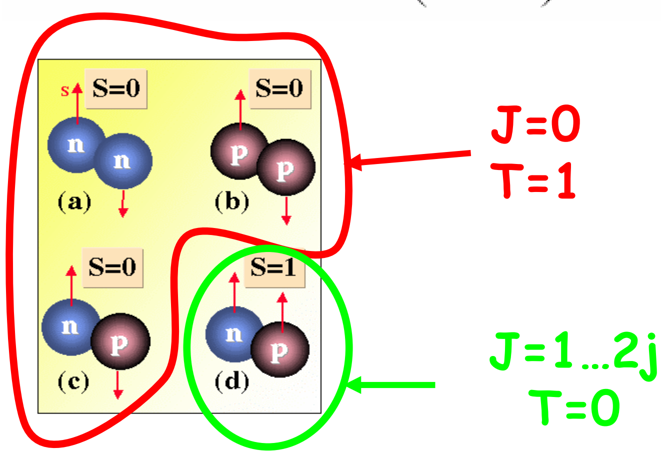
Eff. 80%



High-spin signatures of proton-neutron T=0 condensate in N=Z



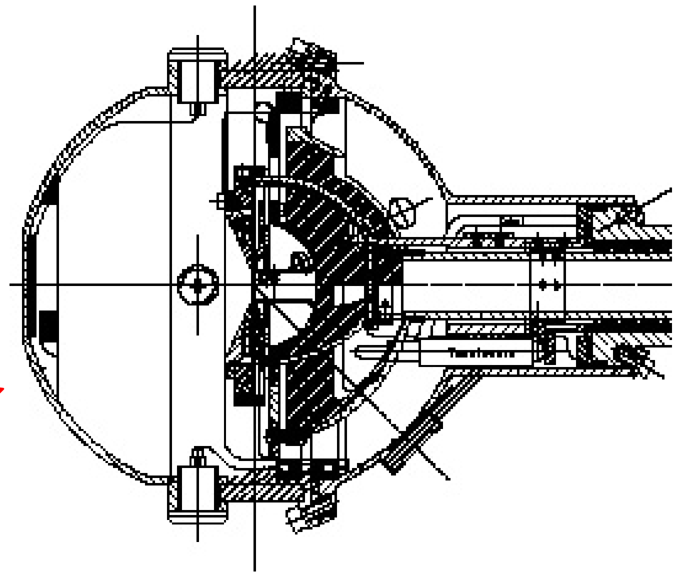




A.O. Macchiavelli et al. Phys. Lett. B 480 (2000) 1
W. Satula and R. Wyss Phys Lett. B 393 (1997) 1
S. Frauendorf , J. Sheikh Nucl. Phys. A 645 (1999) 509
W. Satula , R. Wyss Phys. Rev. Lett. 86 (2001) 4488
W. Satula , R. Wyss Phys. Rev. Lett. 87 (2001) 52504
A.L. Goodmann Phys. Rev. C 63 (2001) 44325J.
Dobaczewski et al., Phys. Rev. C 67 (2003) 034308

Present of GASP:

- GASP Configuration II
- Lifetime measurements campaigns with RDDS and DSA methods
- IKP Koeln Plunger device



Lifetime measurements provide vital information for:

•Shape evolution/coexistence (A.Goergen contribution)

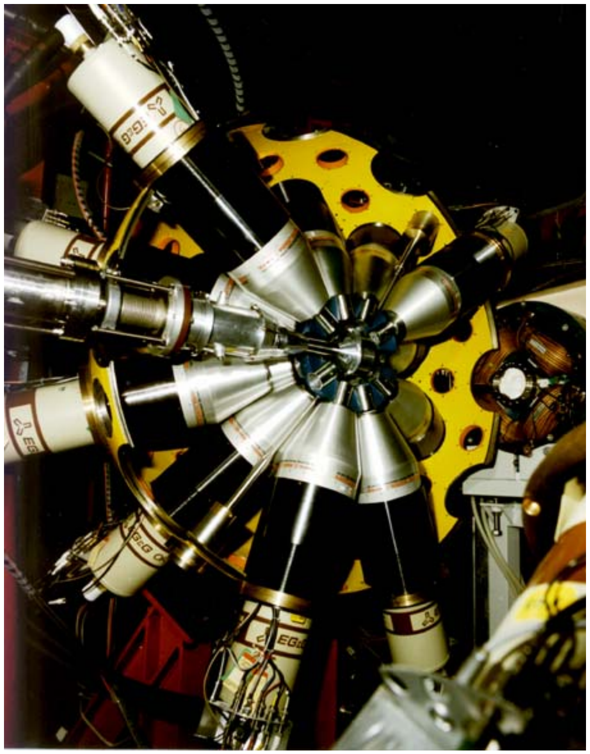
•Chiral bands

•Magnetic & Antimagnetic rotation

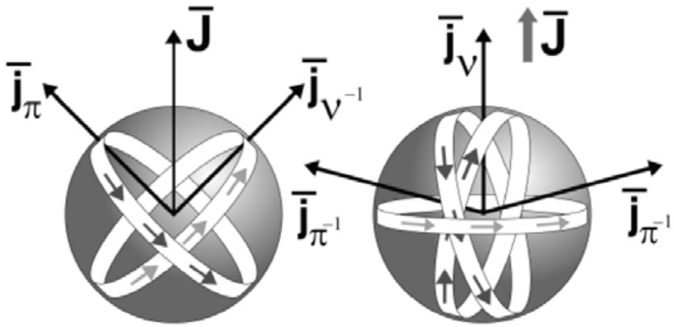
•Dynamic (critical-point) symmetries

•Isospin symmetry (S.Lenzi contribution)

•Etc…



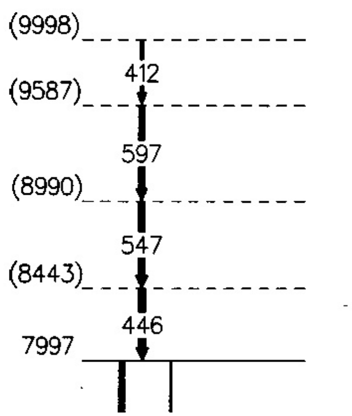
Magnetic & Antimagnetic rotation in light Sn isotopes



magnetic Anti-magnetic

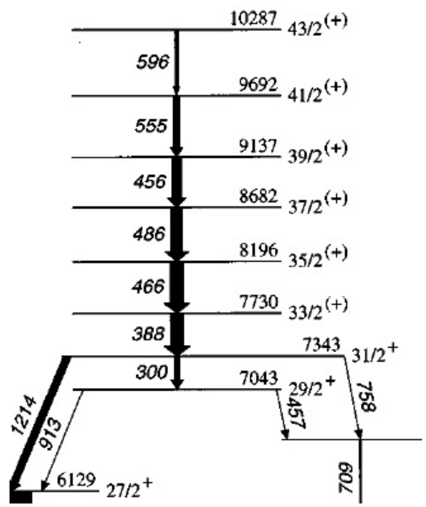
•Magnetic rotation in Sn isotopes identified for first time in 105Sn GASP I. Latter identified for heavier Sn isotopes. Now searched in 104Sn.

IREGULAR BANDS (SMALL DEFORMATION) ← ^{104}Sn ^{108}Sn REGULAR BANDS (LARGER DEFORMATION)



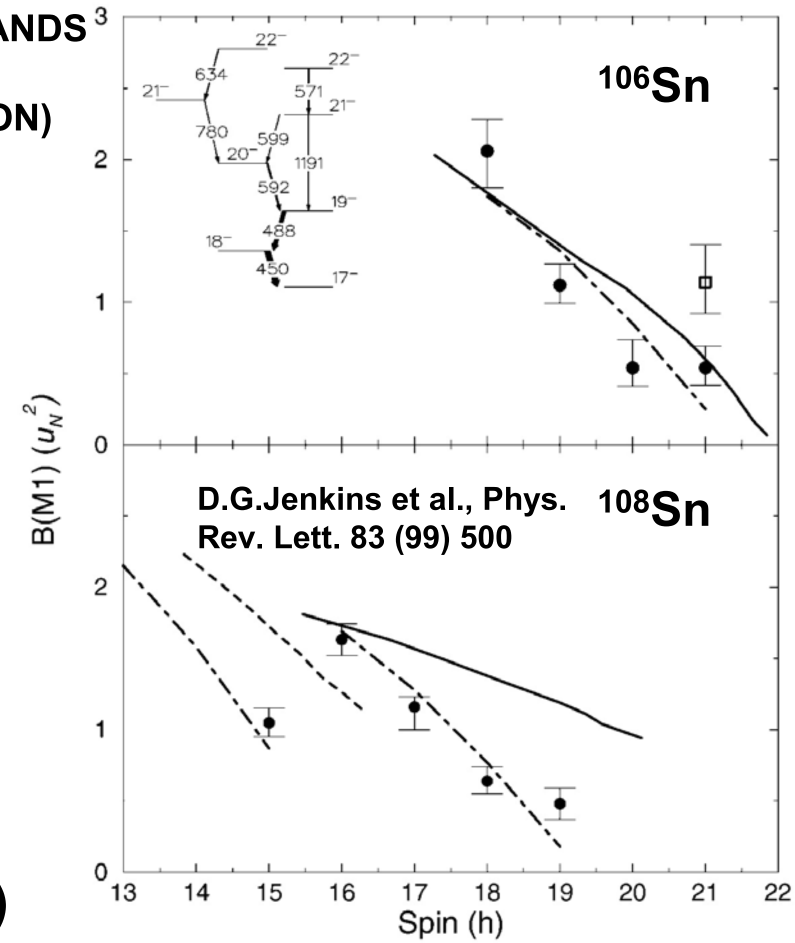
^{104}Sn (GASP)

M.Gorska et al., Phys. Rev. C 58 (98) 108

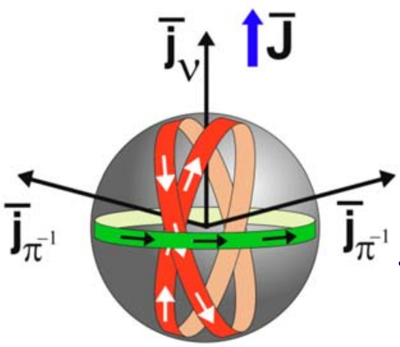


^{105}Sn (GASP)

A.Gadea et al., Phys. Rev. C 55 (97) R1

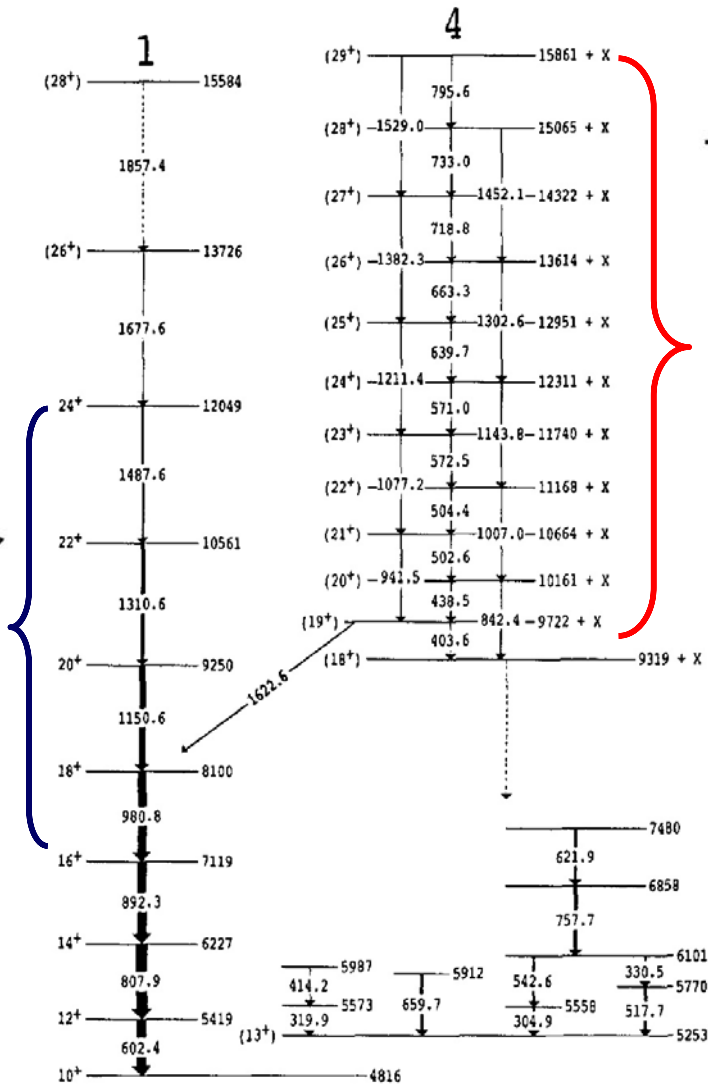


Recent lifetime measurement in ^{104}Sn (M.Gorska)

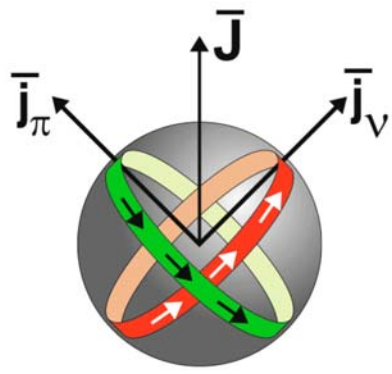


Anti-magnetic

CAESAR (ANU)

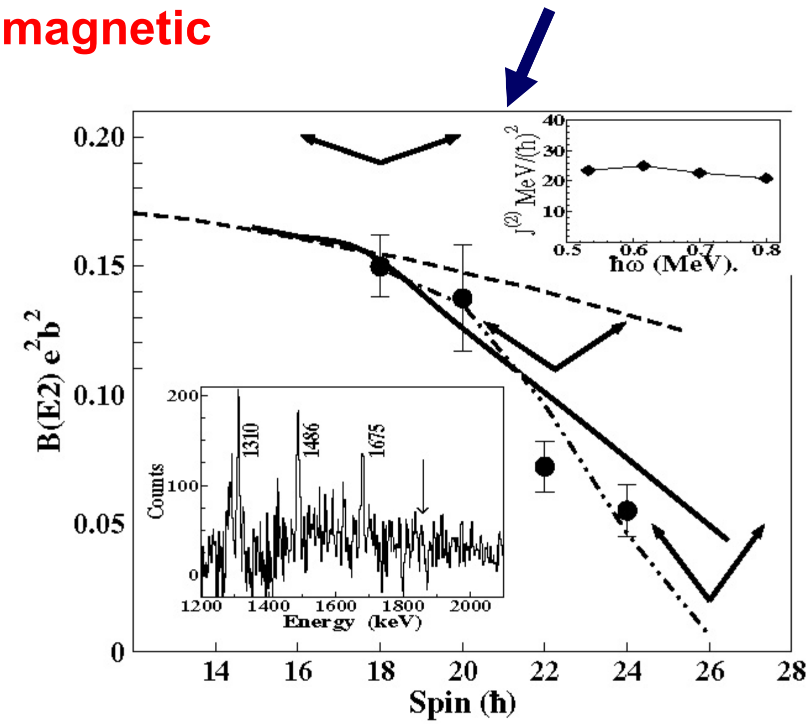


^{106}Cd (excerpt)



magnetic

Gammasphere (LBNL)

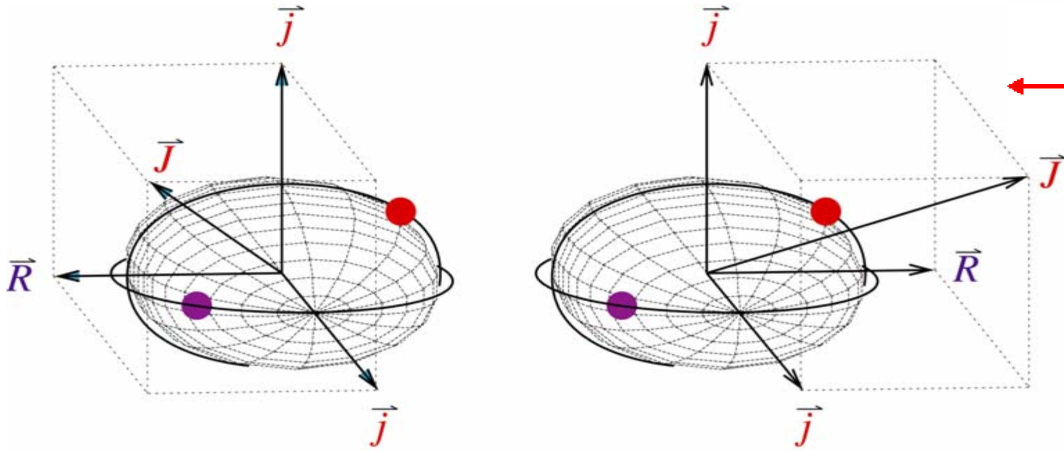


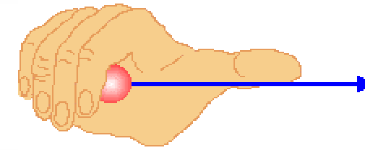
P.H.Regan et al., Nucl. Phys.A583(95)351

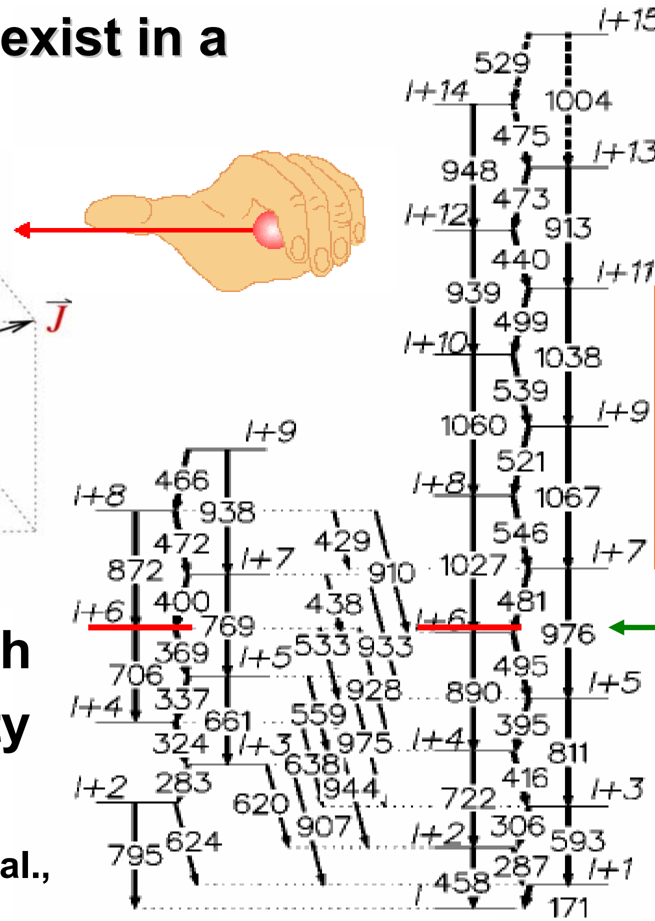
A.J.Simons et al., Phys.Rev.Lett.91(04) 162501

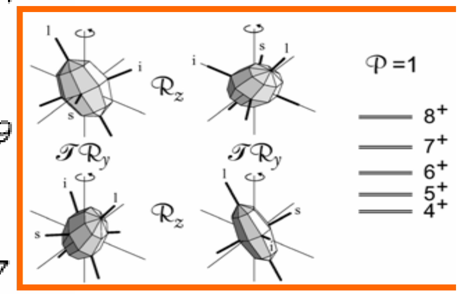
Chiral symmetry realized in odd-odd triaxial nuclei?

Spin in triaxial odd-odd nucleus can exist in a left-handed and right-handed mode





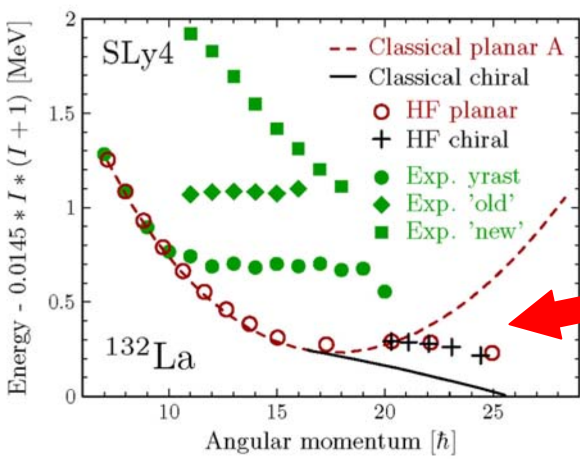




ΔE=36 keV

observed nearly degenerate states with identical angular momentum and parity

the energies of the excited states for the left-handed and right-handed systems should be identical



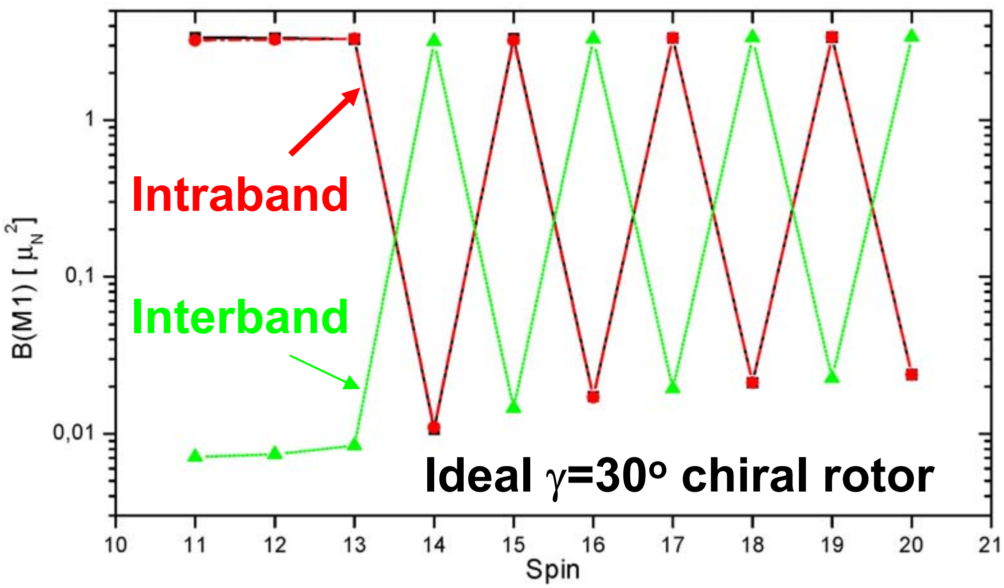
P. Olbratowski et al., Phys.Rev.Lett. 93 (04) 052501

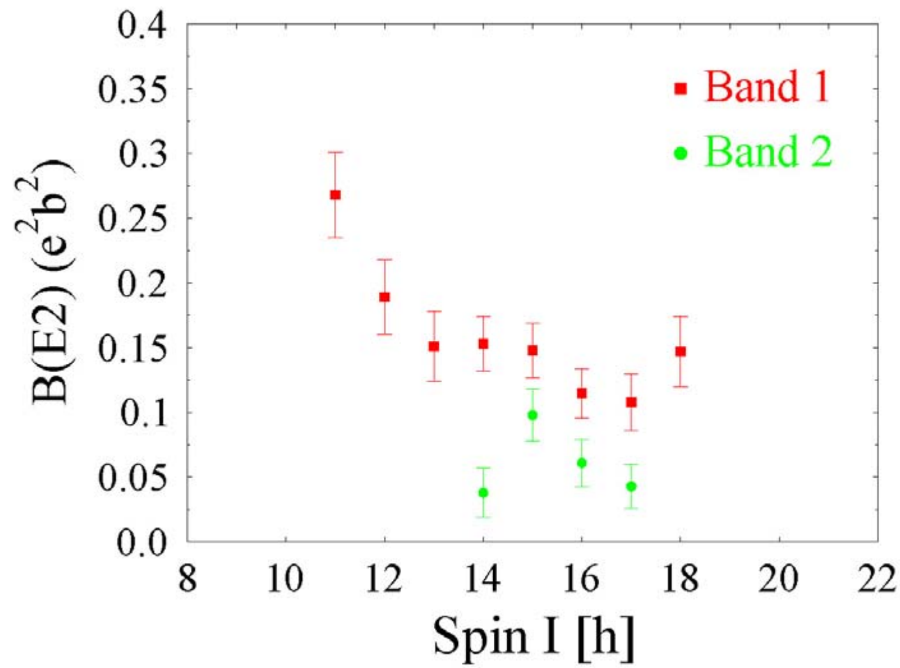
Expected only at high rotation frequency

^{134}Pr

59 75

C. Petrache et al., Nucl. Phys. A597 (1996) 106
C. Starosta et al., Phys. Rev. Lett. 86 (2001) 971

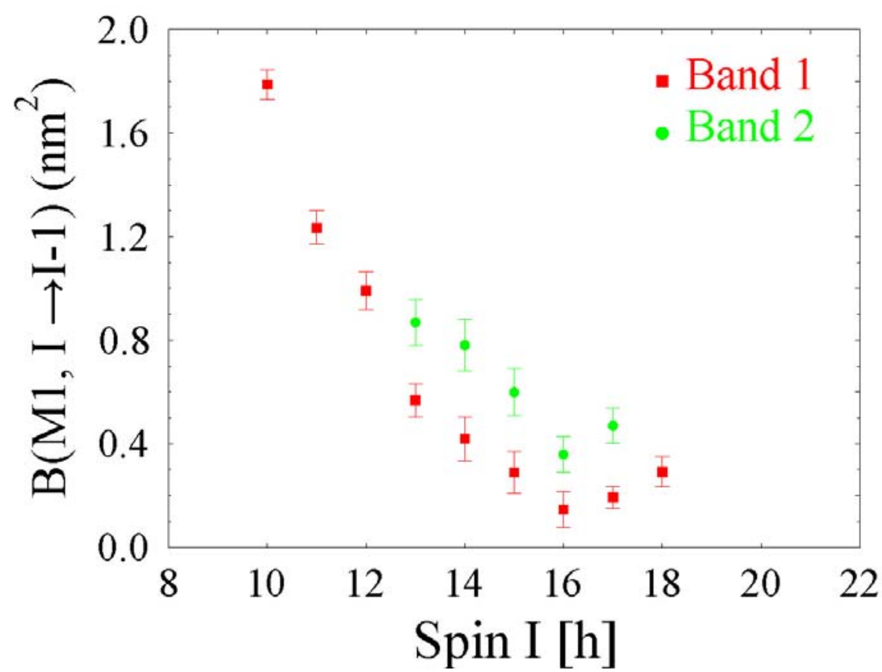




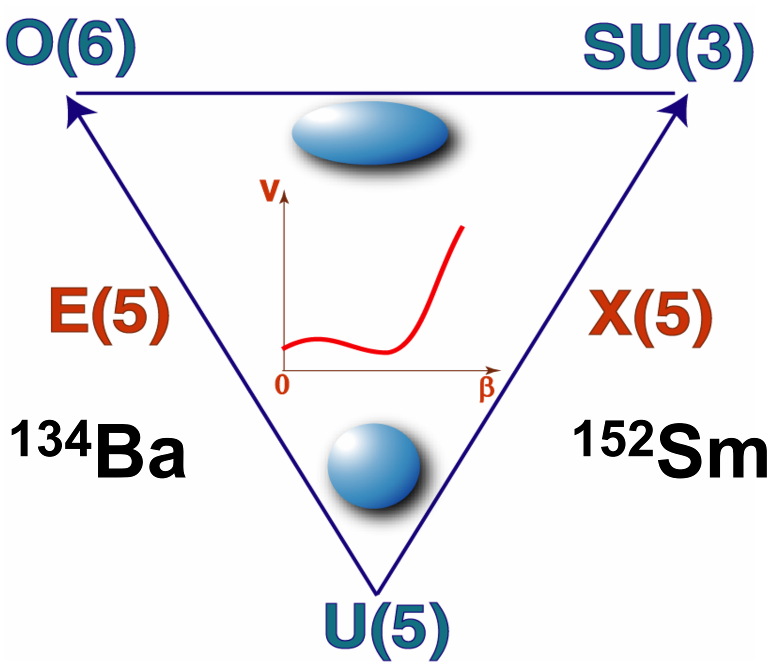
Ideal B(M1) behaviour in chiral bands

B(E2) should be identical for the two Chiral bands

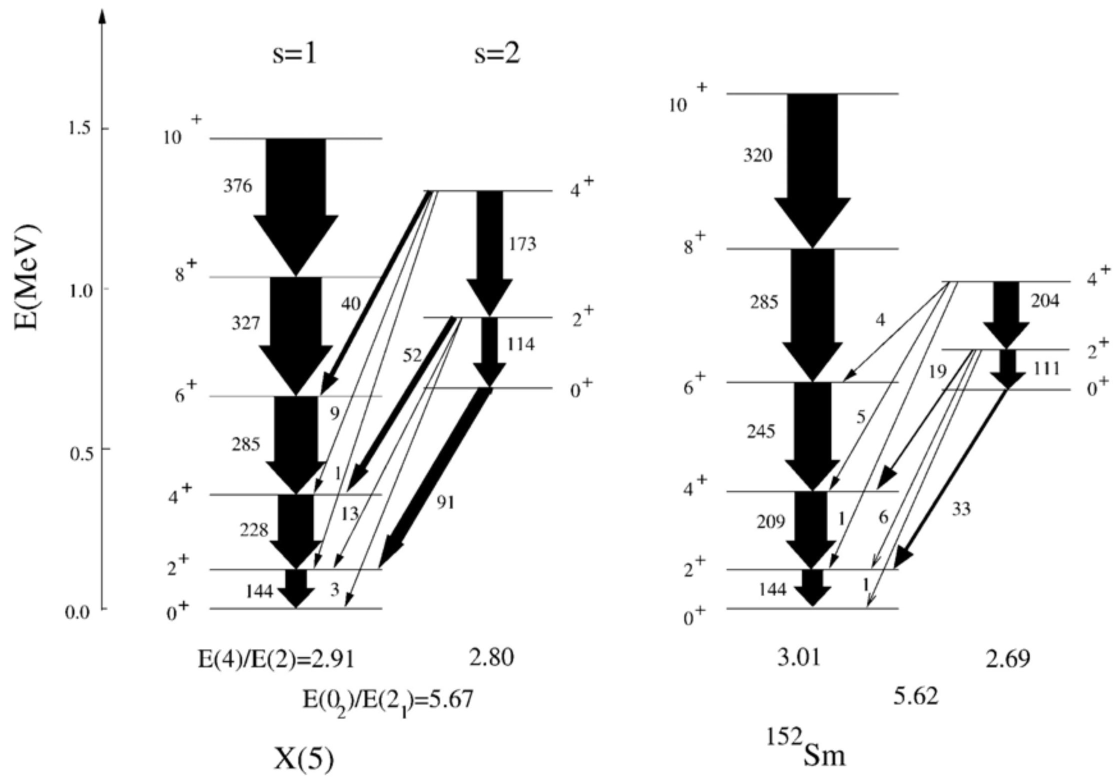
D. Tonev et al., to be published



Critical-Point Symmetries



F. Iachello, Phys. Rev. Lett. 85 (00)3580,
Phys. Rev. Lett. 87 (01) 052502



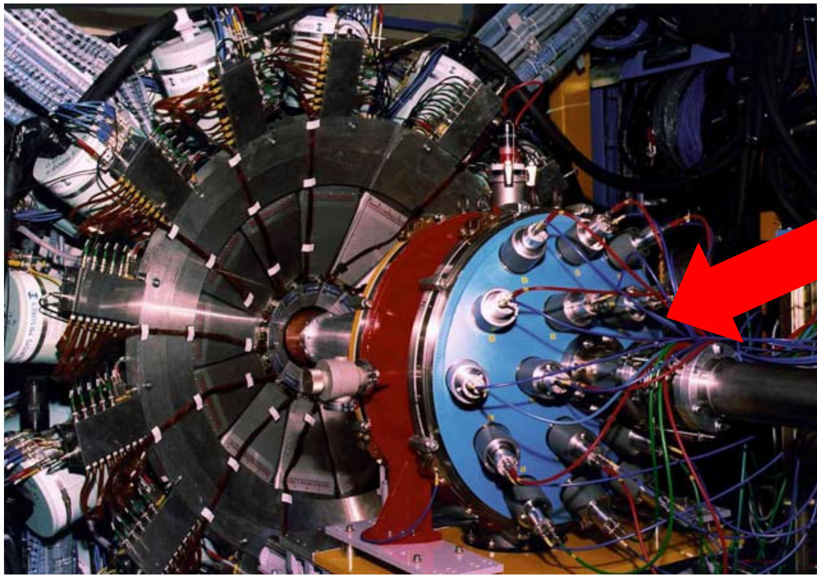
R. F. Casten and N. V. Zamfir,
Phys. Rev. Lett. 87 (01) 052503

Classification based only on the excitation energies and branching ratios is not always sufficient for a unambiguous assignment as was shown in the case of ^{104}Mo (P. G. Bizzeti and A. M. Bizzeti-Sona, Phys. Rev. C 66 (02) 031301R).

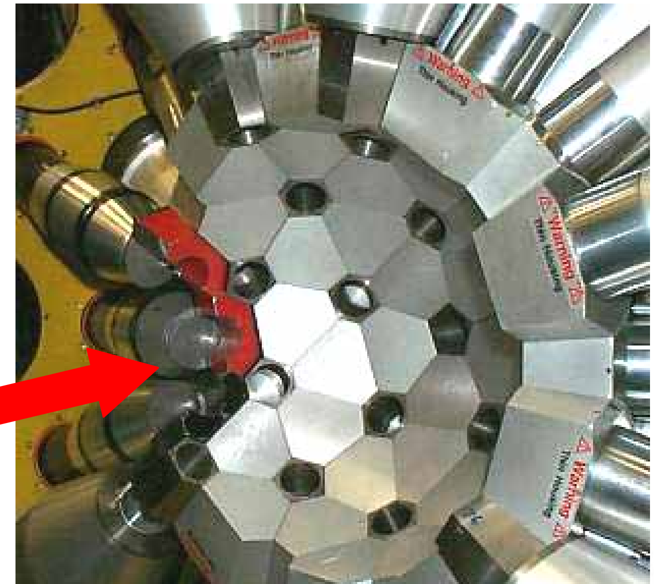
Recent lifetime experiment performed to test X(5) symmetry in the A~180 region (A.Dewald)

Short-term perspectives of GASP:

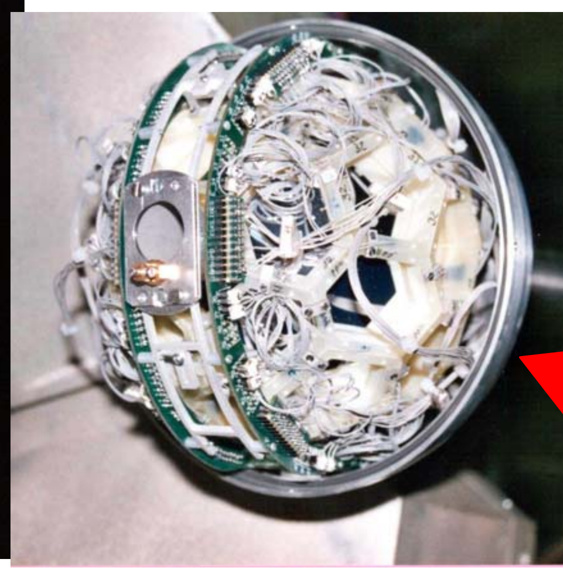
- **GASP Configuration I & II with ancillary detectors**

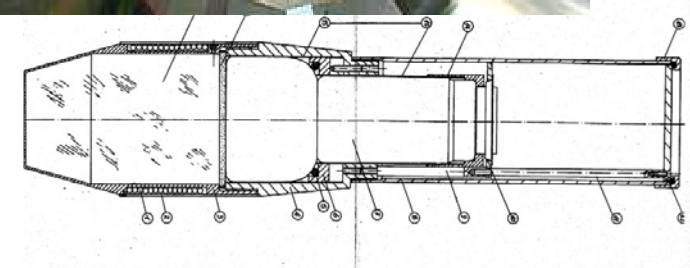


RFD
(Warsaw)



Neutron
Ring
(Eff.~3-5%)

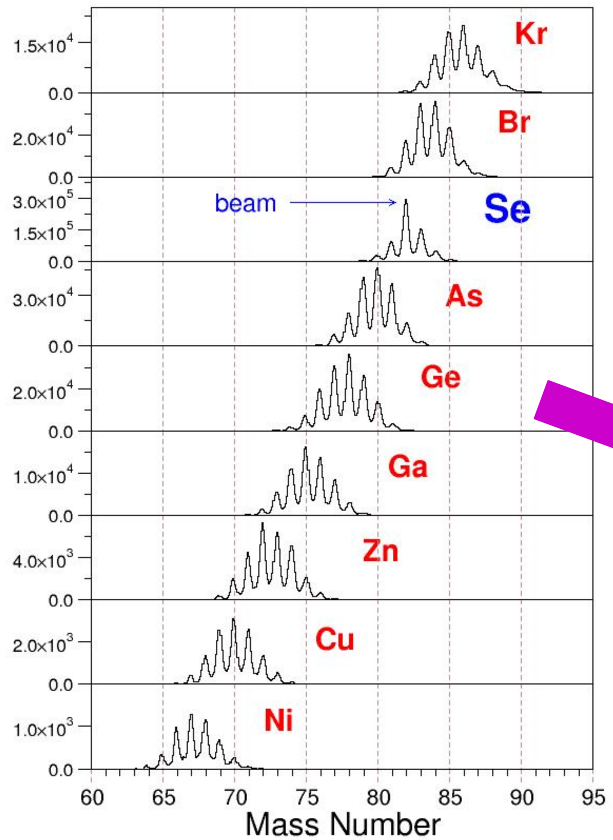


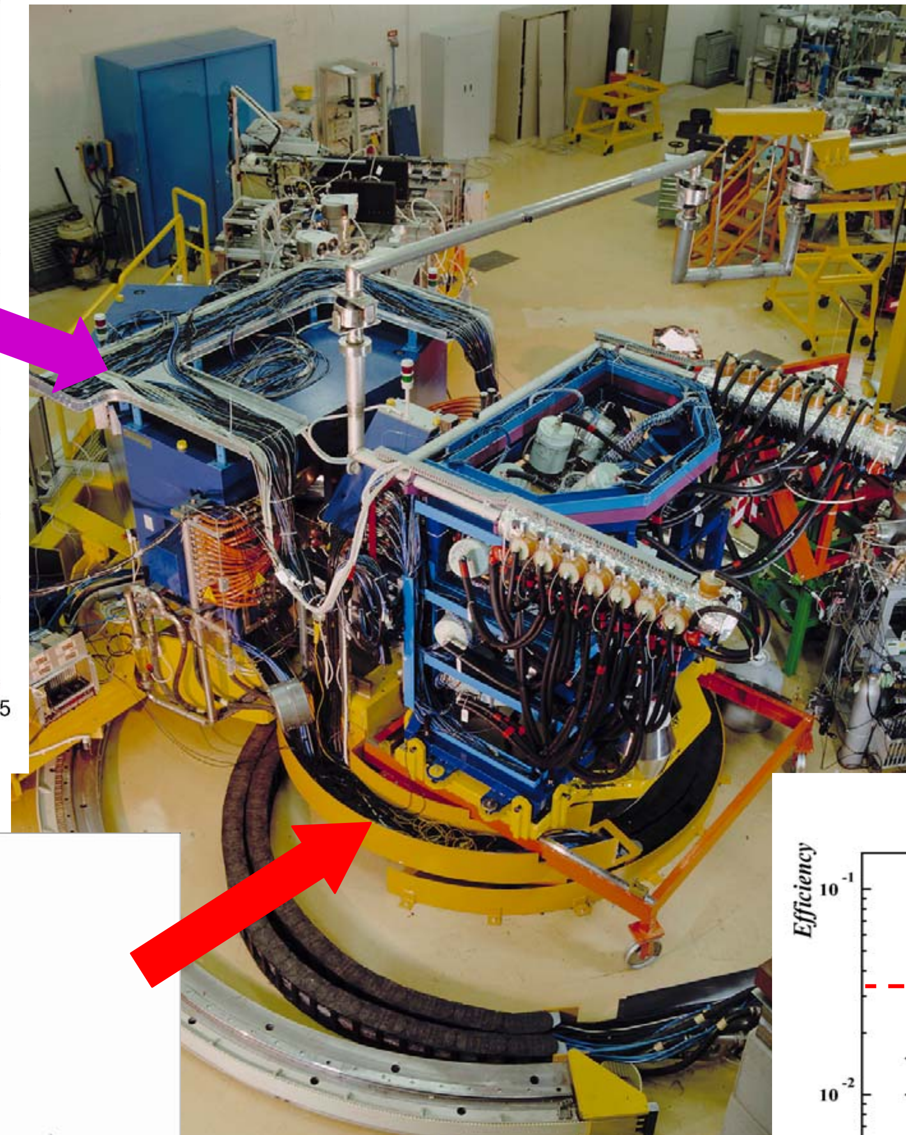


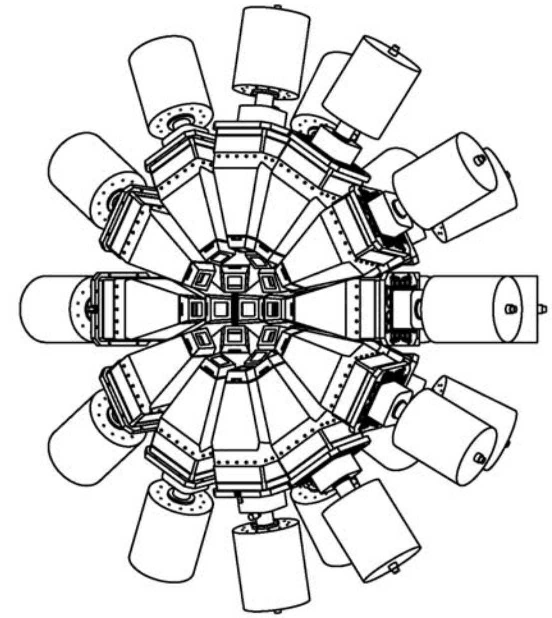
EUCLIDES
4π Si ball

CLARA-PRISMA setup

A & Z identification







25 Euroball Clover detectors

for Eγ= 1.3MeV

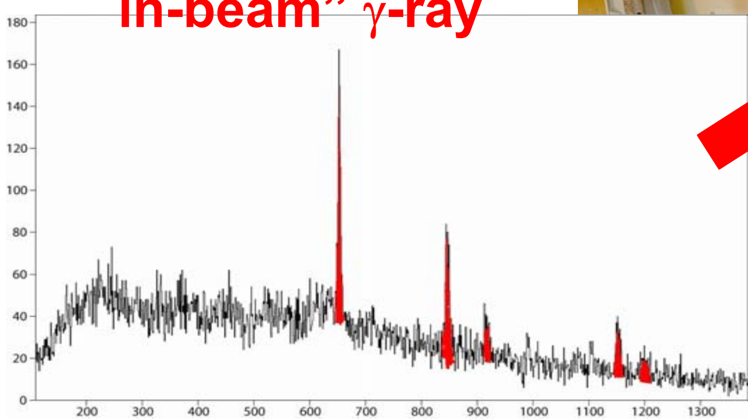
Efficiency ~ 3 %

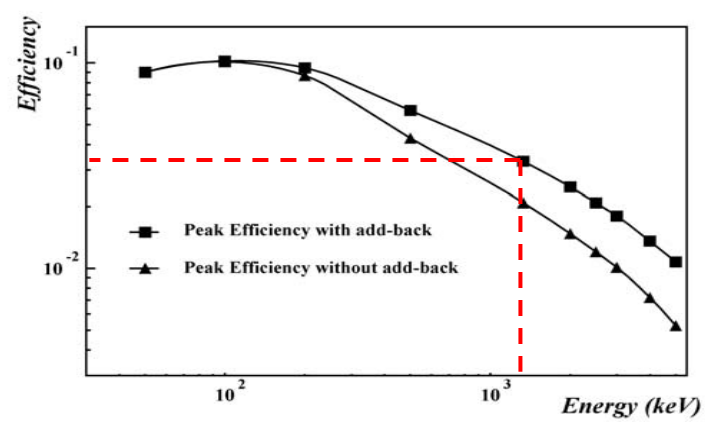
Peak/Total ~ 45 %

FWHM ~ 10 keV

(at v/c = 10 %)

“in-beam” γ-ray





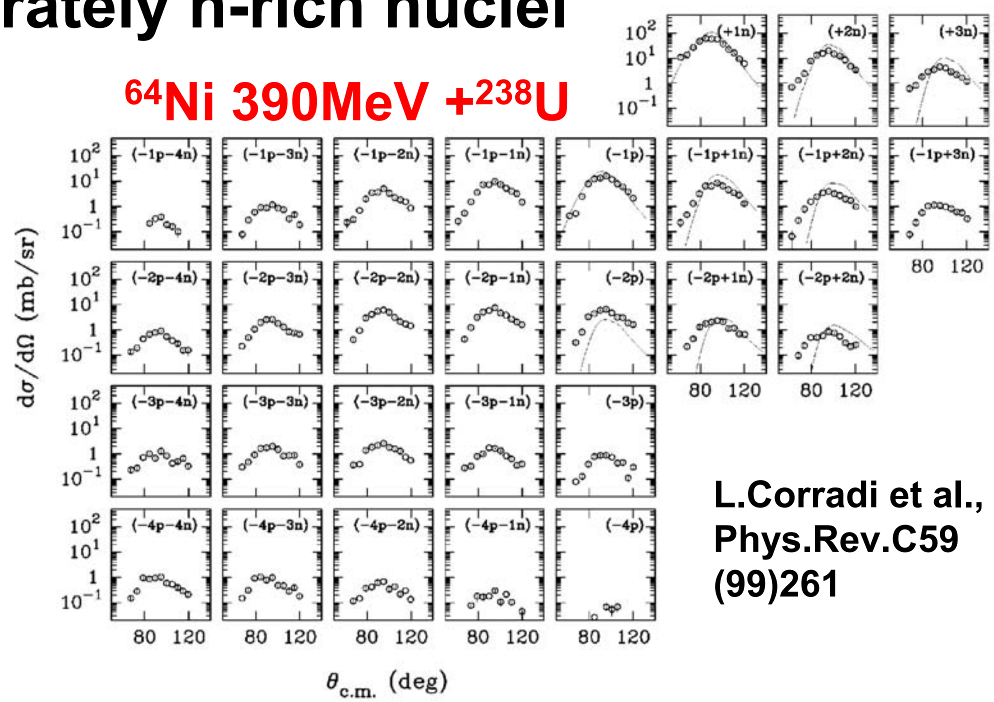
Multinucleon-Transfer and Deep Inelastic reactions as a tool to study moderately n-rich nuclei

- Shell evolution at N=20 and N=50
- Collectivity in n-rich A~60 region (Cr and Fe isotopes)

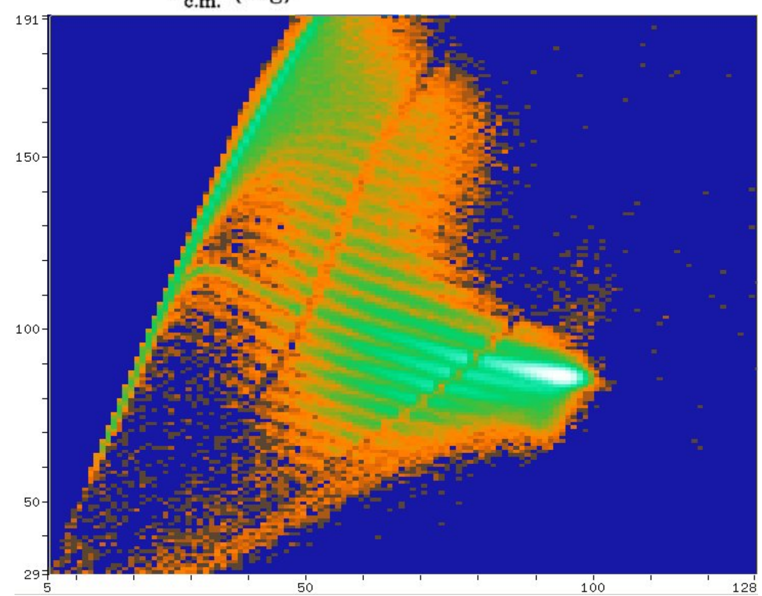
In program:

- Shell model in the 48Ca region
- Quenching of the N=82 shell gap
- Collectivity and critical-point symmetries in the ^{170}Dy region

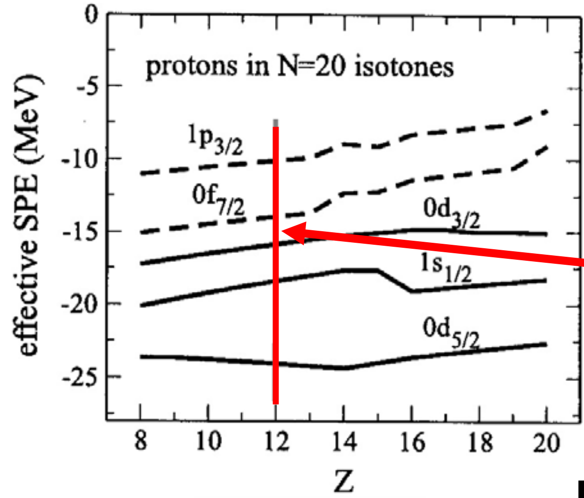
^{64}Ni 390MeV +^{238}U



L.Corradi et al., Phys.Rev.C59 (99)261



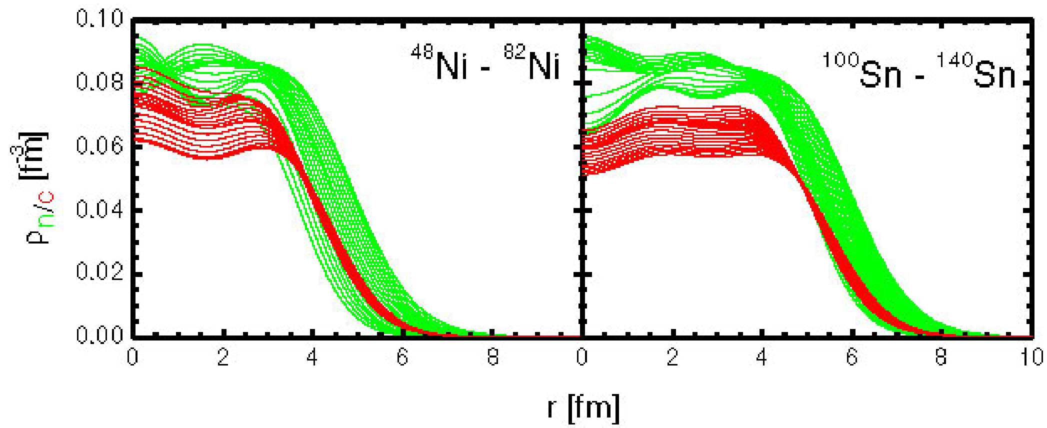
N=20 and N=50 Shell Gaps



T. Otsuka et al.
/ Nuclear Physics A682 (2001) 155c–160c

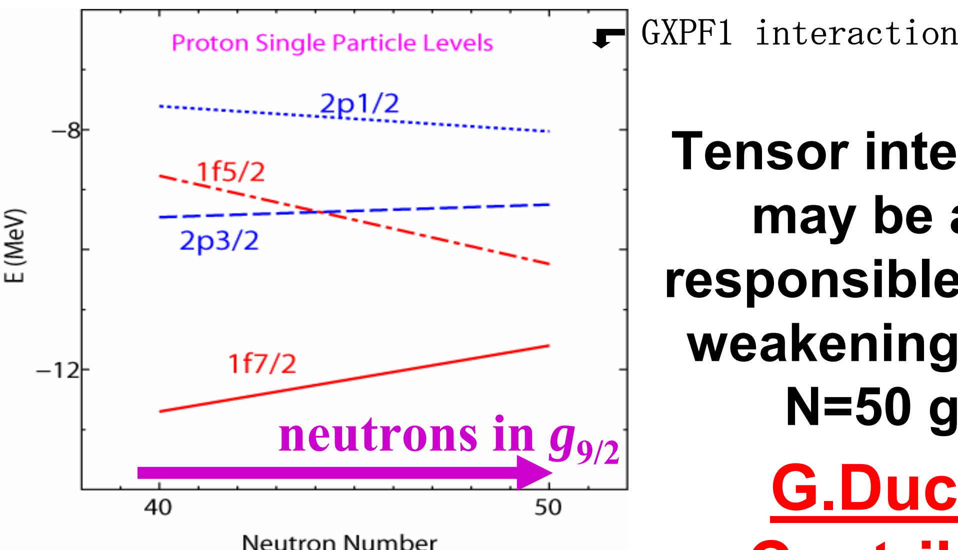
N=20: ^{32}Mg
Island of inversion (due to residual interaction)
Deformation measurements GANIL

Stability of N=50 shell gap



F.Hofmann, C.M.Keil, H.Lenske, Phys.Rev.C64(01)034314.

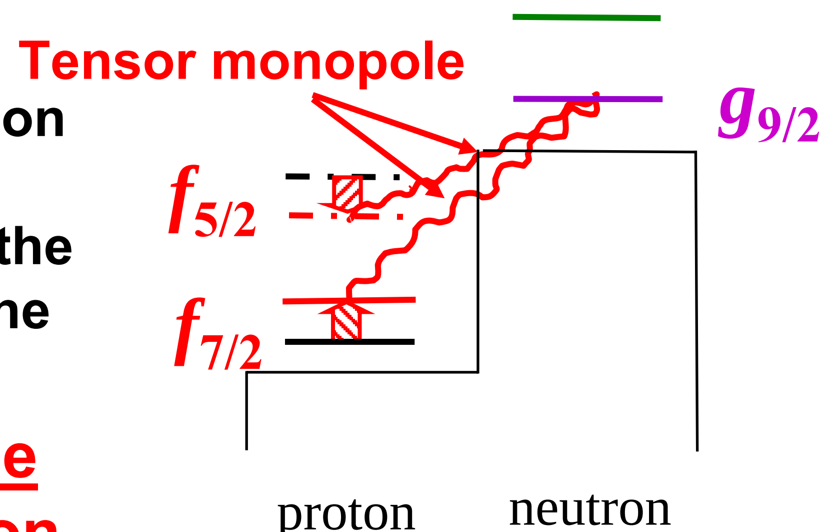
weakening of the spin-orbit force?

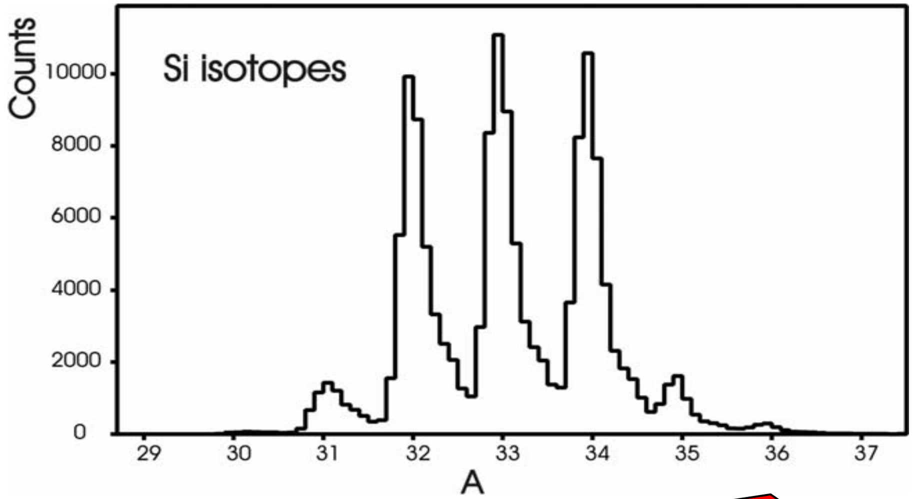


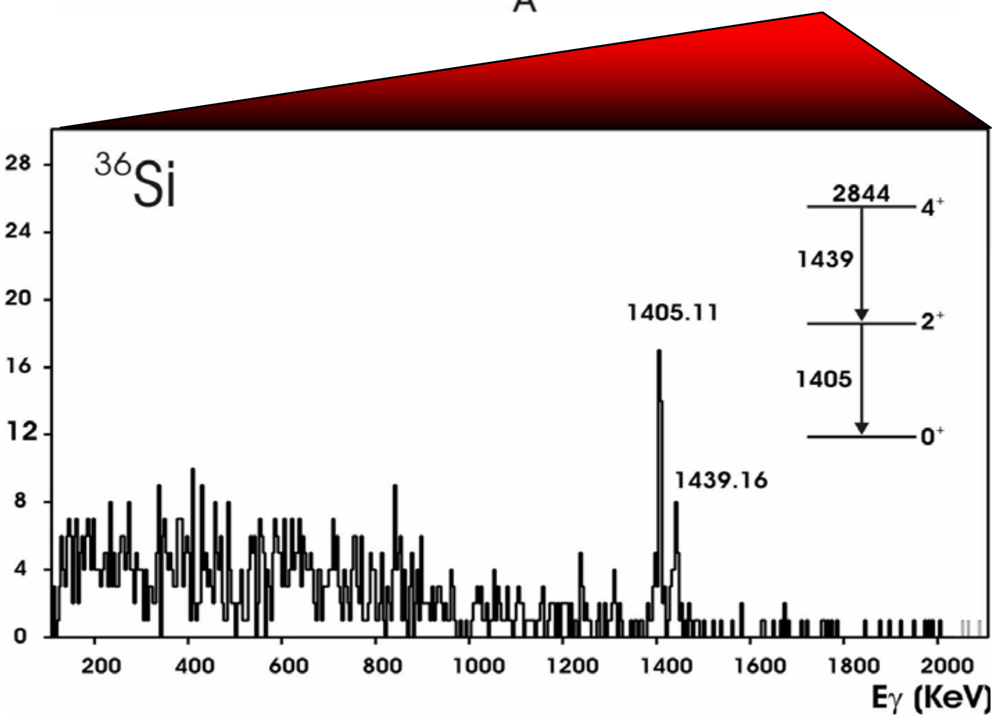
T. Otsuka et al. Zakopane 2004

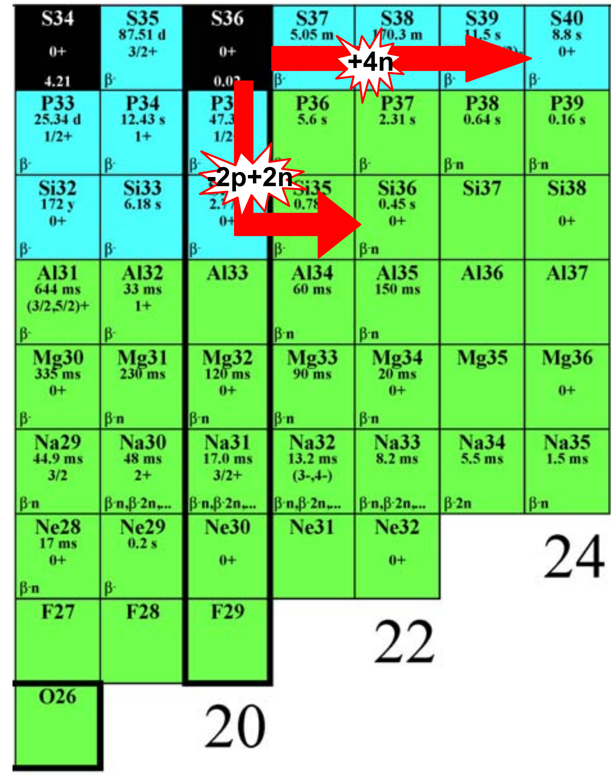
Tensor interaction may be also responsible for the weakening of the N=50 gap

G.Duchêne Contribution





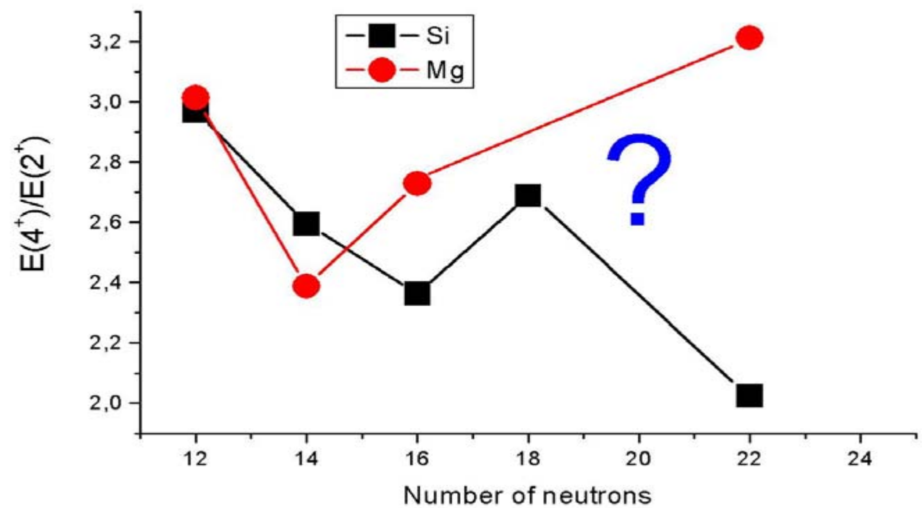




^{36}S 230MeV

+ ^{208}Pb

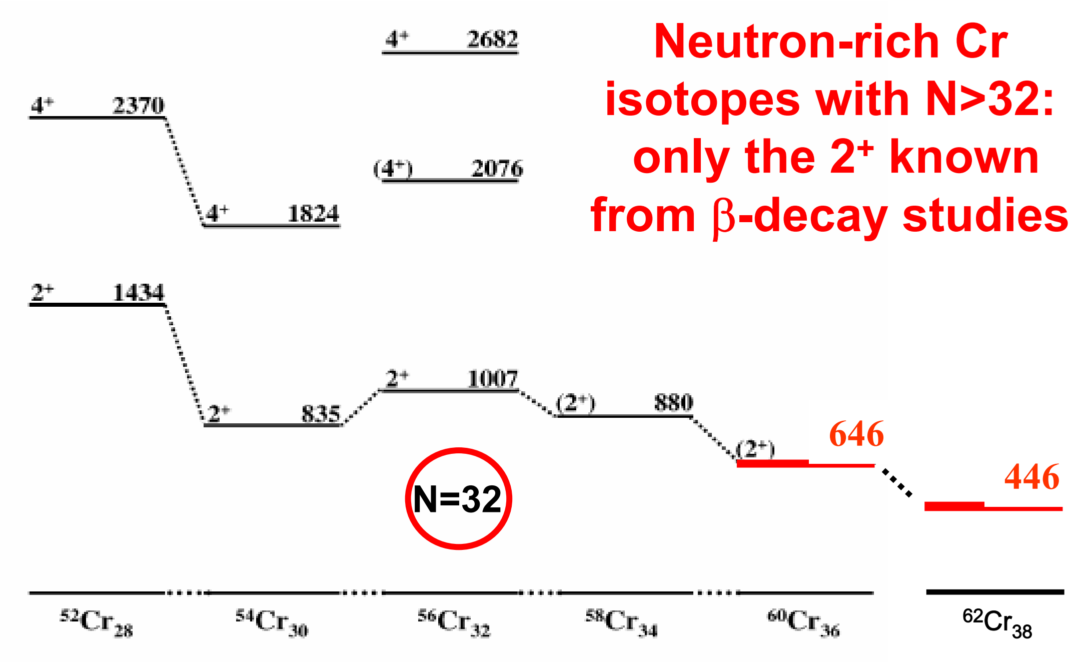
θ_{GR}=56°



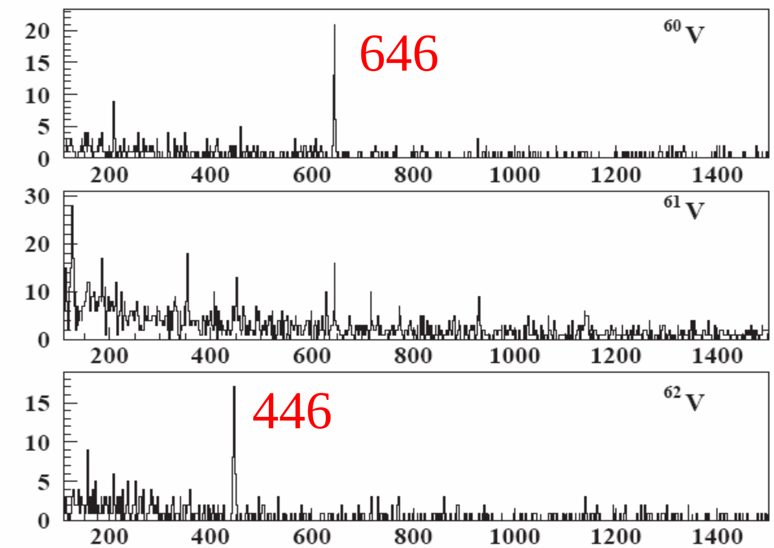
M.Stanoiu, F.Azaiez IPN Orsay

X.Liang Manchester

Collectivity in n-rich A~60 nuclei



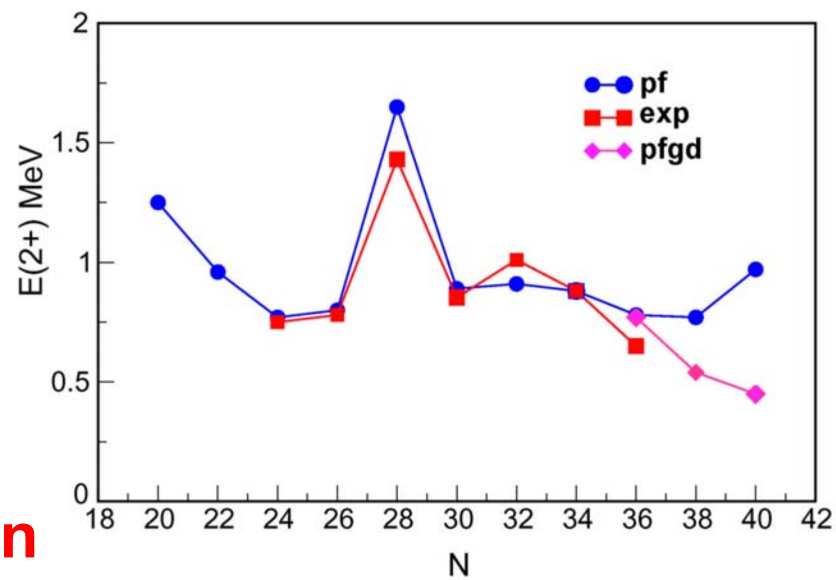
Neutron-rich Cr isotopes with N>32: only the 2^+ known from β-decay studies



GANIL: O.Sorlin et al., Eur. Phys. J. A 16 (2003) 55
MSU: P.F.Mantica et al., Phys. Rev. C 67 (2003) 014311

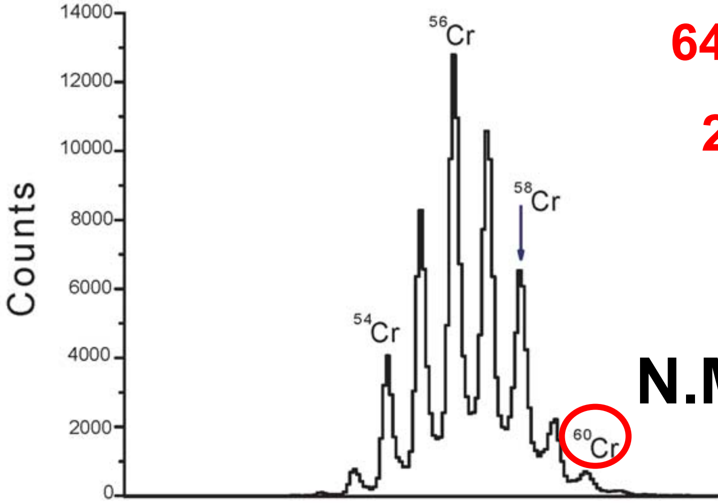
E.Caurier et al., Eur. Phys. J. A 15 (2002) 145

LSSM Calculations



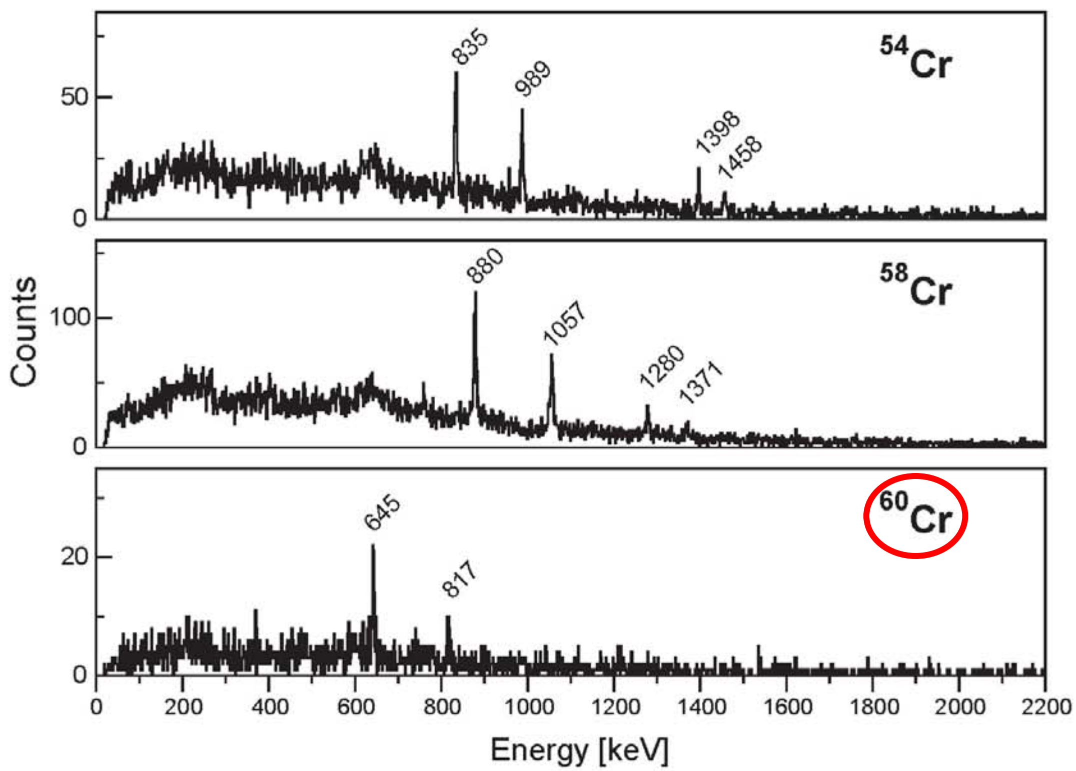
N=32 Shell closure: B.Fornal

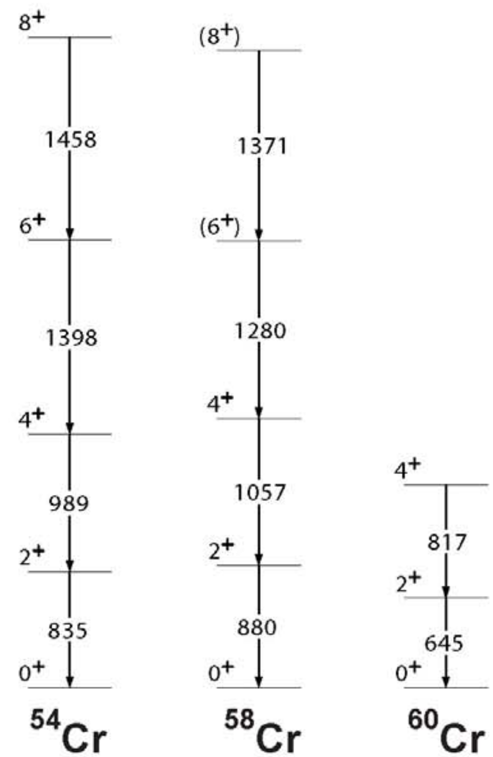
Onset of deformation N>32: S.Freeman



^{64}Ni 400MeV + ^{238}U θ_{GR}=64°

S.M.Lenzi, S.J.Freeman, N.Marginean, et al.

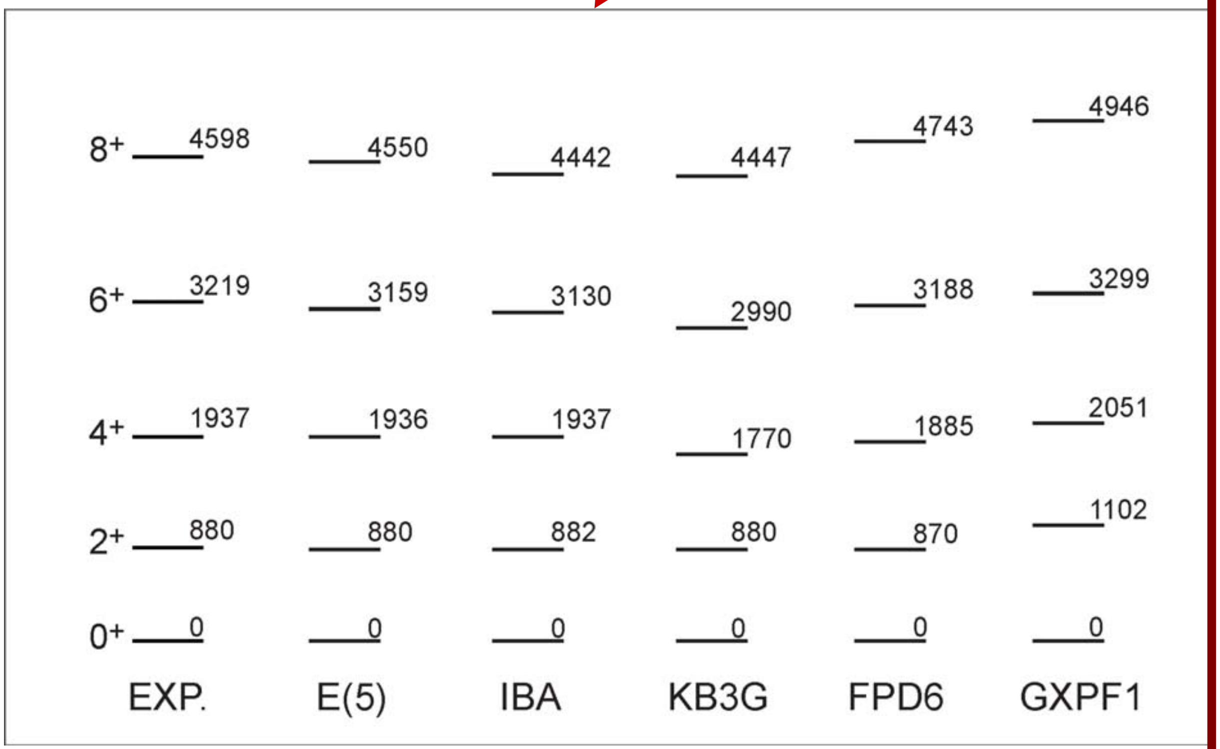




From our data the 1056.4 keV transition is the $4^+ \rightarrow 2^+$ member of the yrast cascade. The ^{58}Vg.s. is probably 3^+, also predicted at low energies.

Agreement between experiment and E(5) limit calculations. Pure fp shell LSSM calculations also reproduce the experimental levels in this slightly deformed nucleus

^{58}Cr



N.Marginean et al., to be published

$E_{4+}/E_{2+} = 2.20$

$E_{6+}/E_{2+} = 3.65$

E(5) critical point symmetry

vibrator to γ-unstable rotor

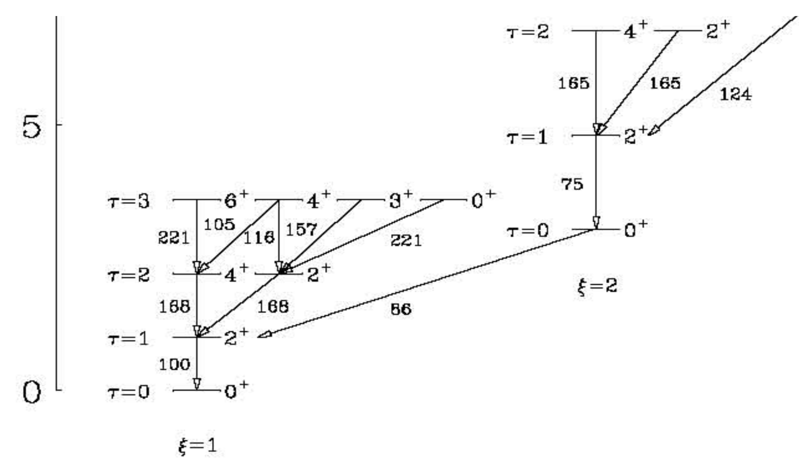
TABLE 1. Excitation energies of the E(5) symmetry.

	$\xi = 1$	$\xi = 2$	$\xi = 3$	$\xi = 4$
$\tau = 0$	0	3.03	7.58	13.64
$\tau = 1$	1	4.80	10.11	16.93
$\tau = 2$	2.20	6.78	12.86	20.44
$\tau = 3$	3.59	8.97	15.81	24.16

VOLUME 85, NUMBER 17 PHYSICAL REVIEW LETTERS 23 OCTOBER 2000

Dynamic Symmetries at the Critical Point

F. Iachello
Center for Theoretical Physics, Sloane Laboratory, Yale University, New Haven, Connecticut 06520-8120
(Received 8 May 2000)



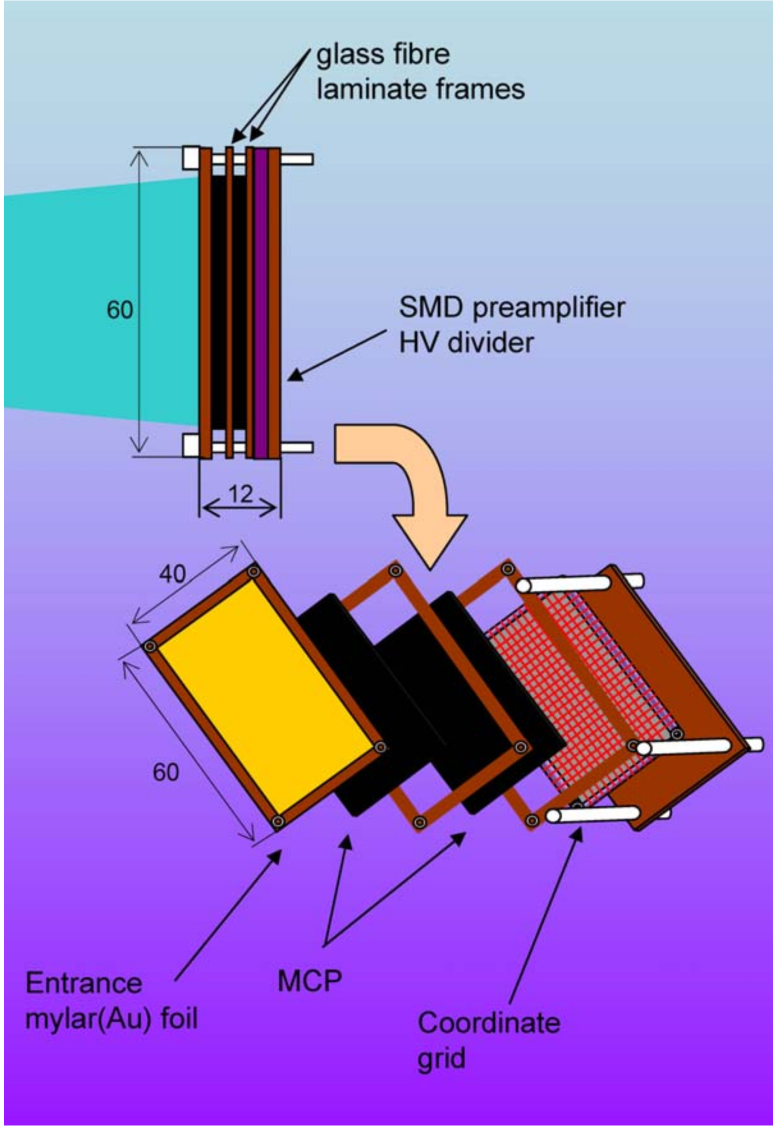
Short-term perspectives for CLARA-PRISMA:

Drawback of the setup: low efficiency for γ–γ–PRISMA coincidences

Development of complementary ancillary devices for Doppler correction.

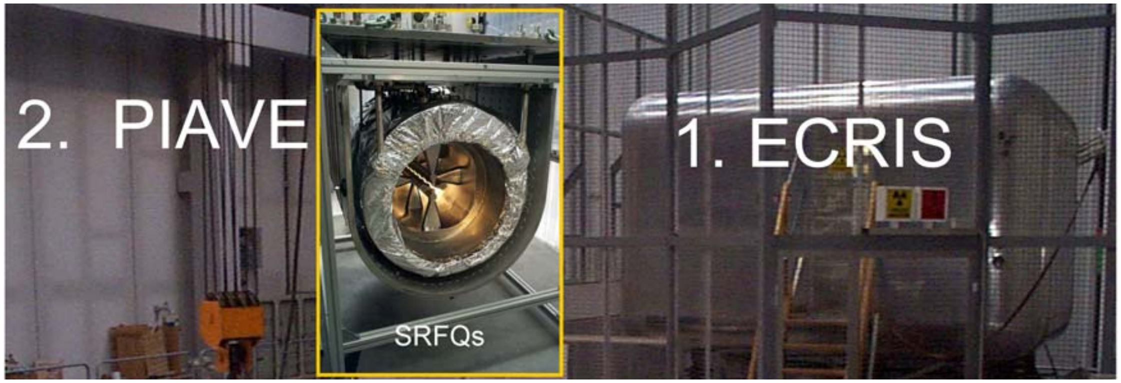
Measurement of γ–PRISMA and γ–γ–ancillary coincidences.

MCP array under development in collaboration with FLNR Dubna



Other perspectives:

Heavier beams from ALPI linac with the new positive ion injector PIAVE.



Summary

- **LNL is hosting two arrays of Compton suppressed Ge detectors GASP and CLARA (until end 2006)**
- **The two arrays are used:**
  - **GASP mainly in spectroscopy with fusion evaporation reactions**
  - **The complex CLARA-PRISMA with binary reaction with heavy-ion beams.**
- **An "status of the art" physics program is being developed in both arrays, with the involvement of INFN and external users.**
- **GASP will work in the next years with several ancillary detectors and devices in configuration I and II.**
- **CLARA is as well being upgraded with an ancillary array to perform "in beam" γ–γ coincidences with Doppler correction**
- **Is foreseen the use of the AGATA clusters to gain efficiency in the CLARA-PRISMA setup**

The CLARA-PRISMA collaboration

•France

IReS Strasbourg
GANIL Caen

•U.K.

University of Manchester
Daresbury Laboratory
University of Surrey
University of Paisley

•Germany

HMI Berlin

GSI Darmstadt

•Italy

INFN LNL-Legnaro
INFN and University Padova
INFN and University Milano
INFN and University Genova
INFN and University Torino
INFN and University Napoli
INFN and University Firenze
University of Camerino

•Spain

University of Salamanca

•Romania
Horia Hulubei NIPNE Bucharest

Experiments performed: March-November 2004

- *Search for excited states in neutron rich ^{37}P and ^{39}P using deep inelastic processes. Medium spin −spectroscopy of Ne, Mg, and Si neutron rich isotopes* X.Liang, Paisley F.Azaiez, Orsay, Zs.Dombradi, Debrecen

(^{36}S + ^{208}Pb)

- *Nuclear spectroscopy of neutron rich nuclei in the N=50 region* G.Duchene, Strasbourg, G.de Angelis, Legnaro

(^{82}Se + ^{238}U)

- *Spectroscopy of deformed neutron rich A ~ 60 nuclei* S.M.Lenzi, Padova, S.J.Freeman, Manchester

(^{64}Ni + ^{238}U)

- *Pair transfer effects in ^{90}Zr+^{208}Pb* L.Corradi, Legnaro

(^{90}Zr + ^{208}Pb)

- *Isotensor MED across the f7/2 shell: identification of the 6+ state in ^{54}Co* A.Gadea, Legnaro

(^{54}Fe + ^{58}Ni)

- *Resonances in 24Mg+24Mg and molecular states in 48Cr* F.Haas, Strasbourg

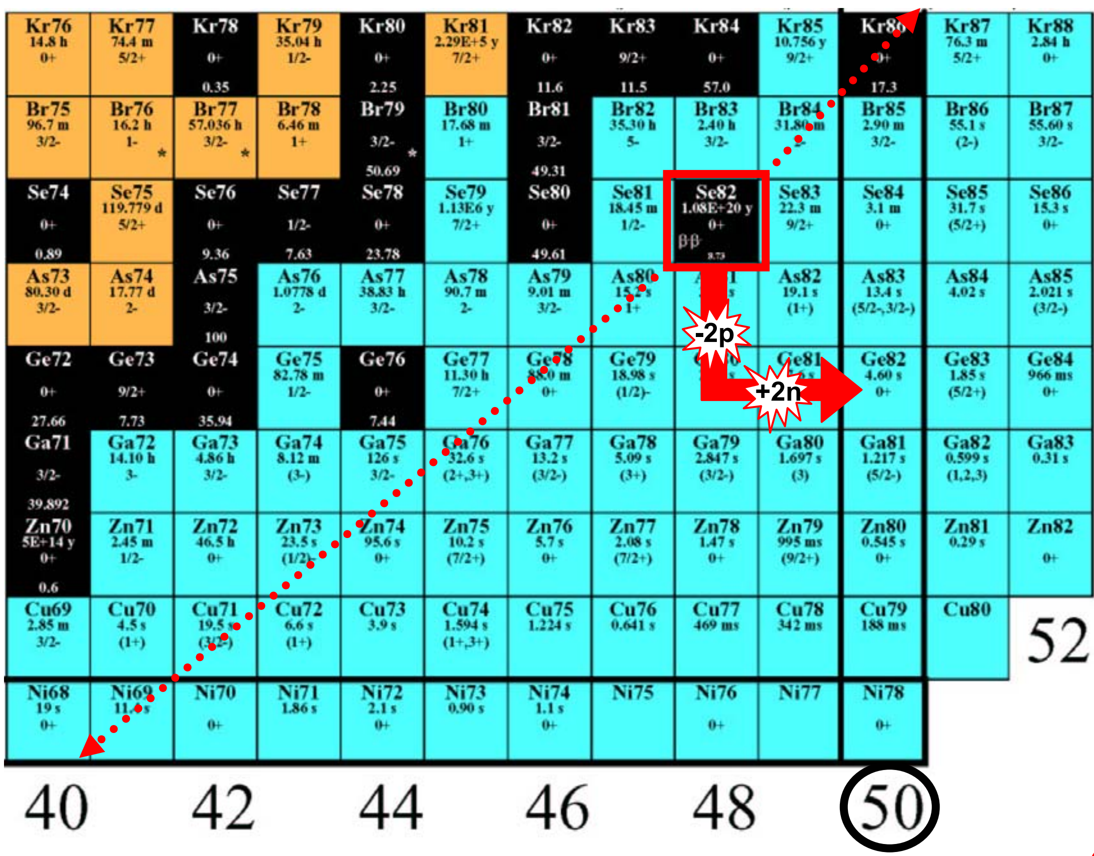
(^{24}Mg + ^{24}Mg)

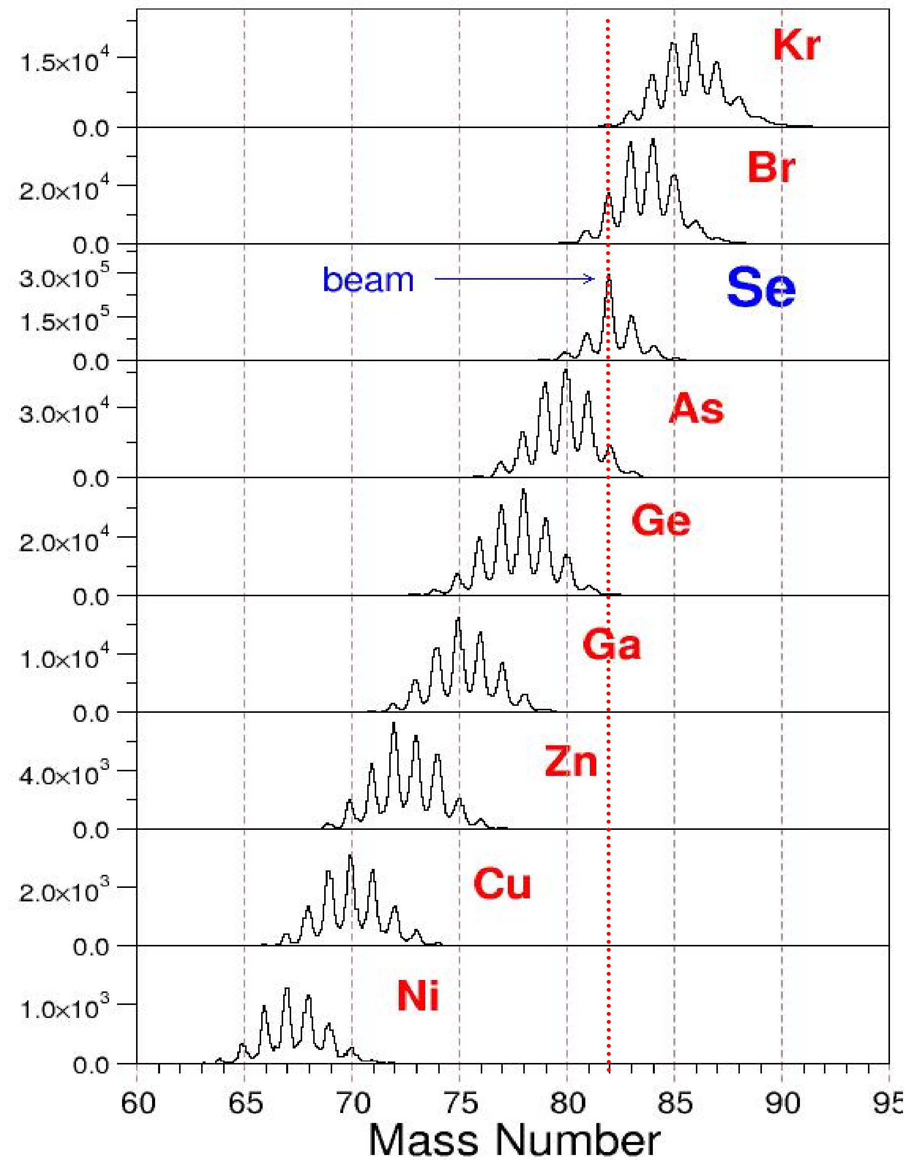
- *Anomalous MED in ^{31}S.* D.R.Napoli, M.Marginean, Legnaro

(^{32}S + ^{58}Ni)

^{82}Se + ^{238}U E=505 MeV (ALPI)
4 days, PRISMA at θ_G=64°

G.deAngelis, G.Duchêne
Analysis: N.Marginean

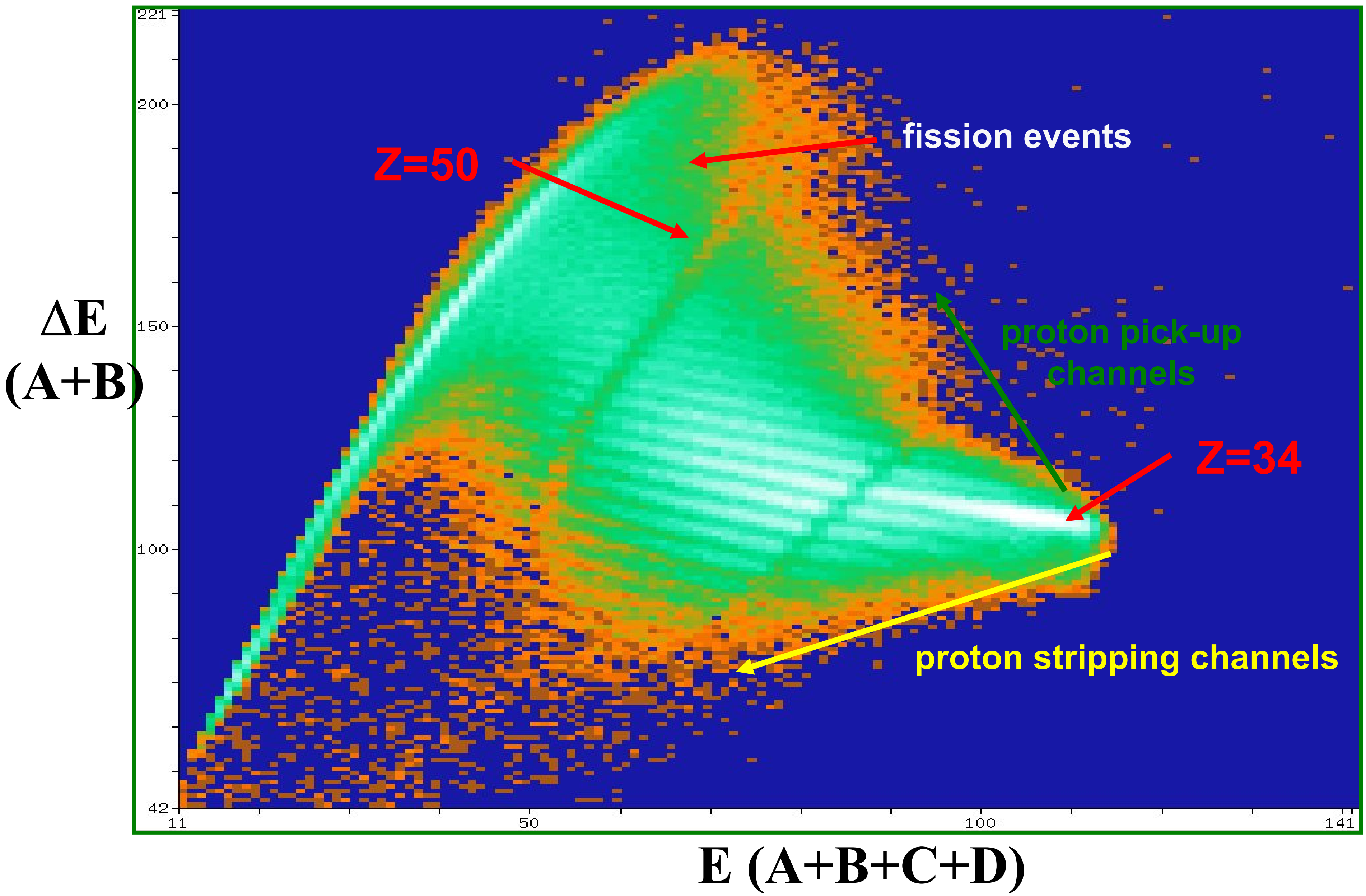


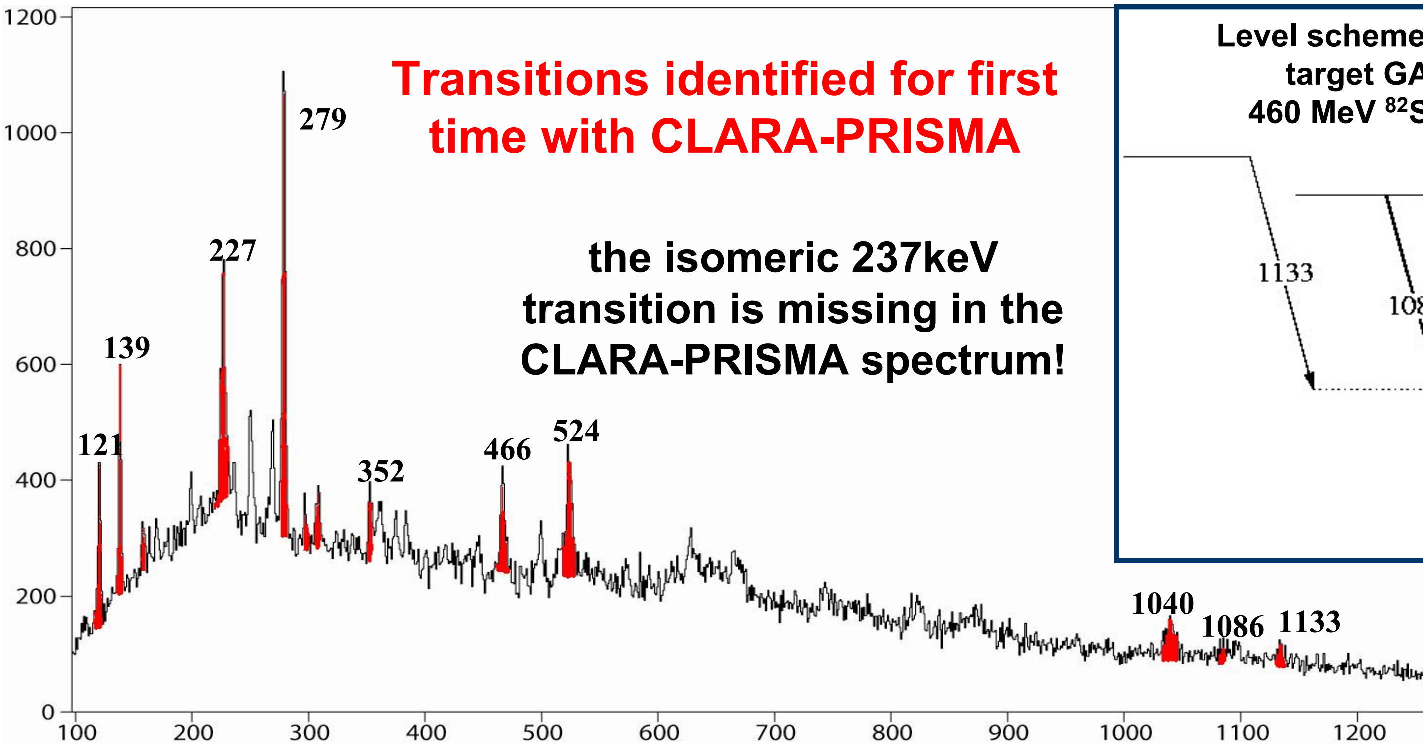


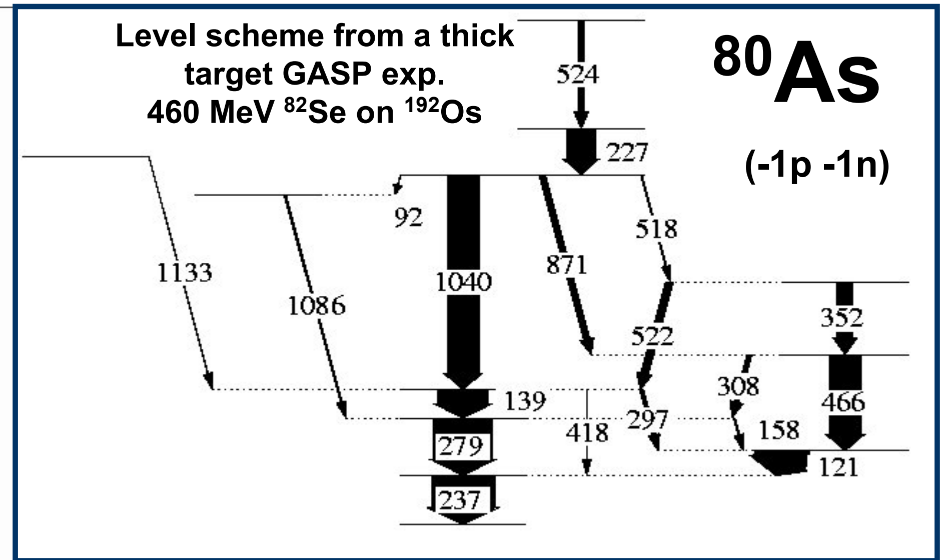
Evolution of the N=50 shell: Searching for the shell gap quenching (onset of deformation as in N=20 Z~12)

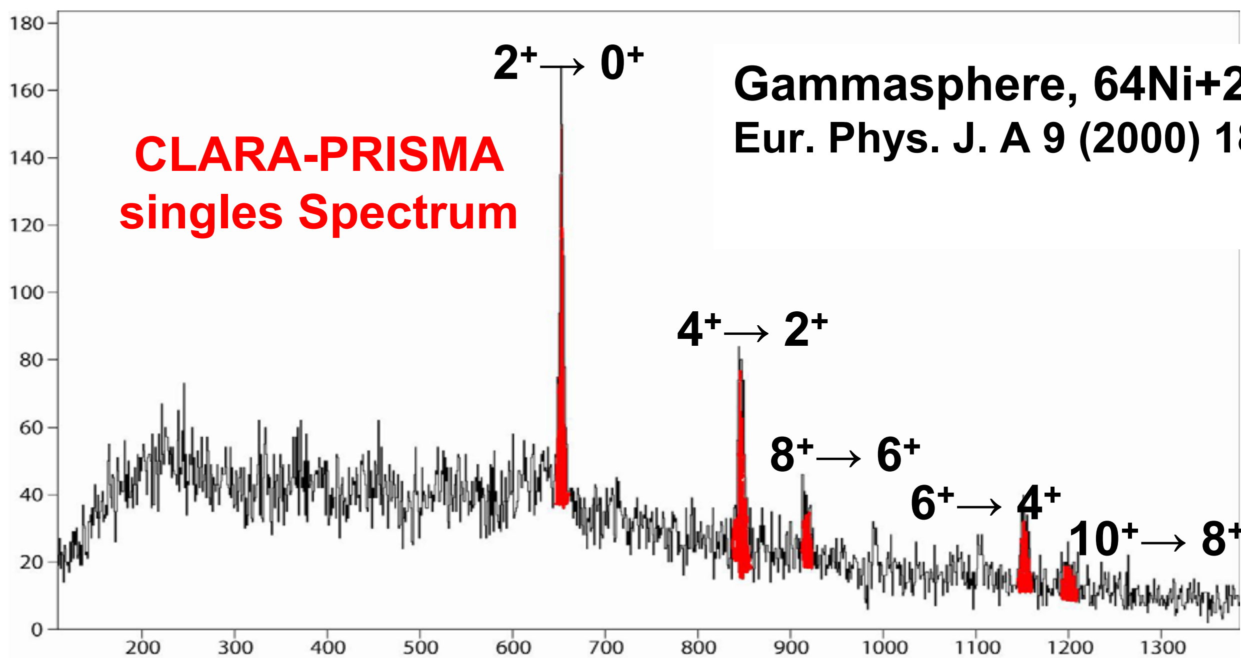
Z=32: INM, R.C.Nayak et al. PRC 60 (1999) 064305
Z=24-26: RMF, L.S.Geng et al. nucl-th/0402083

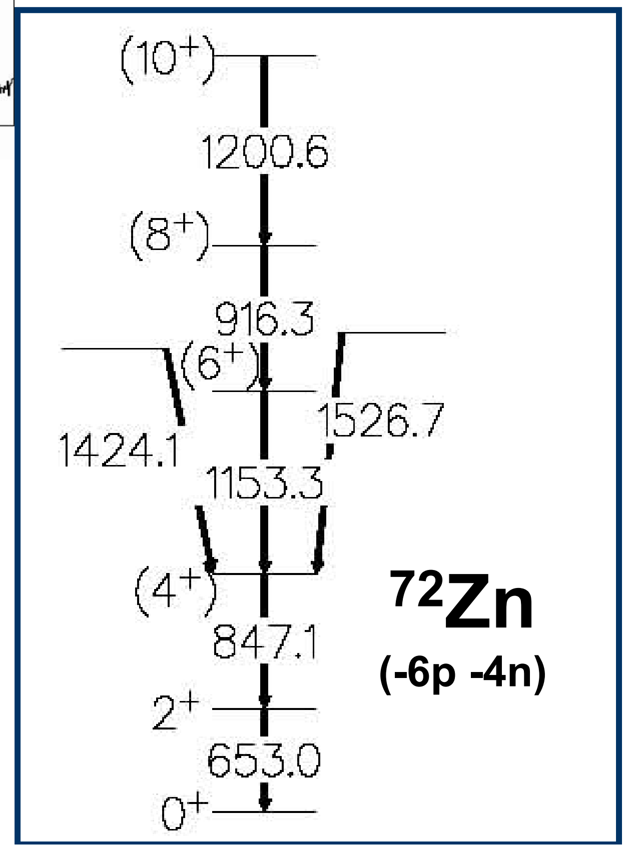
$^{82}Se + ^{238}U$ E=505 MeV $\theta_G=64^o$ IC ΔE-E Matrix



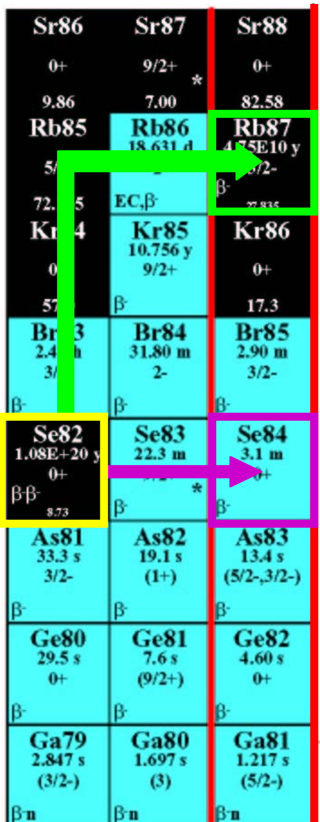

Transitions identified for first time with CLARA-PRISMA
the isomeric 237keV transition is missing in the CLARA-PRISMA spectrum!
121
139
227
279
352
466
524
1040
1086
1133
0
200
400
600
800
1000
1200
100
200
300
400
500
600
700
800
900
1000
1100
1200

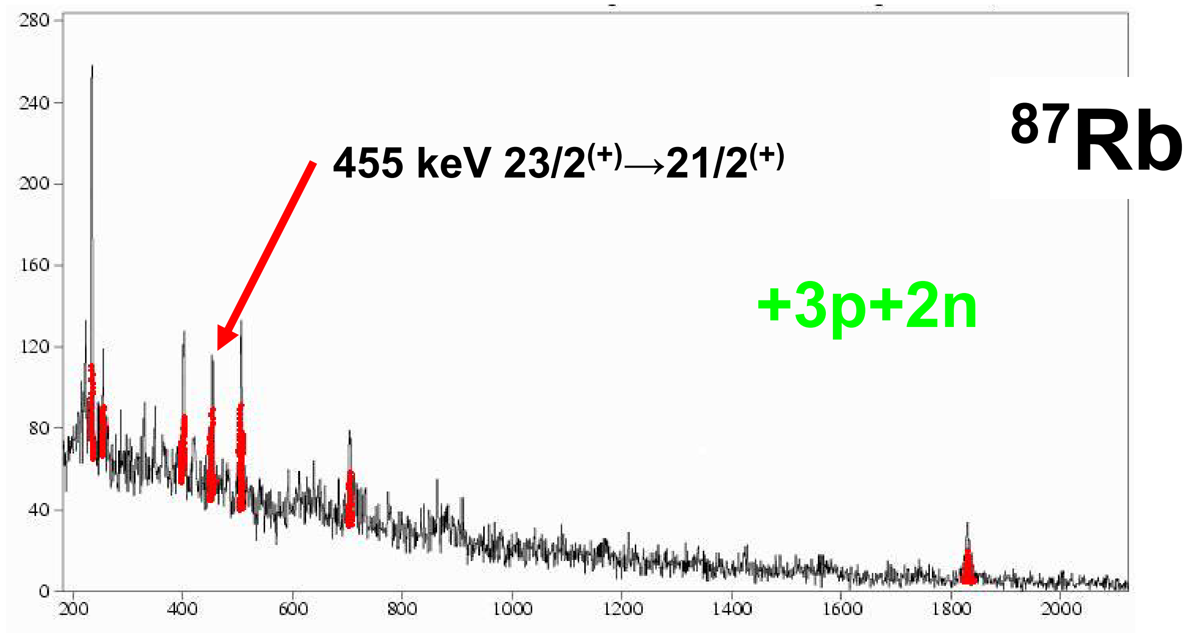

Level scheme from a thick target GASP exp.
460 MeV 82Se on 192Os
80As
(-1p -1n)
524
227
92
1040
871
518
1133
1086
352
522
139
308
466
418
297
158
279
121
237

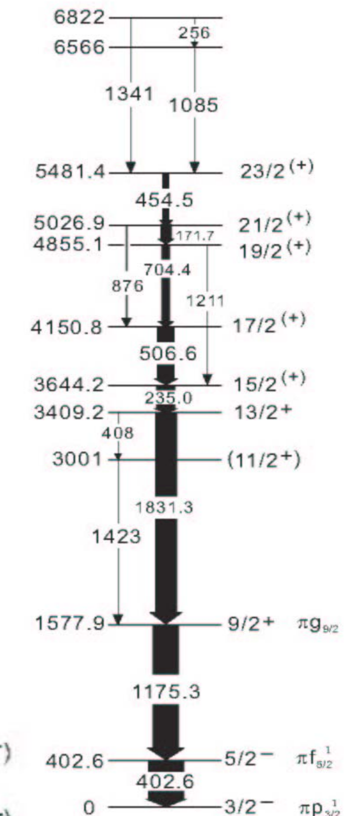

CLARA-PRISMA singles Spectrum
Gammasphere, 64Ni+208Pb
Eur. Phys. J. A 9 (2000) 183
2+→ 0+
4+→ 2+
8+→ 6+
6+→ 4+
10+→ 8+
0
20
40
60
80
100
120
140
160
180
200
300
400
500
600
700
800
900
1000
1100
1200
1300

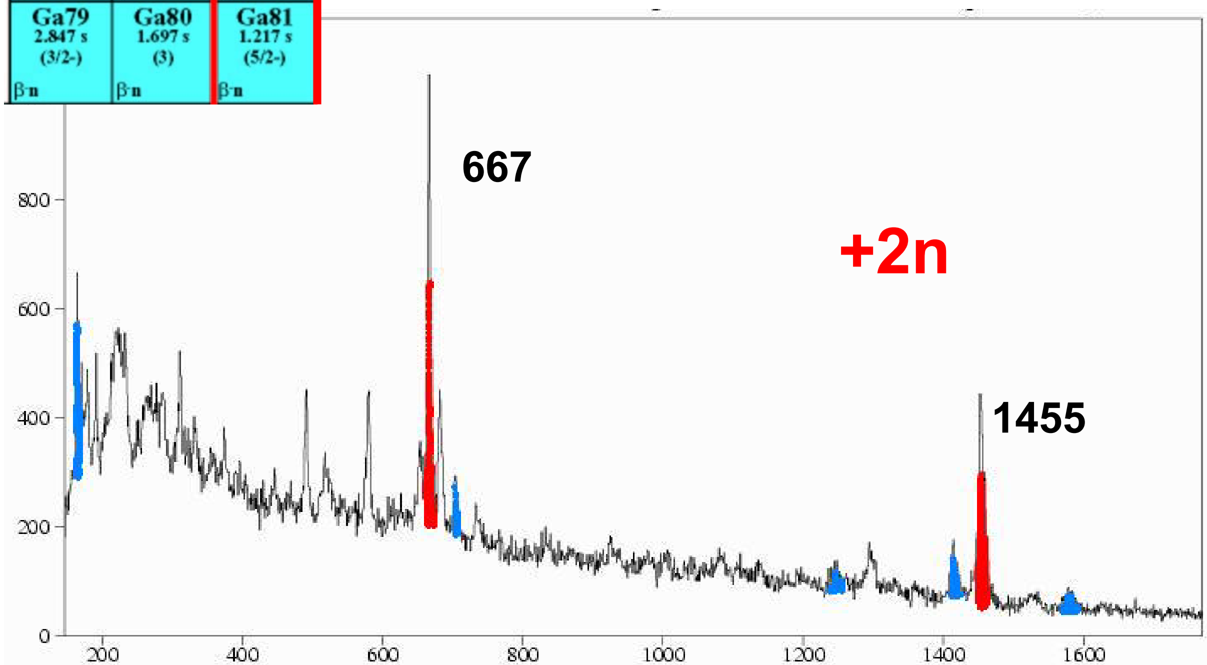

(10+)
1200.6
(8+)
916.3
(6+)
1424.1
1526.7
1153.3
(4+)
847.1
2+
653.0
0+
72Zn
(-6p -4n)

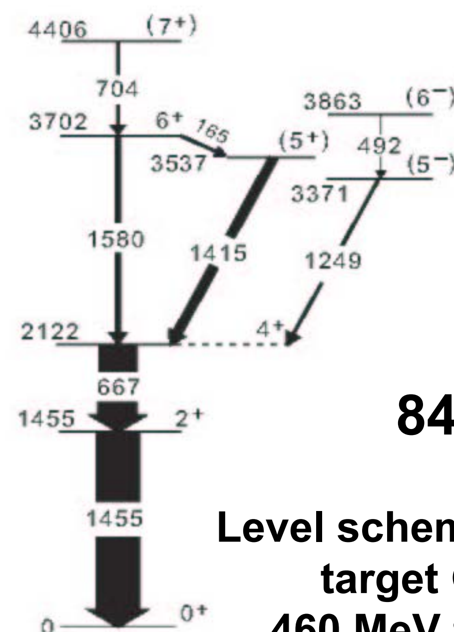
^{82}Se + ^{238}U E=505 MeV











^{84}Se

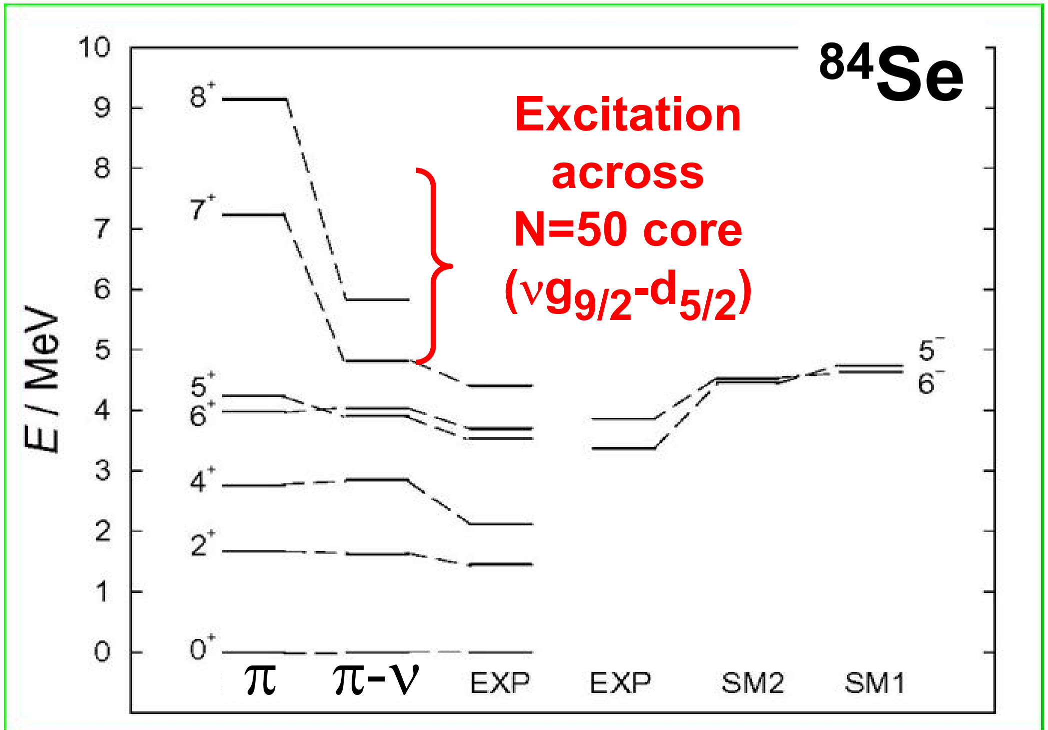
Level schemes from a thick target GASP exp.
460 MeV ^{82}Se on ^{192}Os

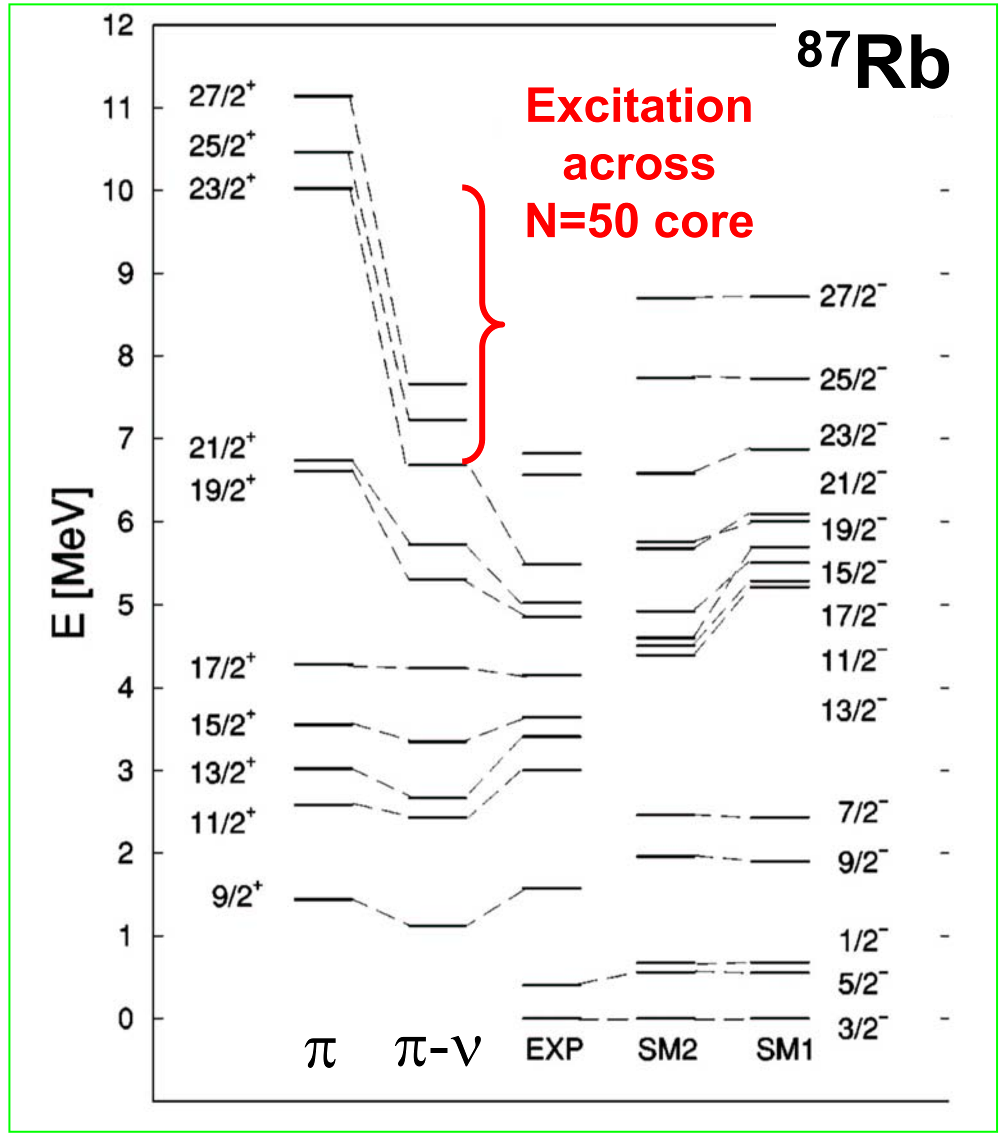
Stability of the N=50 Shell down to Z~32

Shell model with renormalized SPE ($f_{5/2}$-$g_{9/2}$)

TBME: X.Ji & B.H. Wildenthal PRC 37(1988)1256

SPE: Lisetskiy et al., nucl-th/0402082

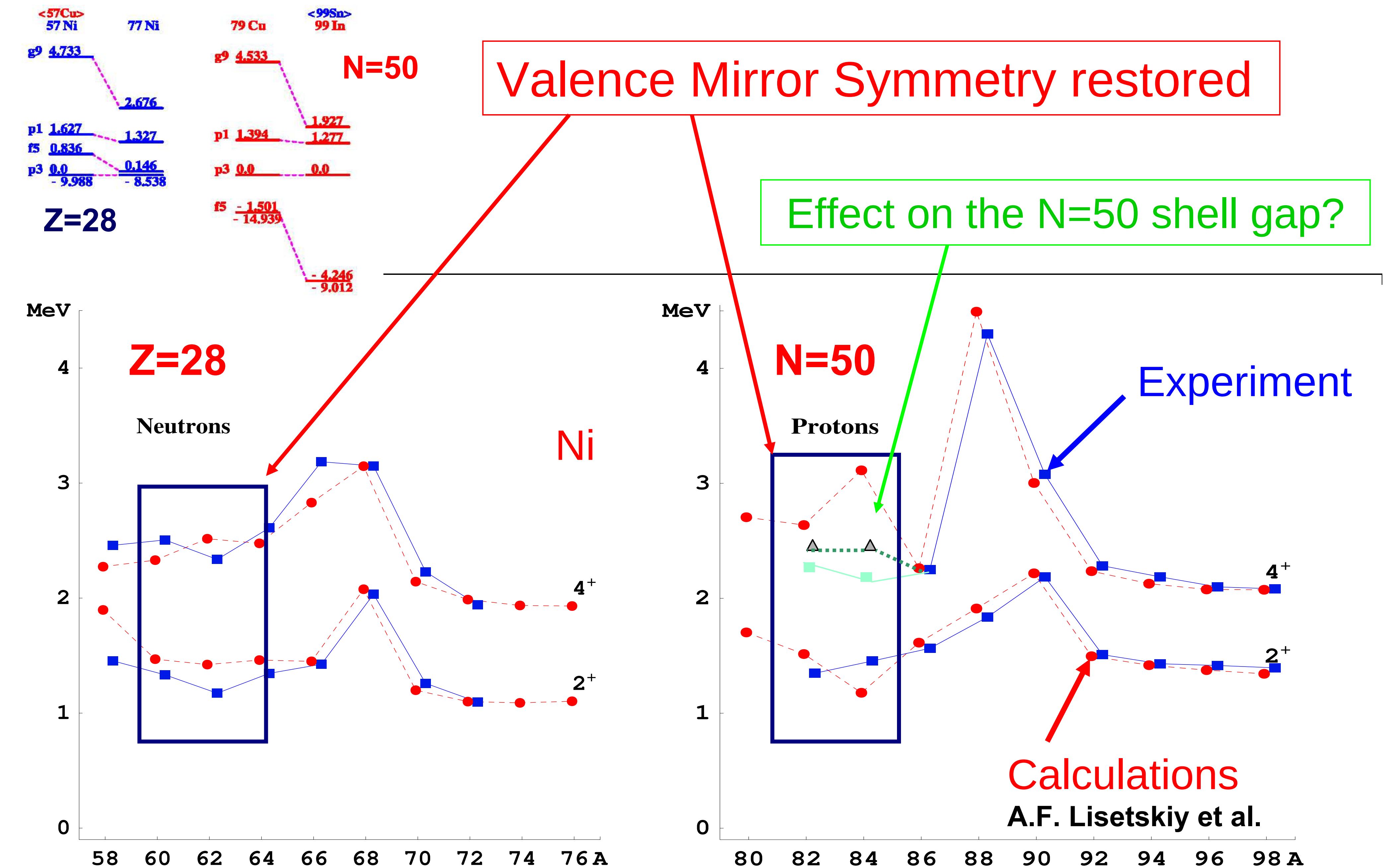




Space: $\pi f_{5/2}\ p_{3/2}\ p_{1/2}\ g_{9/2}\quad \nu p_{1/2}\ g_{9/2}\ d_{5/2}$

The description of these semi-magic nuclei (within the shell model framework) can be done with a constant N=50 shell gap.

Y.H.Zhang et al., PRC 70(2004)024301



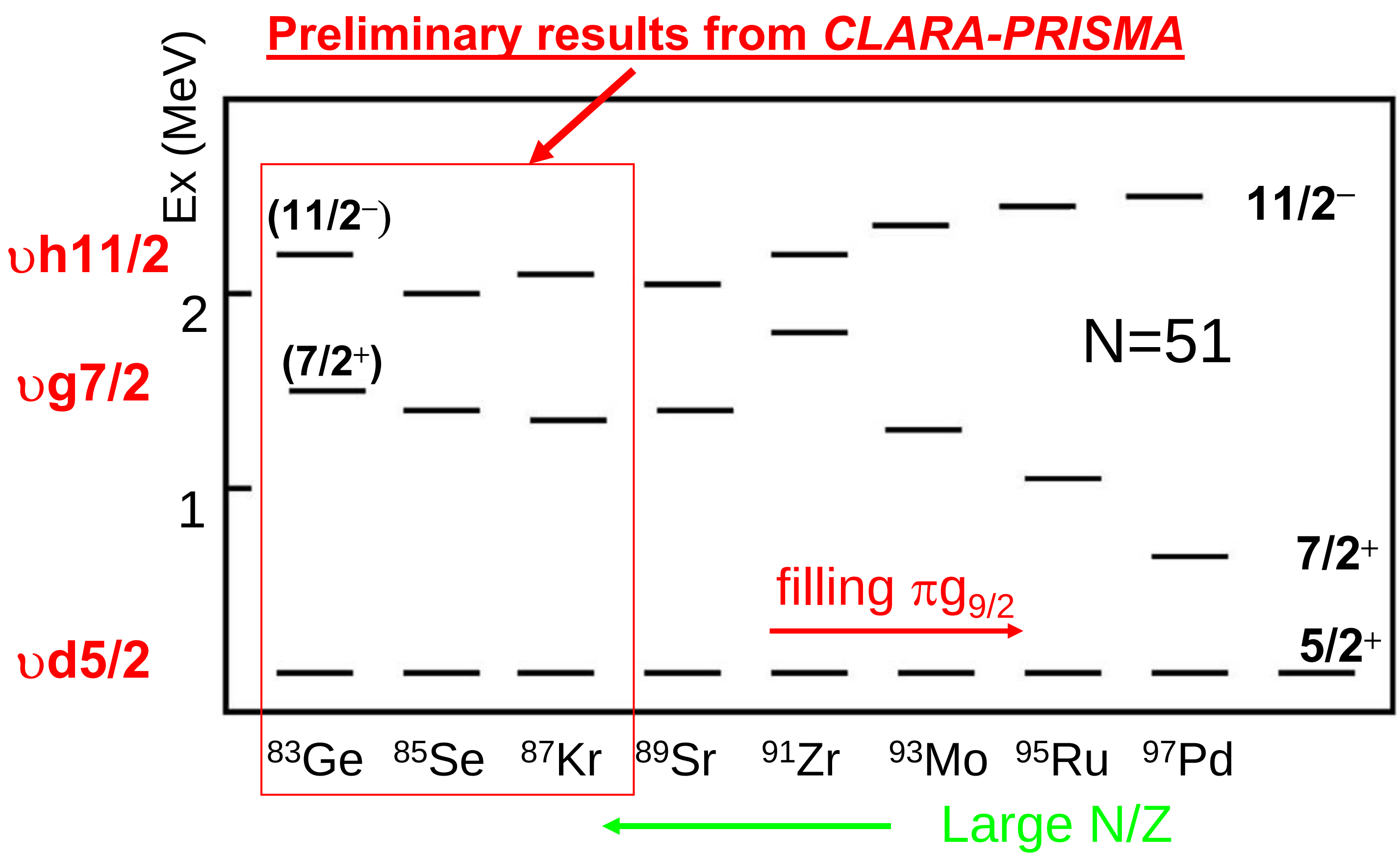
A.F. Lisetskiy, B.A.Brown, M. Horoy, H. Grawe nucl-th0402082 (G-Matrix based on Bonn-C)

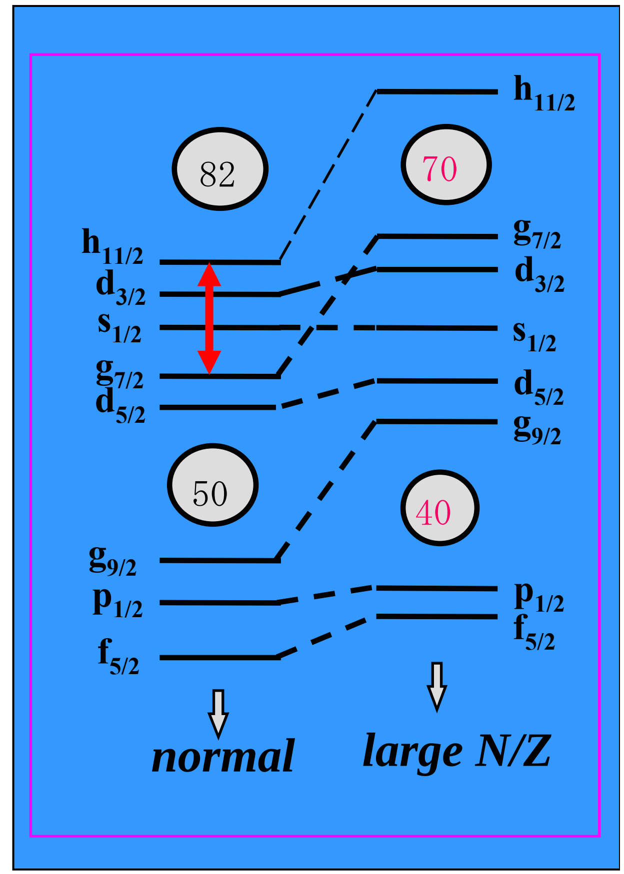
N=51 isotones

Monopole shift of the single particle levels ?

Downward shift of the $\upsilon g_{7/2}$ in proton rich N=51 isotones as $\pi g_{9/2}$ is filled

The $\upsilon d_{5/2}$-$h_{11/2}$ splitting is "constant" in neutron rich N=51 isotones: it should increase if the *ls* term was getting weaker – No diffused potential?

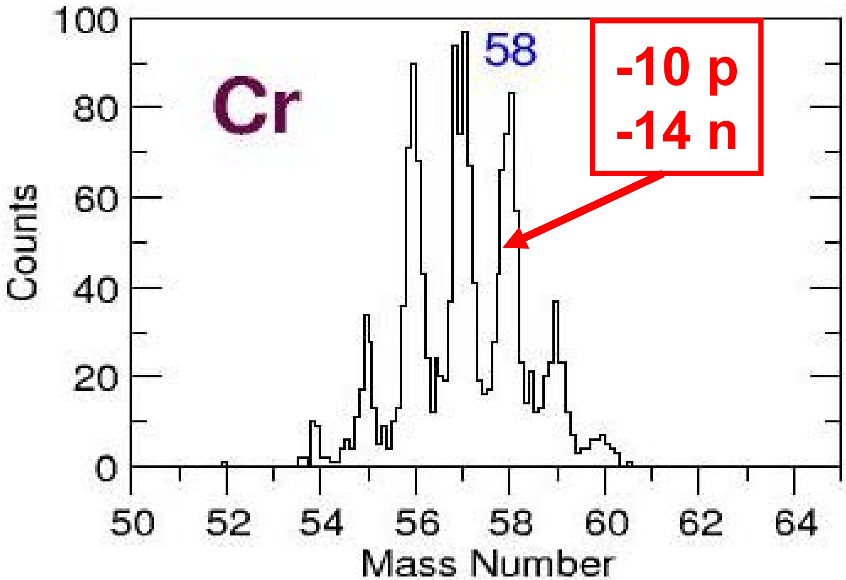


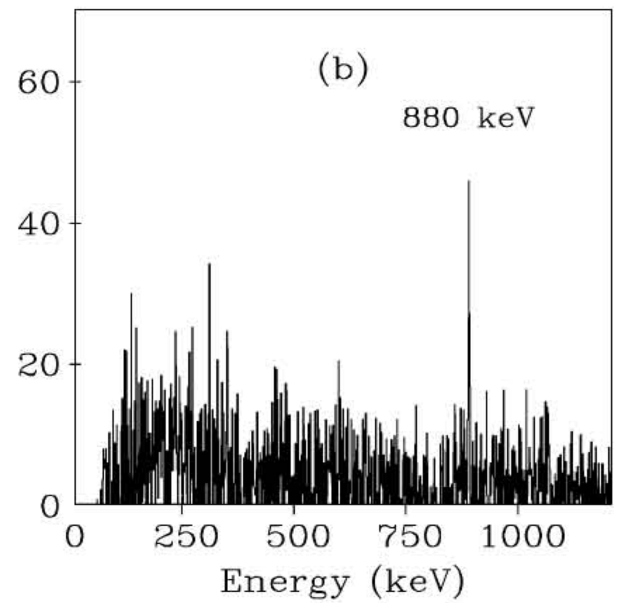


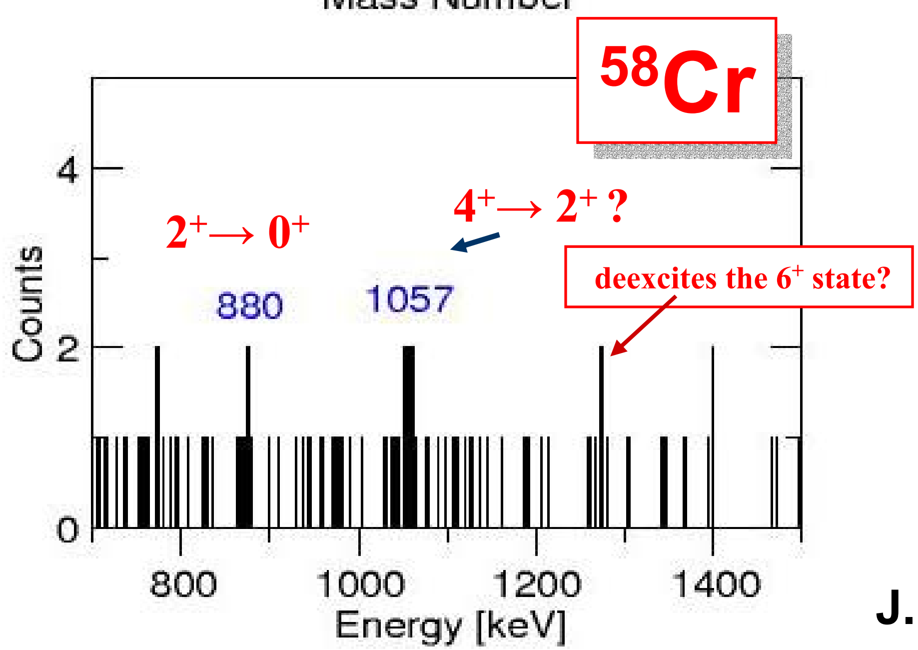
^{82}Se 505 MeV + ^{238}U

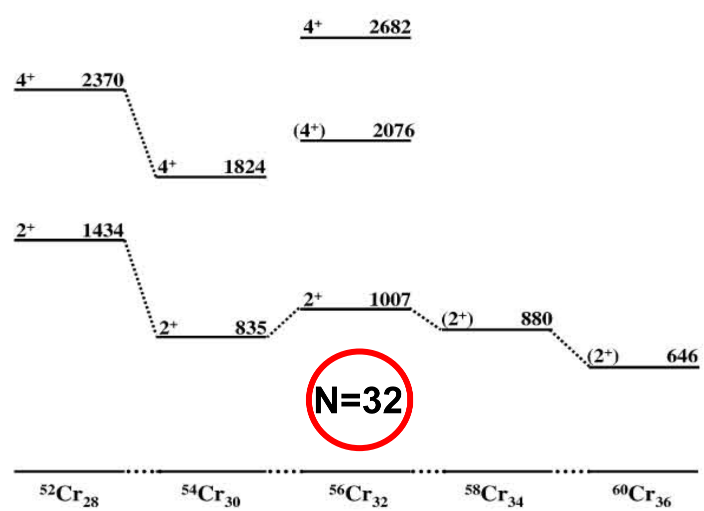
24 nucleons removed from projectile

G.deAngelis, G.Duchêne
Analysis: N.Marginean







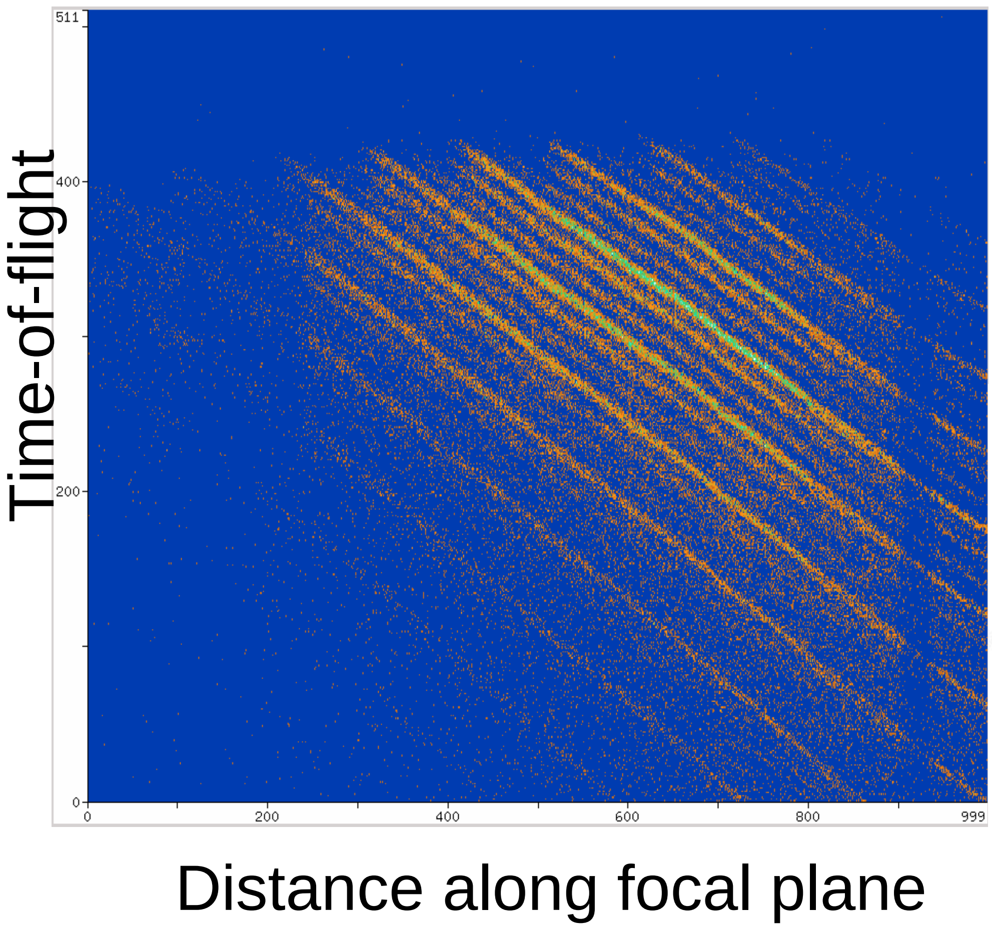


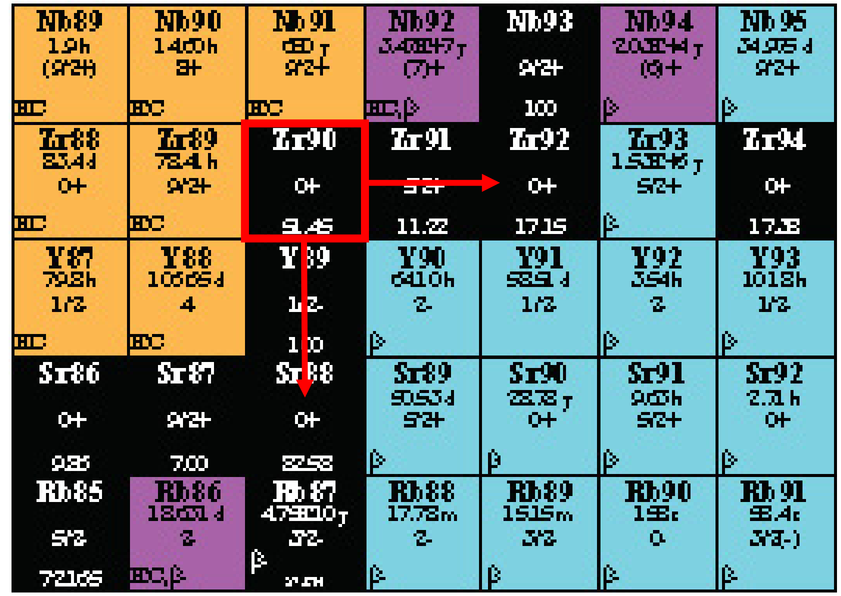
J.I.Prisciandaro et al., Phys.Lett.B 510(2001)17

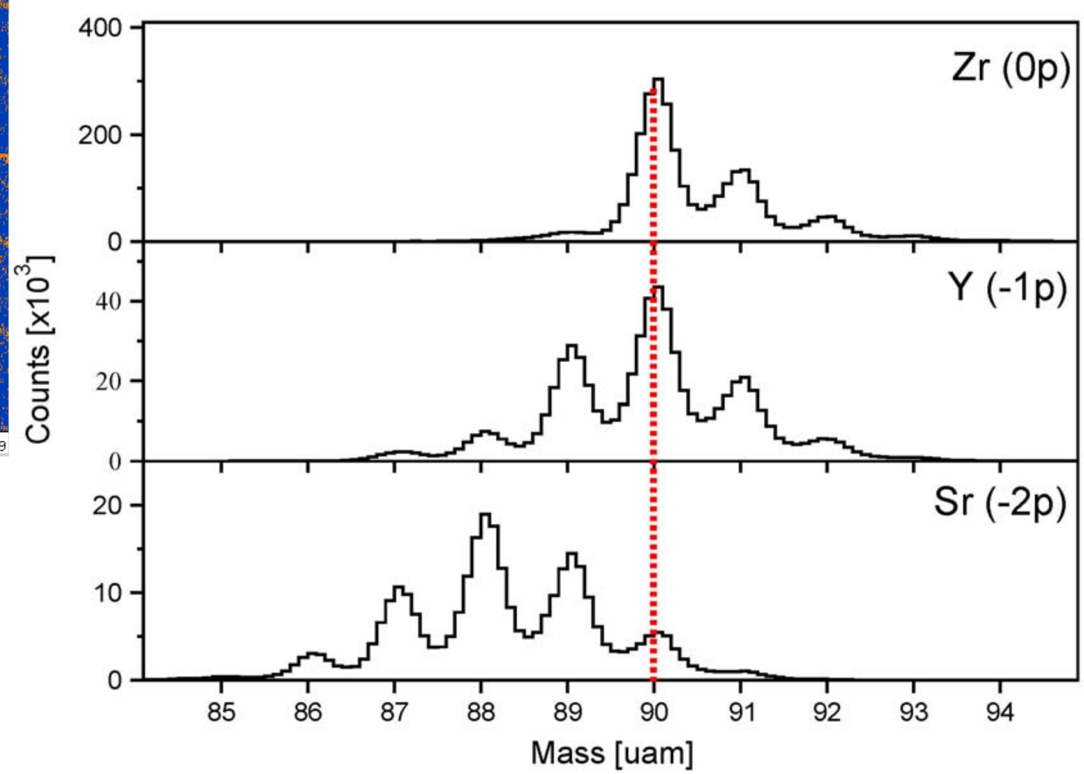
^{90}Zr 560MeV + ^{208}Pb

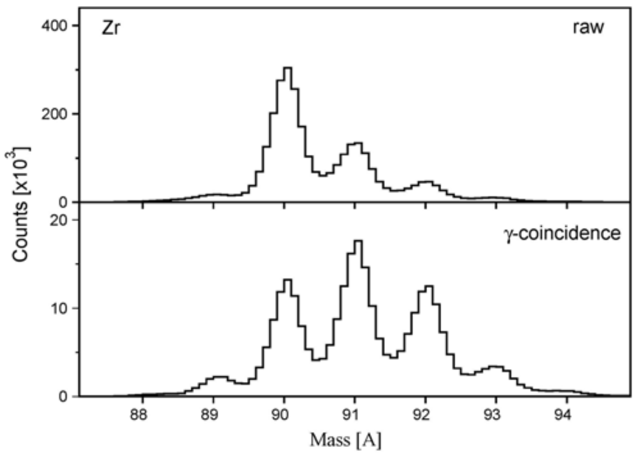
1 day beam time (4 pnA)

L.Corradi, C.A.Ur, et al.

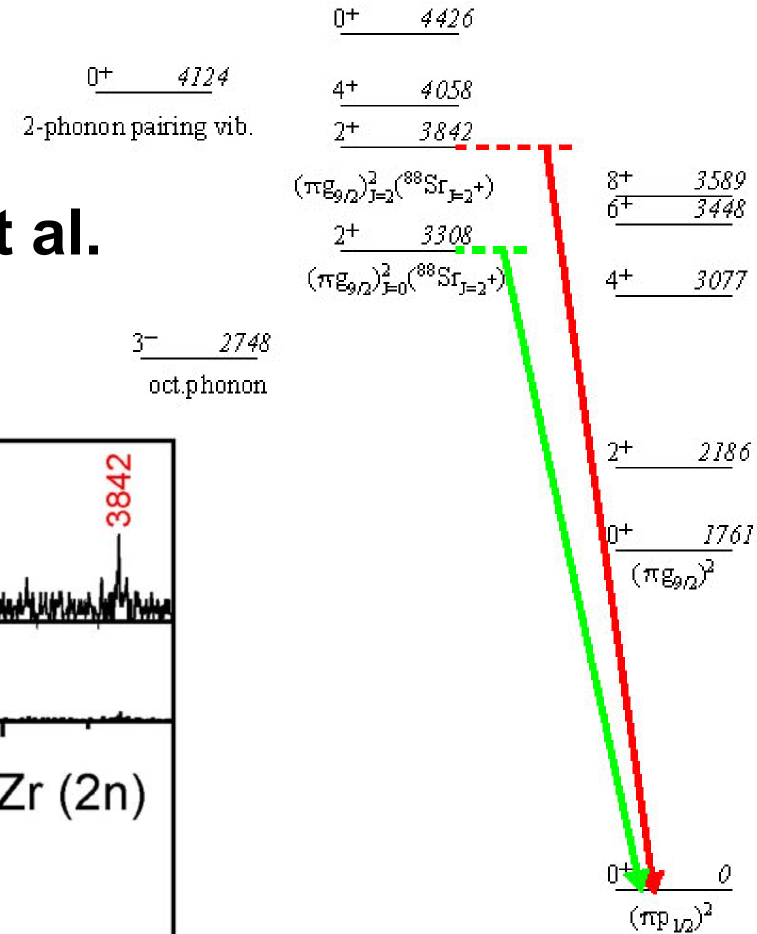


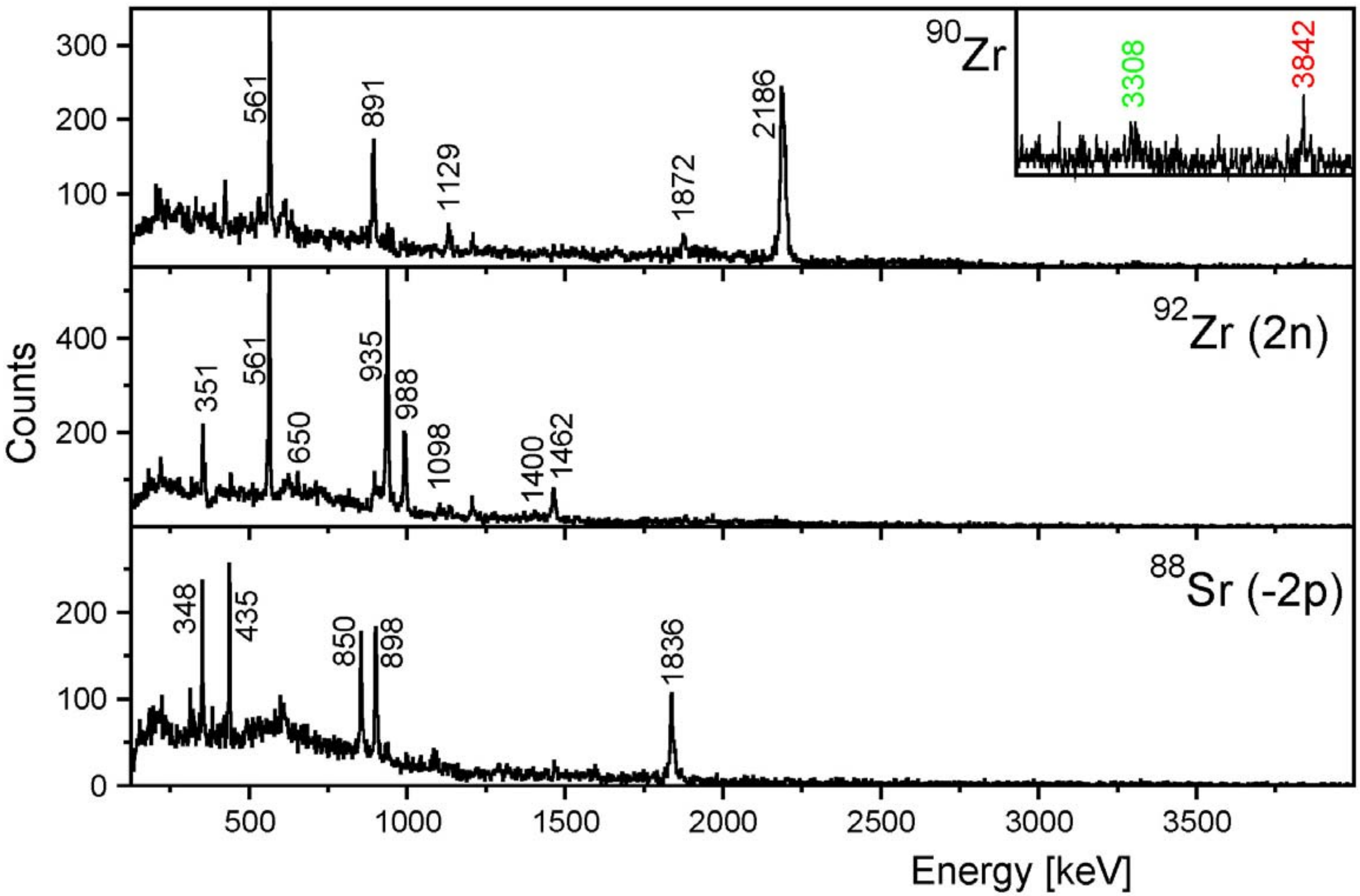






^{90}Zr 560MeV + ^{208}Pb
L.Corradi, C.A.Ur et al.





Level Scheme from: ^{90}Zr(n,n`γ) P.E.Garrett et al., Phys.Rev.C68 (2003)024312

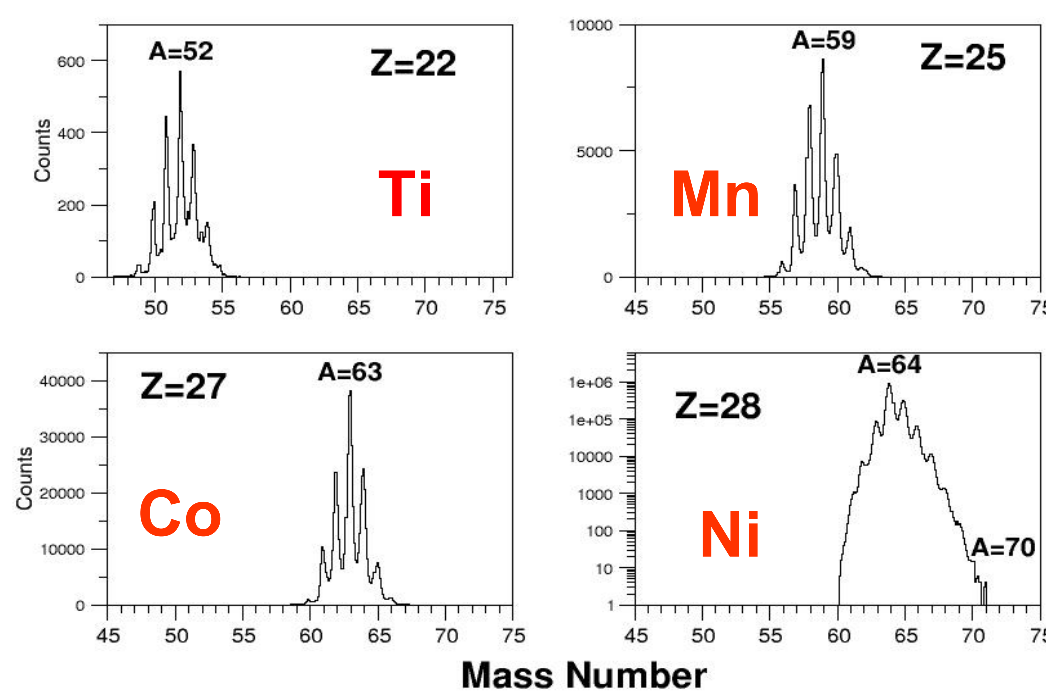
Spectroscopy of deformed neutron rich A ~ 60 nuclei

^{64}Ni 400MeV + ^{238}U

S.M.Lenzi, S.J.Freeman
Analysis: N.Marginean

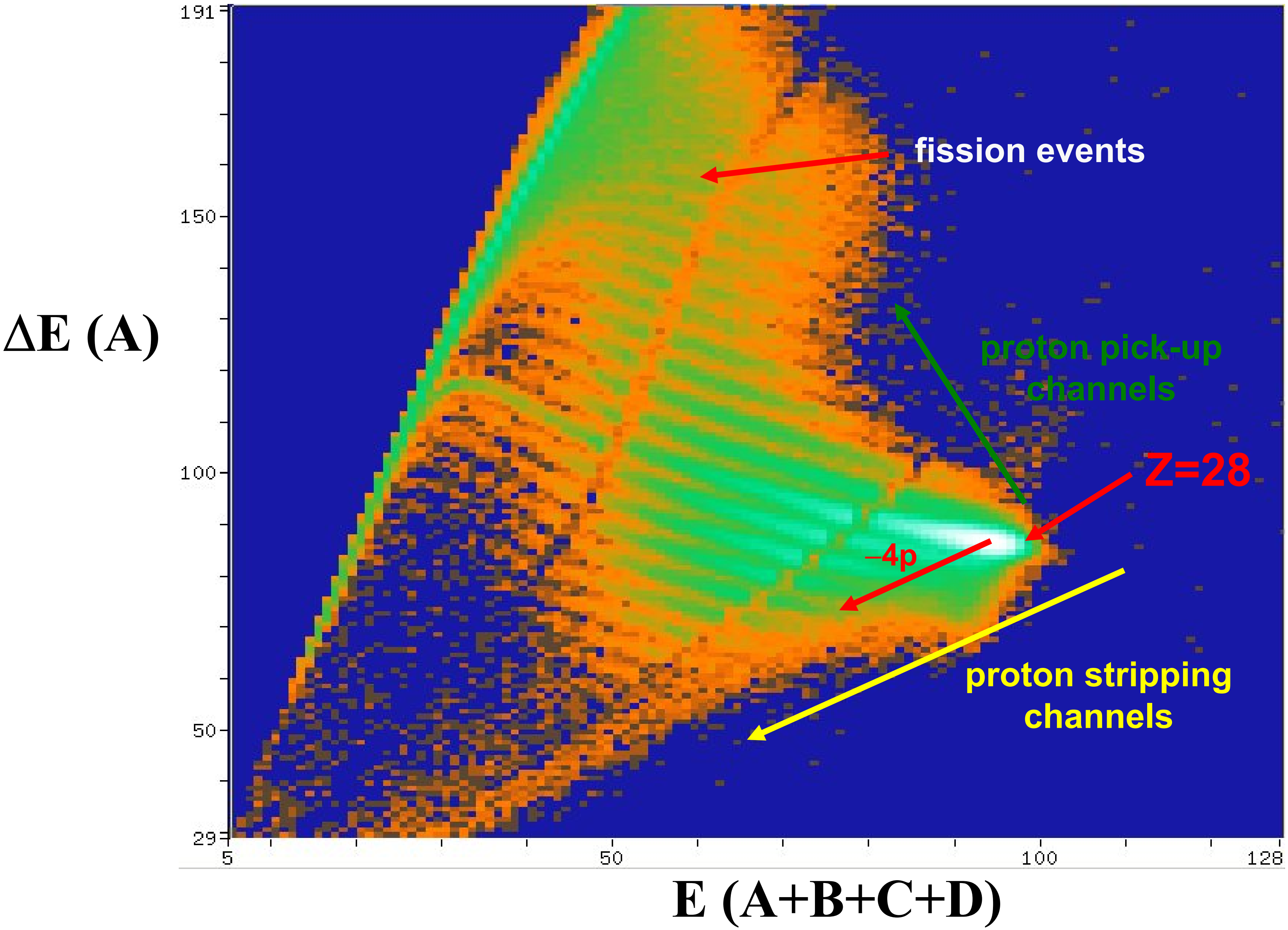
Preliminary (only ½ sorted)

MASS & Z selection

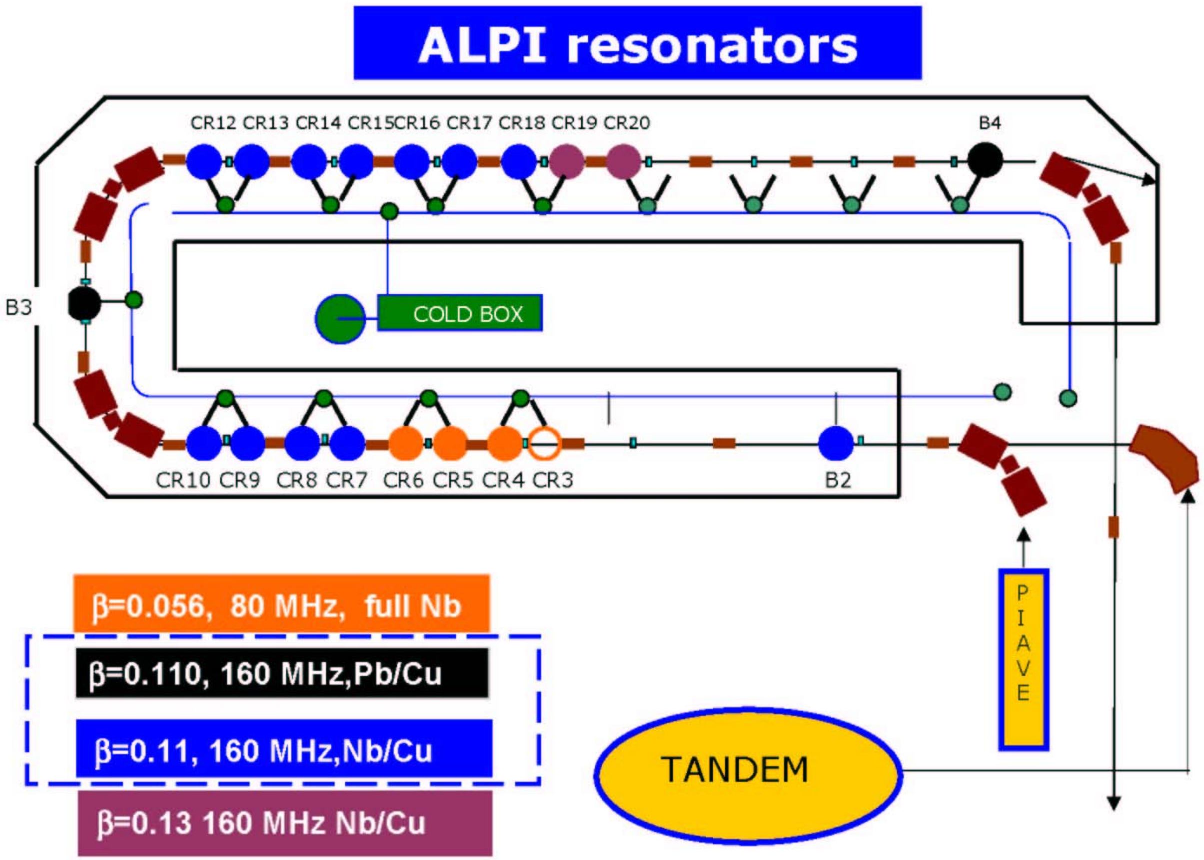


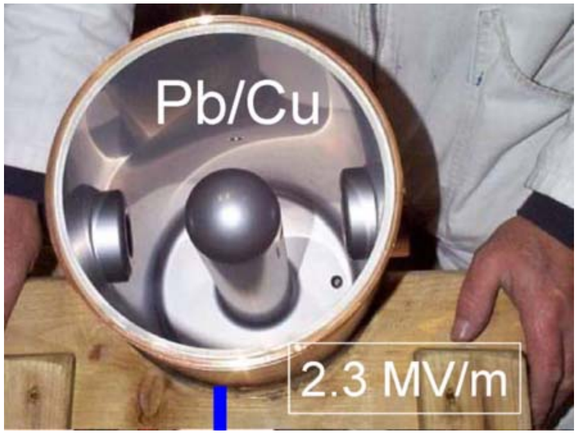
Goal: n-rich A~60 (Cr,Fe &Ti) nuclei, deformation effects in the middle of the $\pi f_{7/2}$ νpf-shell

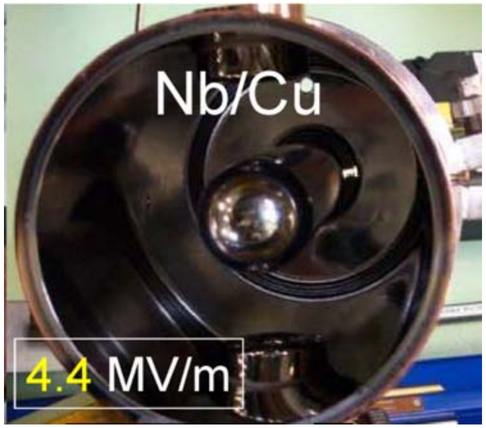
^{64}Ni 400MeV + ^{238}U IC ΔE-E matrix



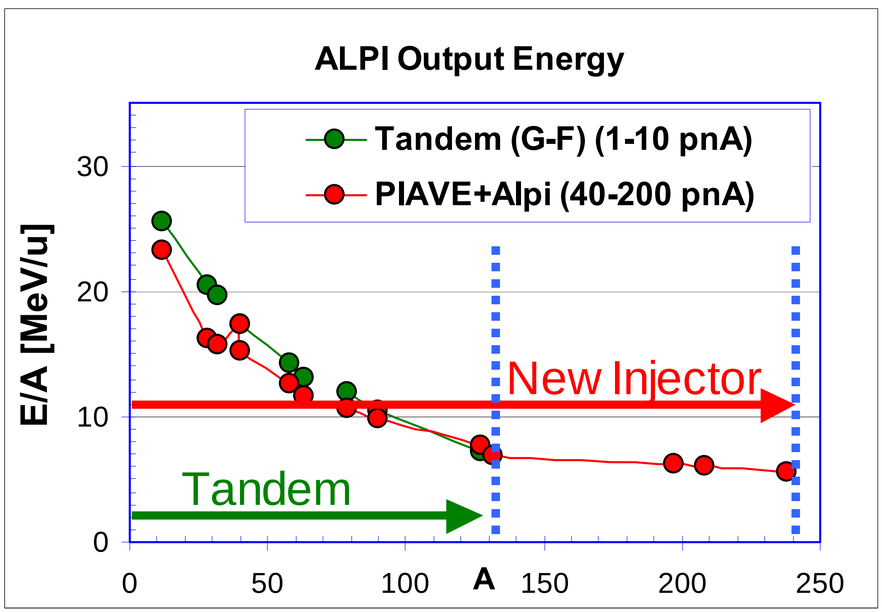
Present at LNL :
Tandem – ALPI beams (therefore Tandem beams) up to A~100. Beam intensities increased up to few pnA (6pnA for 82Se, 4pnA for 90Zr) due to the ALPI energy upgrade (equivalent to ~32MV). Heavier beams available with the low β cavities.







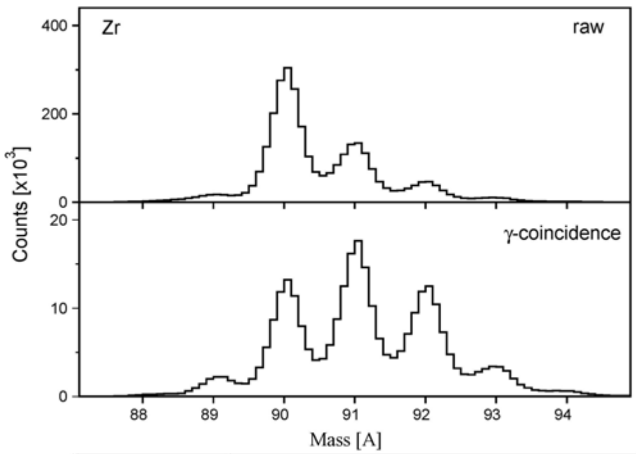
Perspectives:



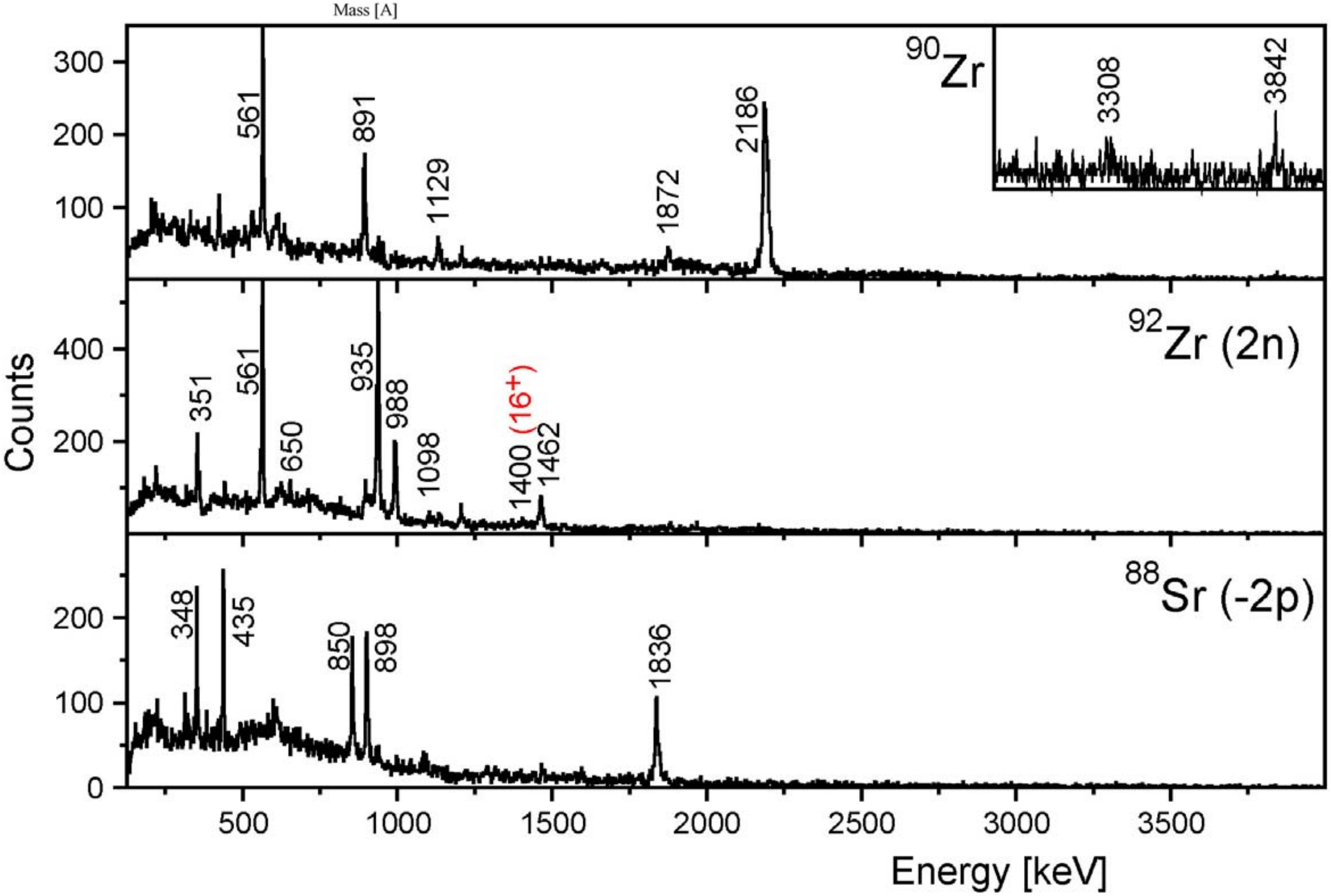
Positive ion injector ECRIS + PIAVE commissioned with O and Kr beams. Transmission 40%. Ar, Kr and Xe (also Ag and Cu) beams during 2005, program to develop Sn, Cd, Sm and Pb beams at the ECR started

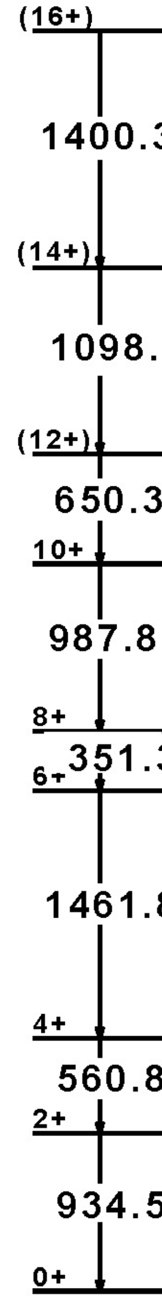
Summary

- The CLARA-PRISMA setup consisting on an array of 25 EUROBALL Clover detectors coupled with the large acceptance magnetic spectrometer PRISMA is installed and fully functional al LNL.
- The first preliminary result show the capabilities of such installation in combination with the stable beam delivered by the LNL Tandem-ALPI complex. In the future with PIAVE-ALPI.
- In a single few days experiment ~50 nuclei could be studied.
- At the present stage of the instrument and for most cases, additional experimental information is required to build the level scheme once the transitions are assigned.
- The first results show how experiments with stable beams and instruments as CLARA-PRISMA can contribute to the study of exotic nuclei



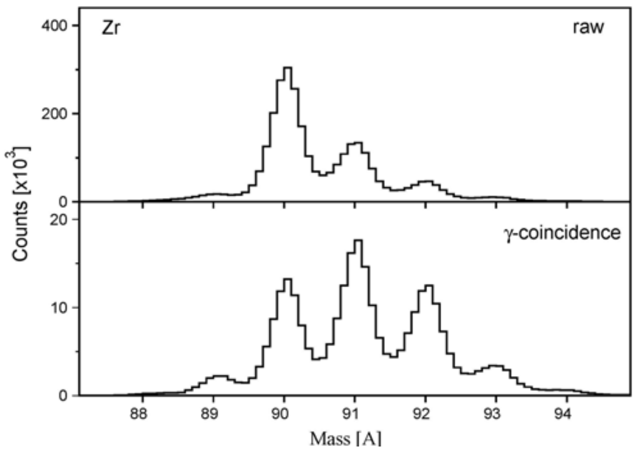
^{90}Zr 560MeV + ^{208}Pb
L.Corradi, C.A.Ur et al.



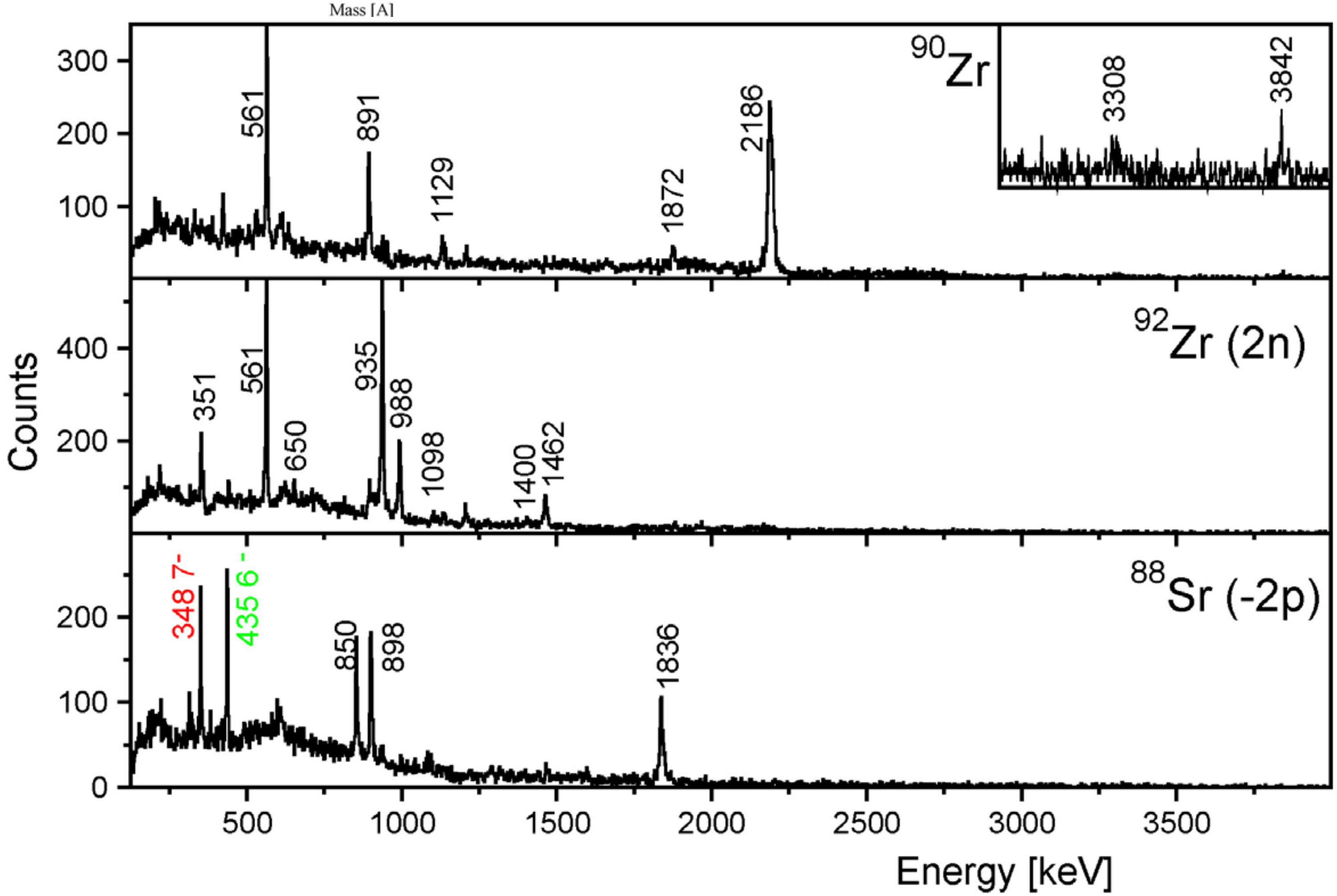


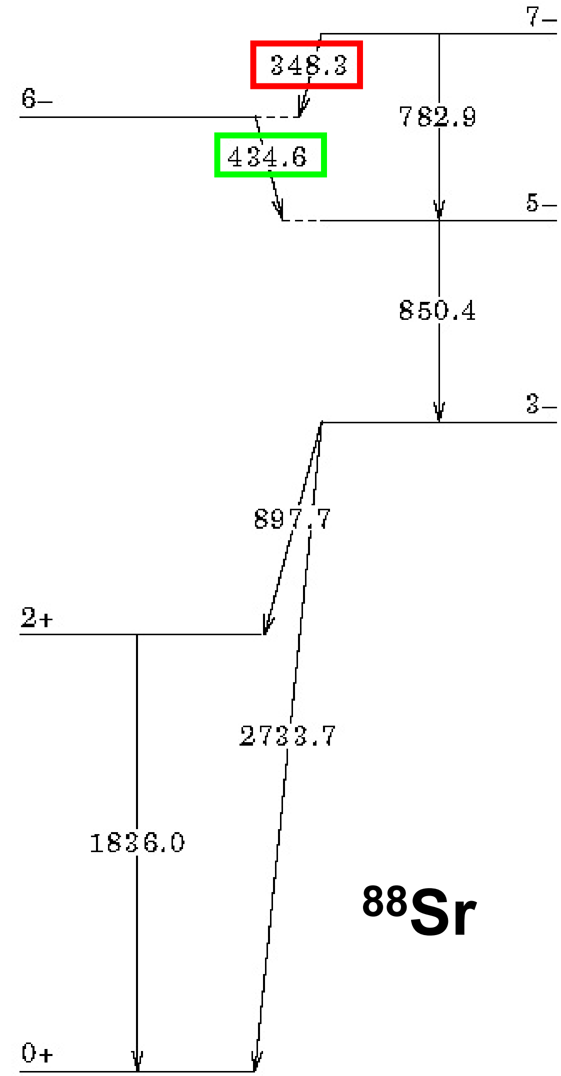
^{92}Zr

Adopted NNDC Level Scheme



^{90}Zr 560MeV + ^{208}Pb
L.Corradi, C.A.Ur et al.





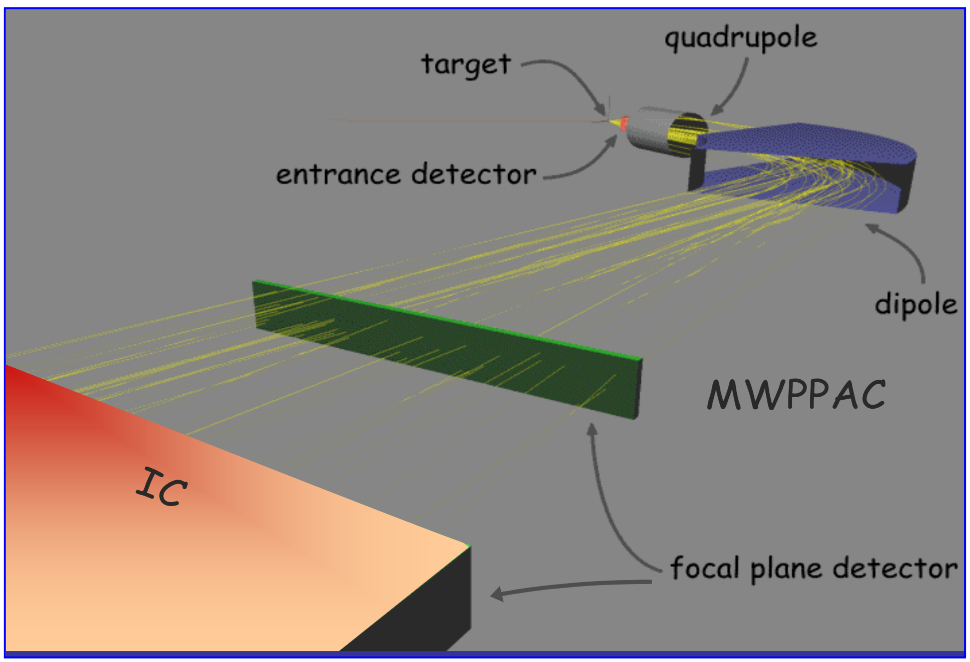
^{88}Sr

Adopted NNDC Level Scheme

Analysis of PRISMA (CLARA) data

A complete tracking algorithm for PRISMA was developed

Ingredients
- Entrance detector position (MCP)
- TOF Entrance detector- MWPPAC (~5m)
- Focal Plane position MWPPAC + IC
- Total Energy and Z ($\Delta E/E$) from IC



Doppler correction
- precise position on entrance detector
- true recoil velocity

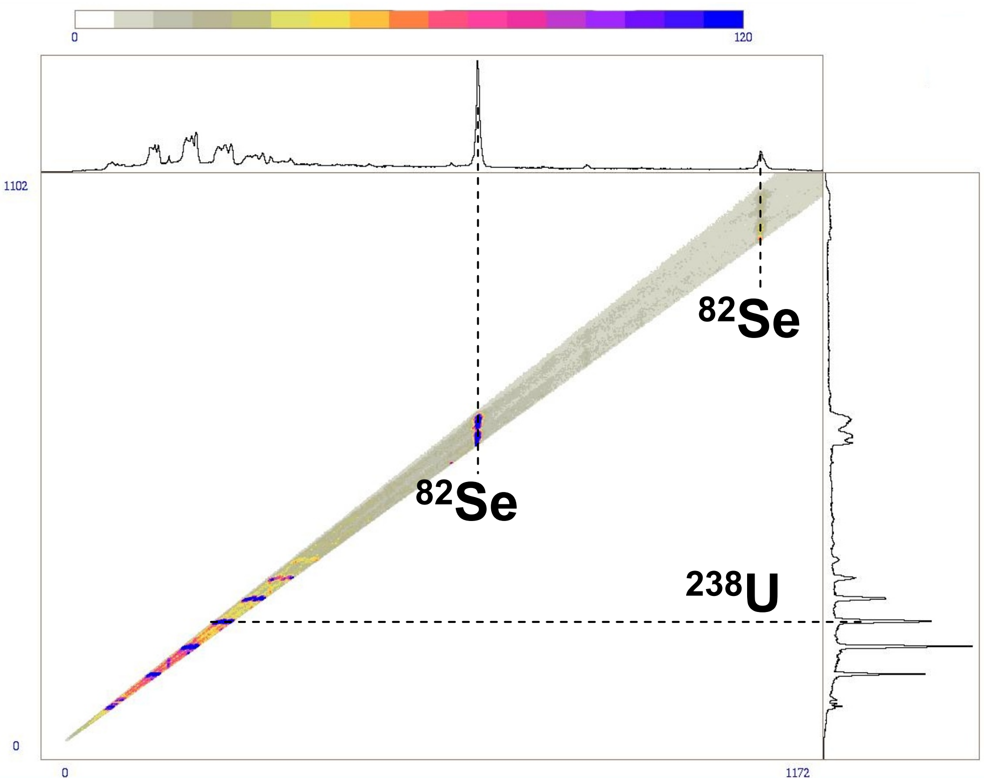
A/q

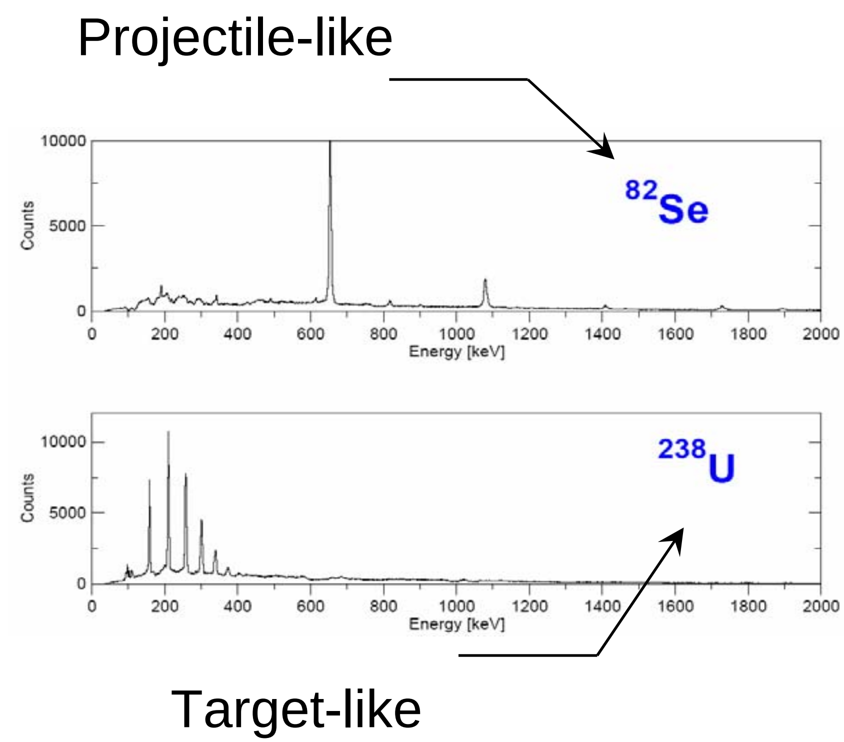
Charge state
- trajectory in dipole
- total energy

CLARA Doppler correction

Energy resolution of 1% at recoil velocity v/c = 10%

^{82}Se+^{238}U with ^{82}Se selected in PRISMA

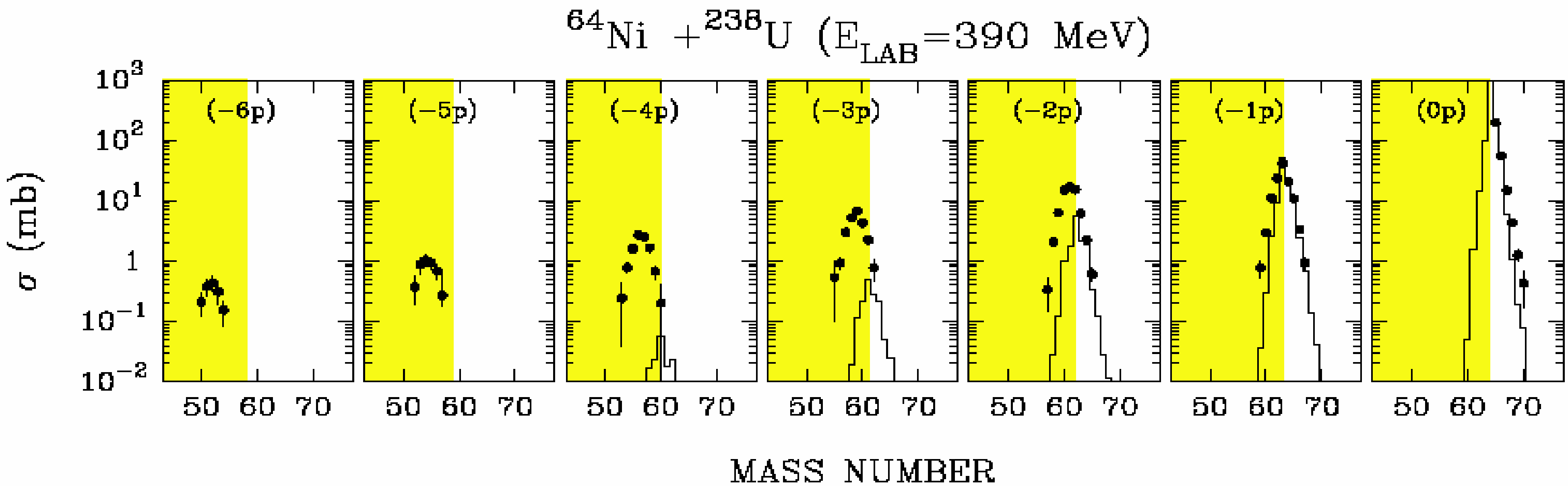




PHYSICAL REVIEW C VOLUME 59, NUMBER 1 JANUARY 1999

Multinucleon transfer processes in $^{64}Ni + ^{238}U$

L. Corradi, A. M. Stefanini, and C. J. Lin
Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, Via Romea 4, I-35020 Legnaro, Padova, Italy



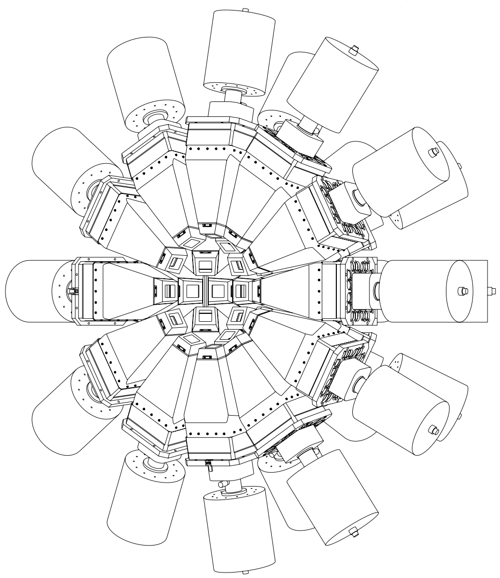
Lifetime measurements with the Clover array at Prisma

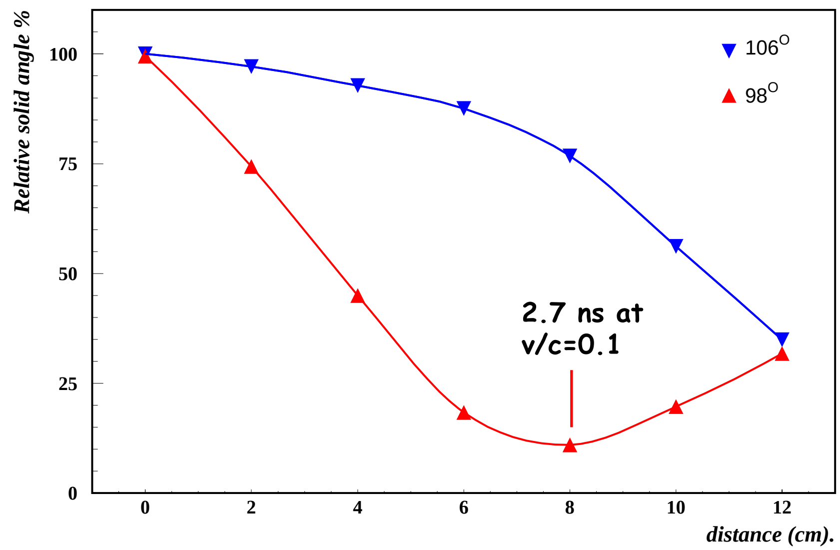
- Recoil Shadow anisotropy method:
  Based on the array-collimator geometry.
  Lifetimes ranging from ~0.5 to ~20 ns.
  E.Gueorguieva et al. NIM A 474 (2001) 132.

- Differential Plunger method (to be developed):
  Needs a degrader foil at different distances form target.
  Lifetimes ranging from ~1 ps to ~1 ns.

- RFD method:
  Developed at the Krakow Recoil Filter Detector.
  Based on the line shape analysis of the Doppler shifted lines and the change of momentum introduced by the straggling of the products in the target.
  Needs an accurate position sensitive detector as the PRISMA start MCP .
  Lifetimes ranging from ~50 fs to ~1 ps.
  P.Bednarczyk, W.Meczynski, J.Styczen et al.

Recoil Shadow Anisotropy Method

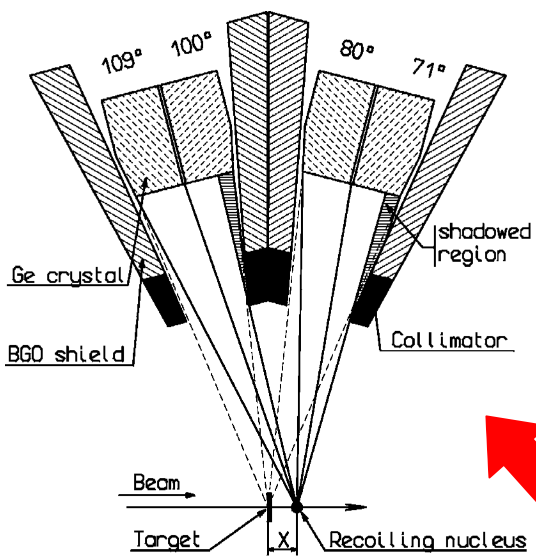


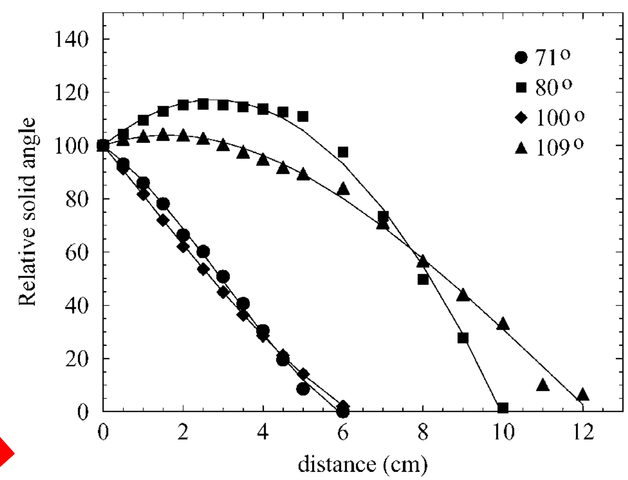


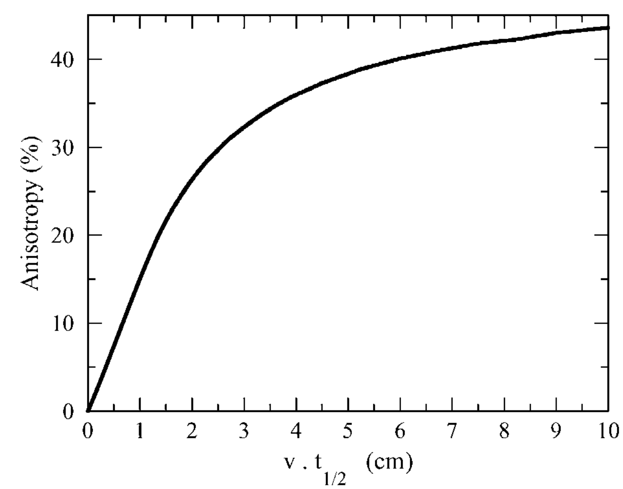
Angles for the Ge crystals of the Clover array ring:

θ = 106 °

θ = 98 °

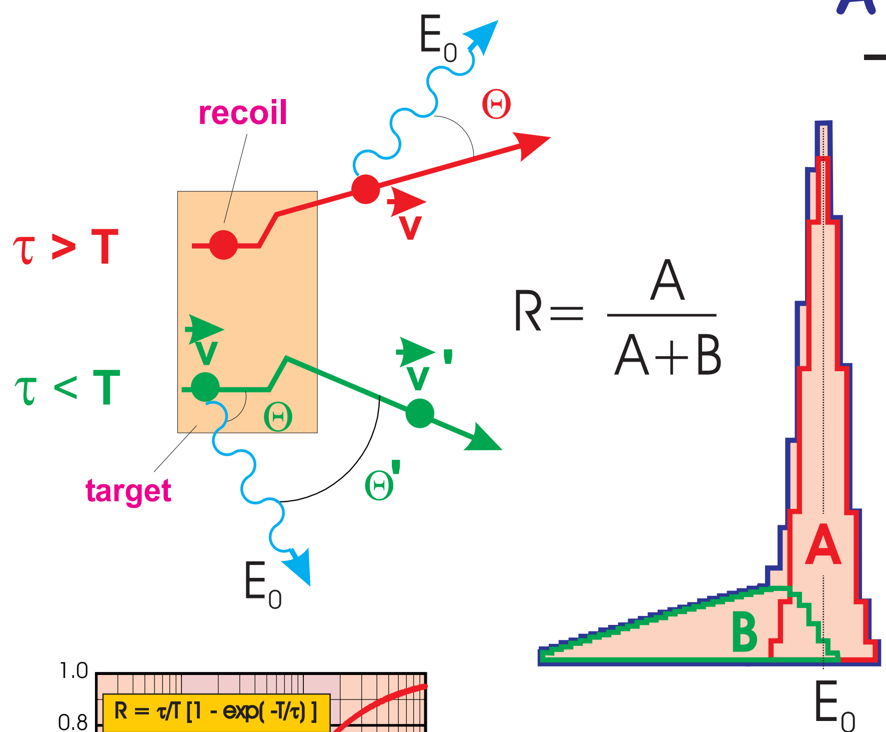


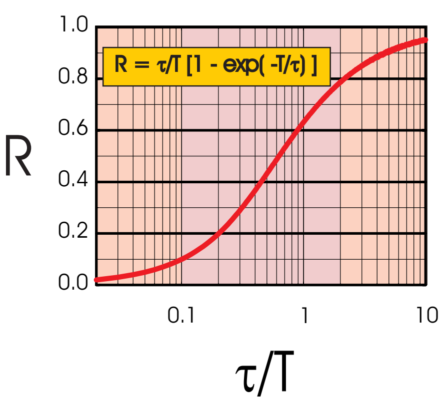




For EUROBALL: E.Gueorguieva et al. NIM A 474 (2001) 132

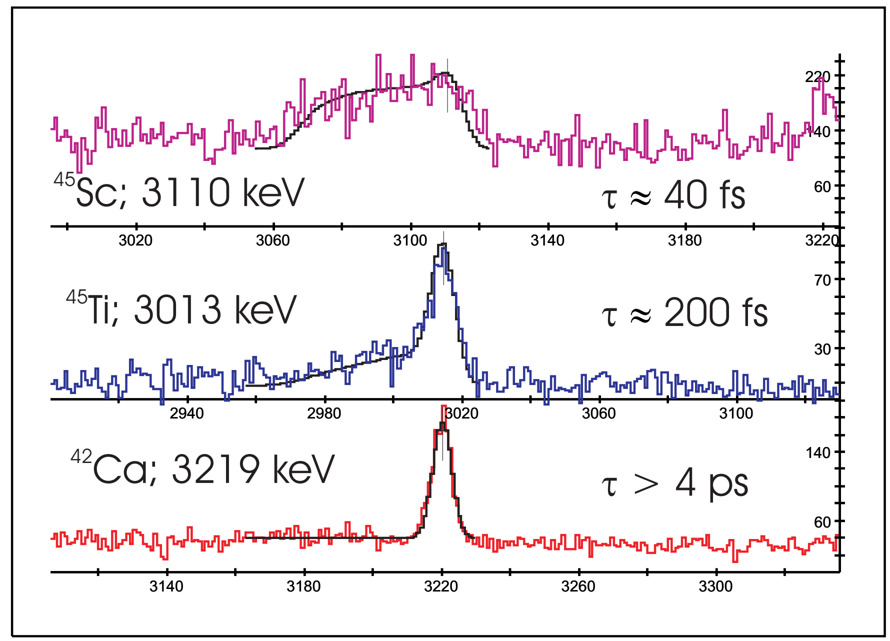
A short lifetime determination with RFD





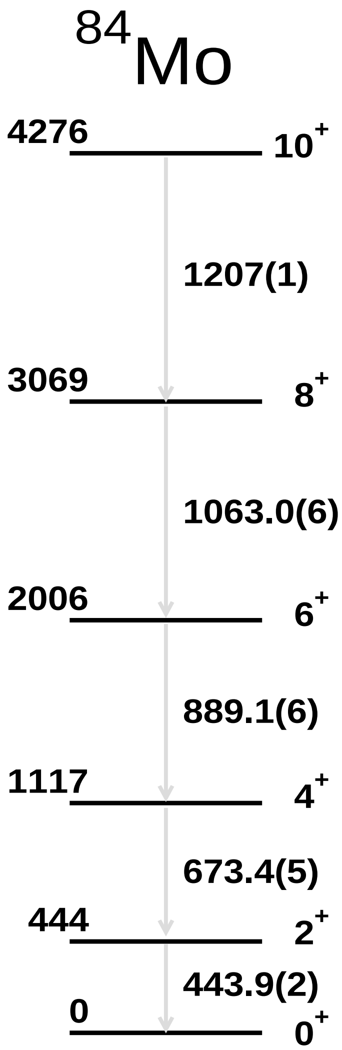
The range of measured lifetimes can be chosen by a selection of the target thickness.

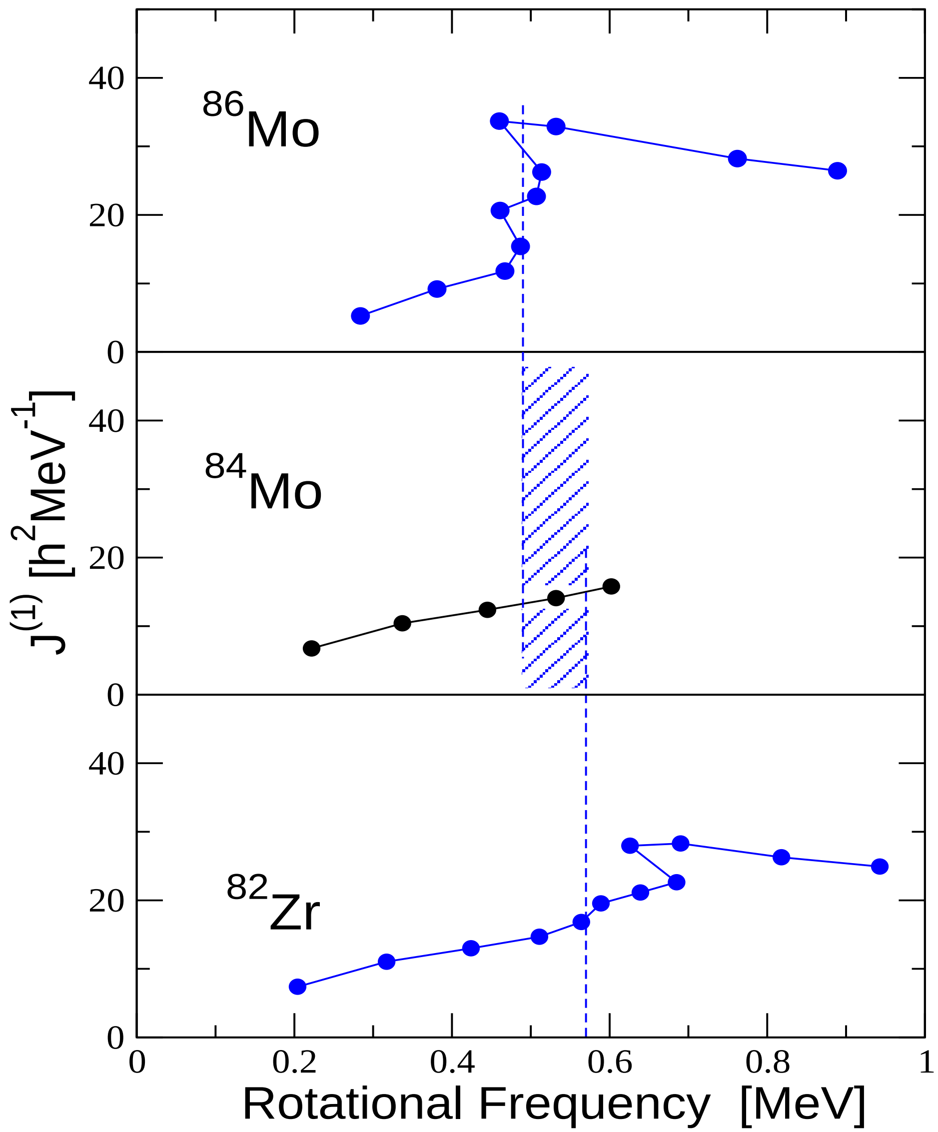
68MeV ^{18}O + 0.8mg/cm^2 ^{30}Si;
Recoil transit time ≈ 0.4 ps



In the measurement τ ranging from 40 to 800 fs could be determined.

P.Bednarczyk, W.Meczynski, J.Styczen et al.





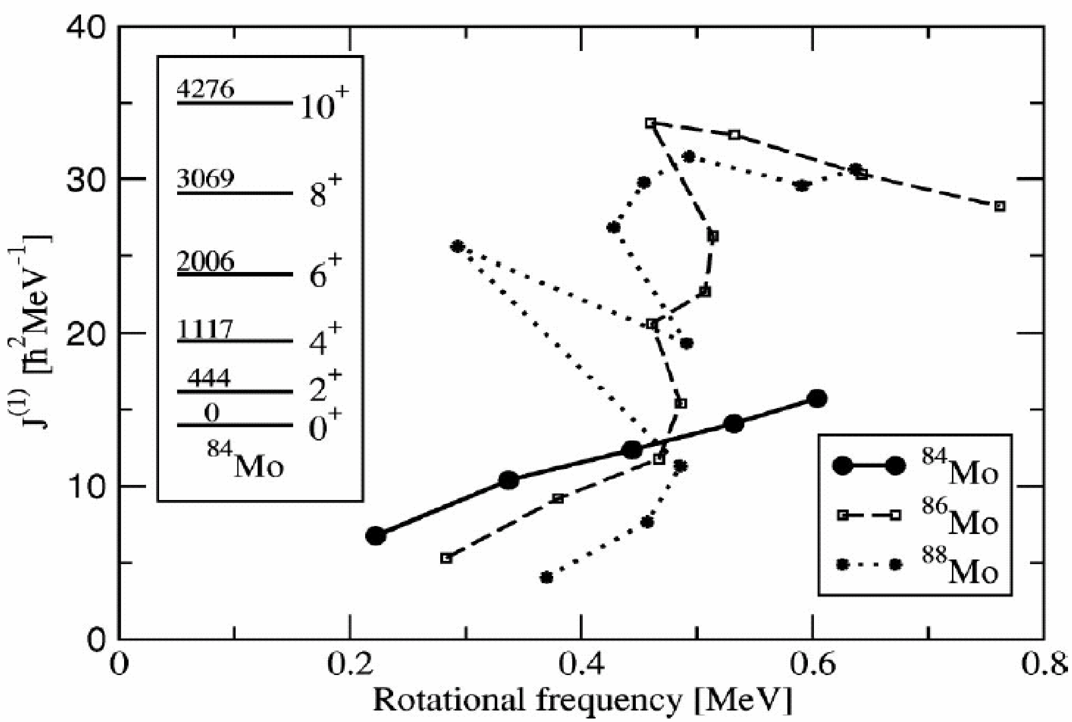
N. Marginean et al. Phys. Rev. C 65 (2002) 051303(R)

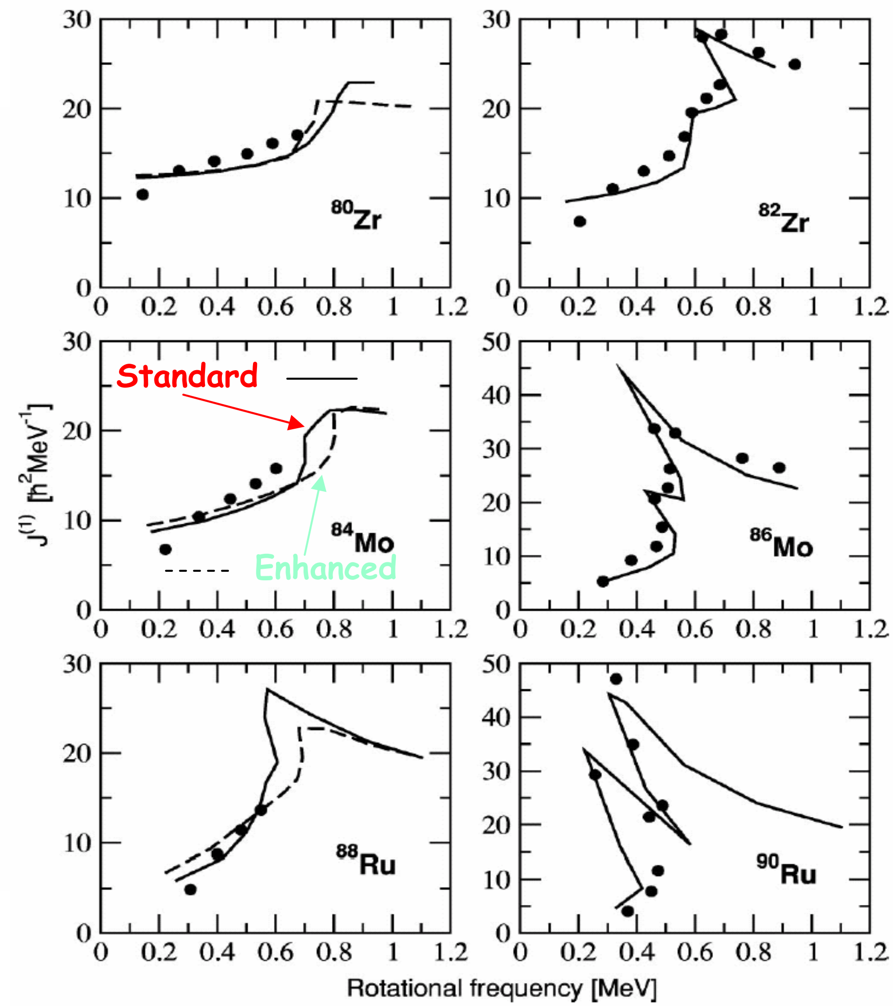
D. Bucurescu et al. Phys. Rev. C 56 (1997) 2497

Delayed alignment in the N=Z nuclei ^{84}Mo and ^{88}Ru

N. Marginean et al. Phys. Rev. C 65 (2002) 051303(R)
N. Marginean et al. Phys. Rev. C 63 (2001) 031303(R)

Higher spin states needed



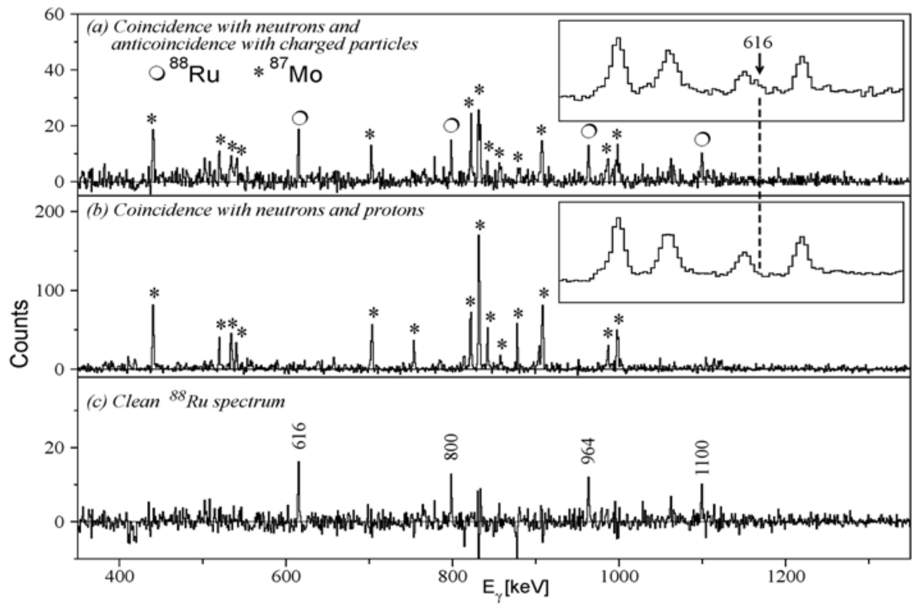


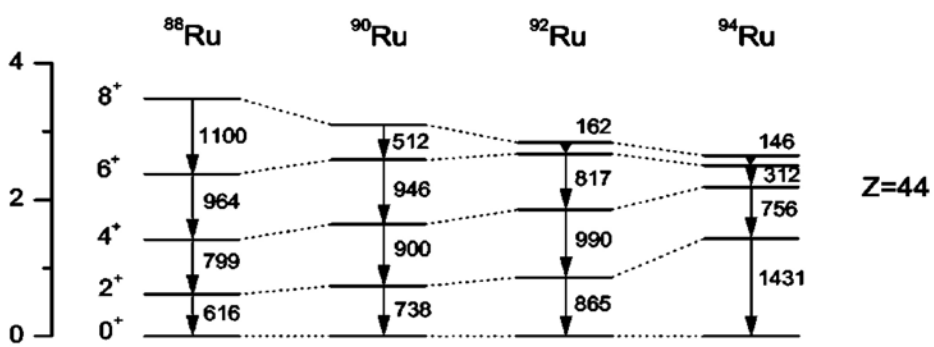
Projected shell model calculations with standard interaction and with enhanced neutron-proton residual interaction (Y. Sun)

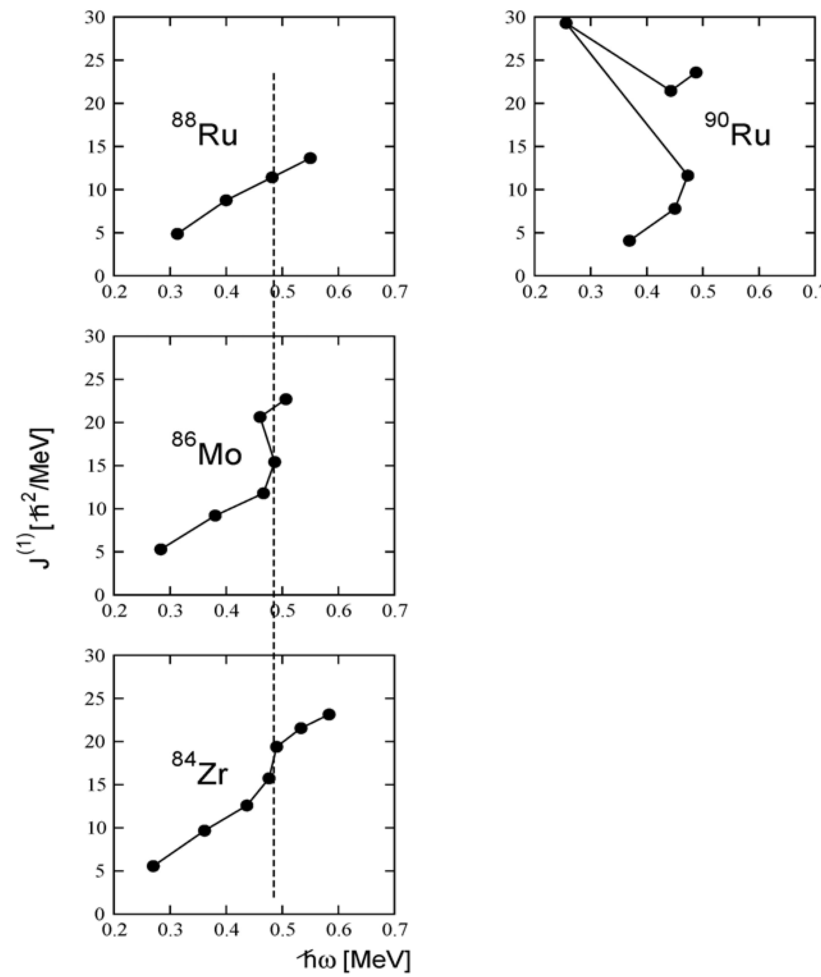
Identification of ^{88}Ru

GASP + ISIS + 6 n-detectors

^{58}Ni + ^{32}Si 105MeV

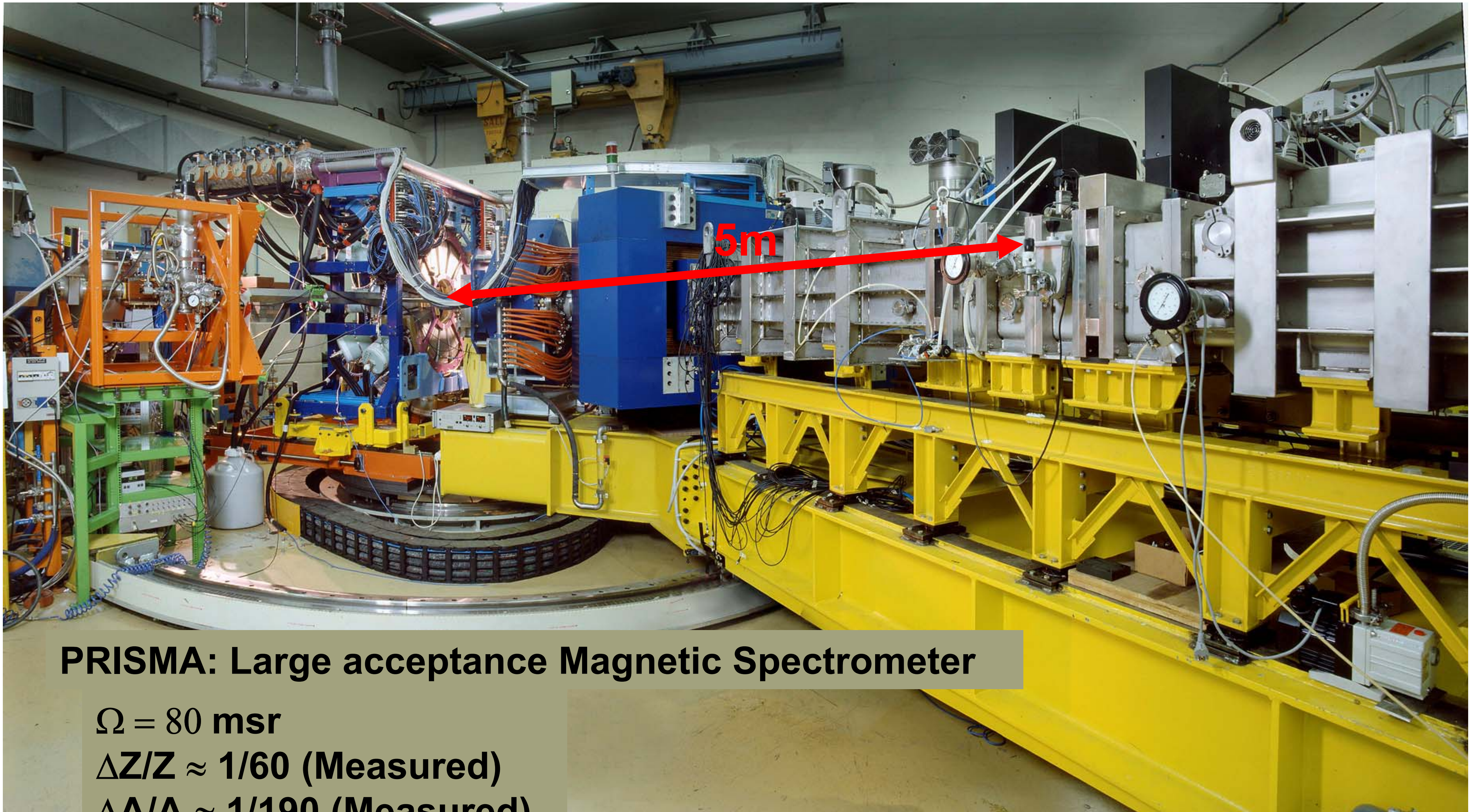






N. Marginean et al. Phys. Rev. C 65 (2002) 051303(R)

CLARA-PRISMA setup

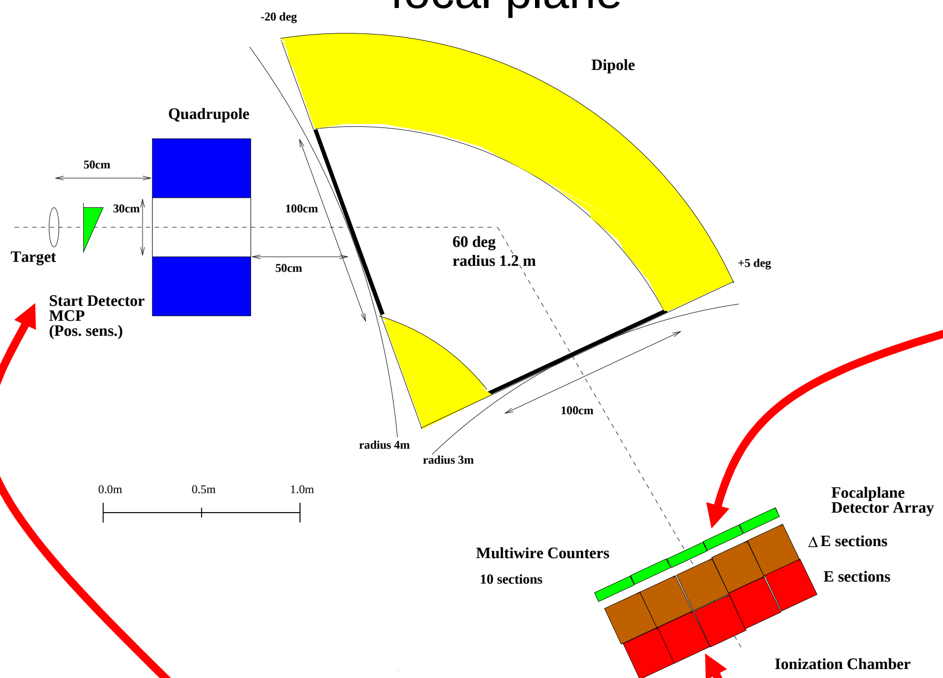


PRISMA: Large acceptance Magnetic Spectrometer

$\Omega = 80$ msr
ΔZ/Z ≈ 1/60 (Measured)
ΔA/A ≈ 1/190 (Measured)
Energy acceptance ±20%
Bρ = 1.2 T.m

The PRISMA Spectrometer Detectors

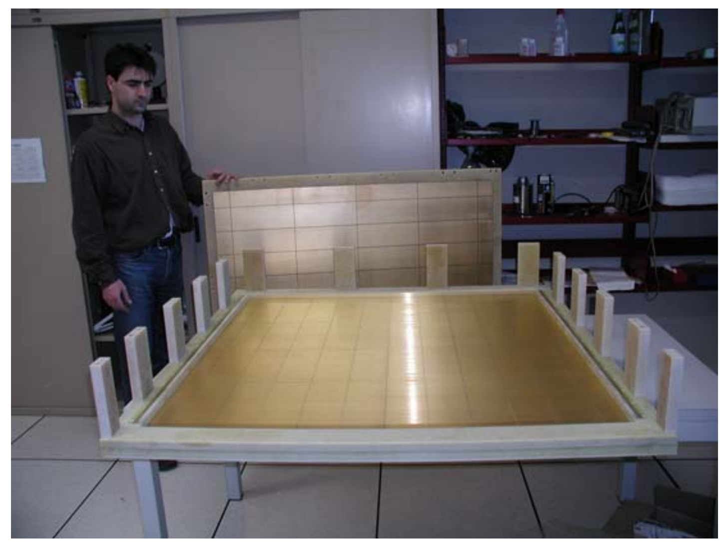
Large dispersion dipole: 4cm / % at the focal plane



10 sections Multiwire PPAC

S.Beghini et al. LNL annual Report 2000 pg.163

10 x 4 sections Ionization Chamber



Position sensitive MCP

G.Montagnoli et al. LNL annual Report 2000 pg.165