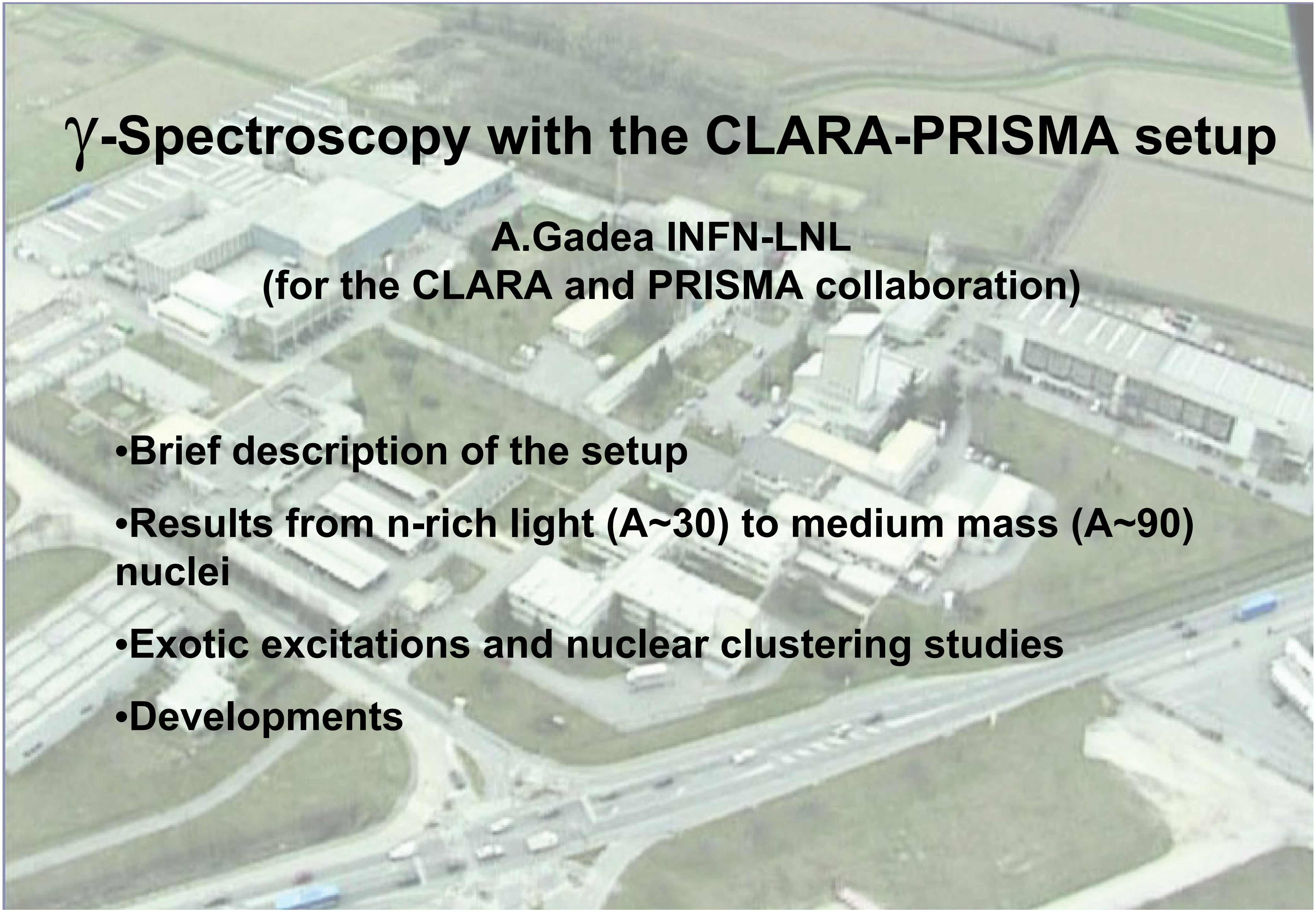
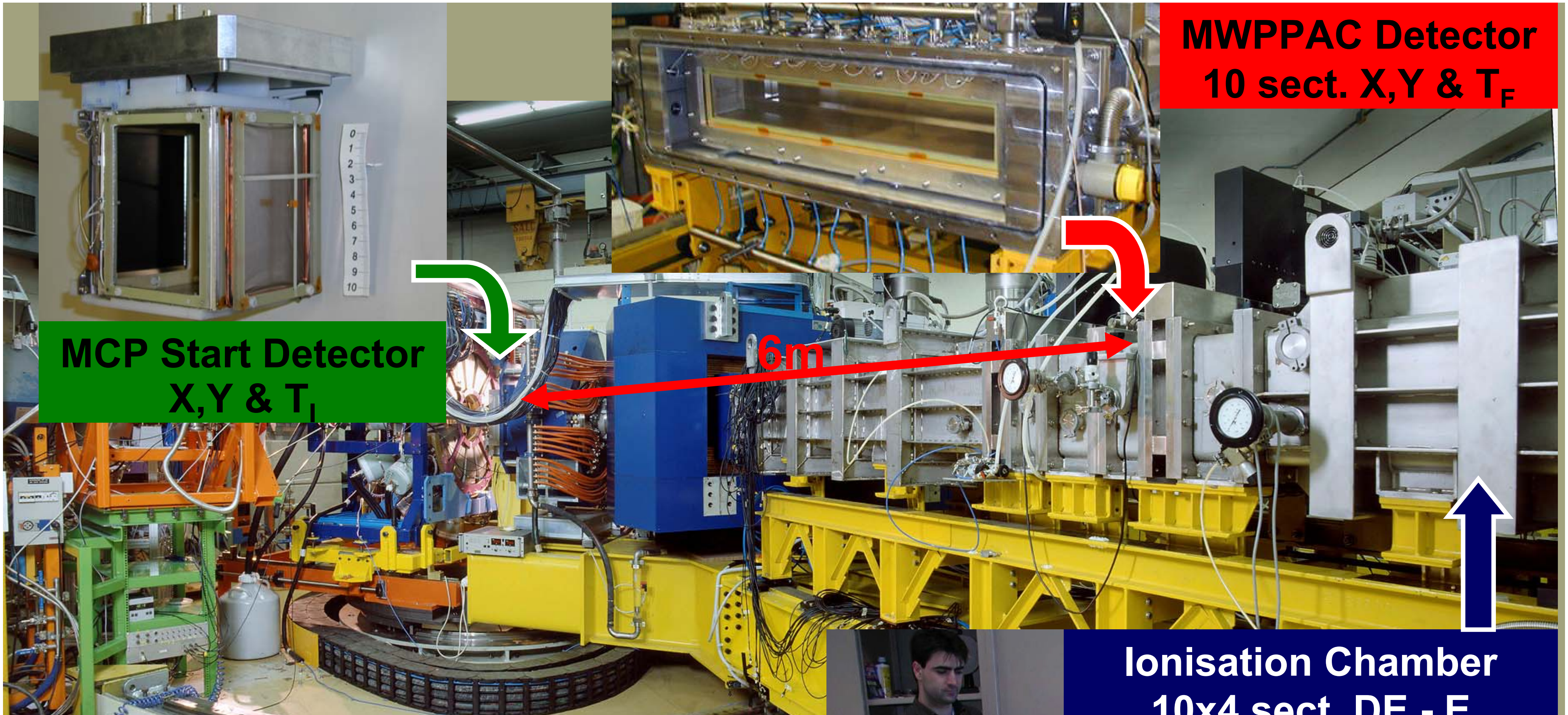


γ-Spectroscopy with the CLARA-PRISMA setup

A.Gadea INFN-LNL
(for the CLARA and PRISMA collaboration)

- **Brief description of the setup**
- **Results from n-rich light (A~30) to medium mass (A~90) nuclei**
- **Exotic excitations and nuclear clustering studies**
- **Developments**

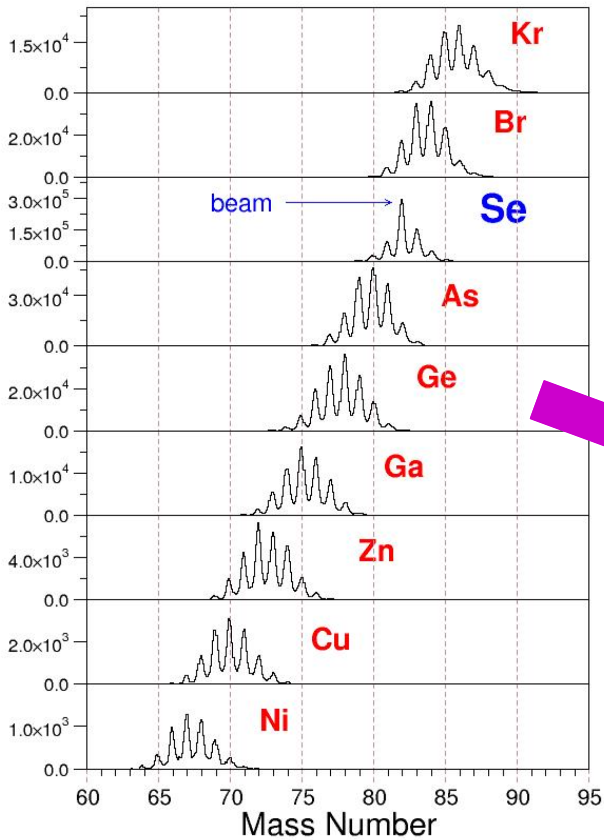


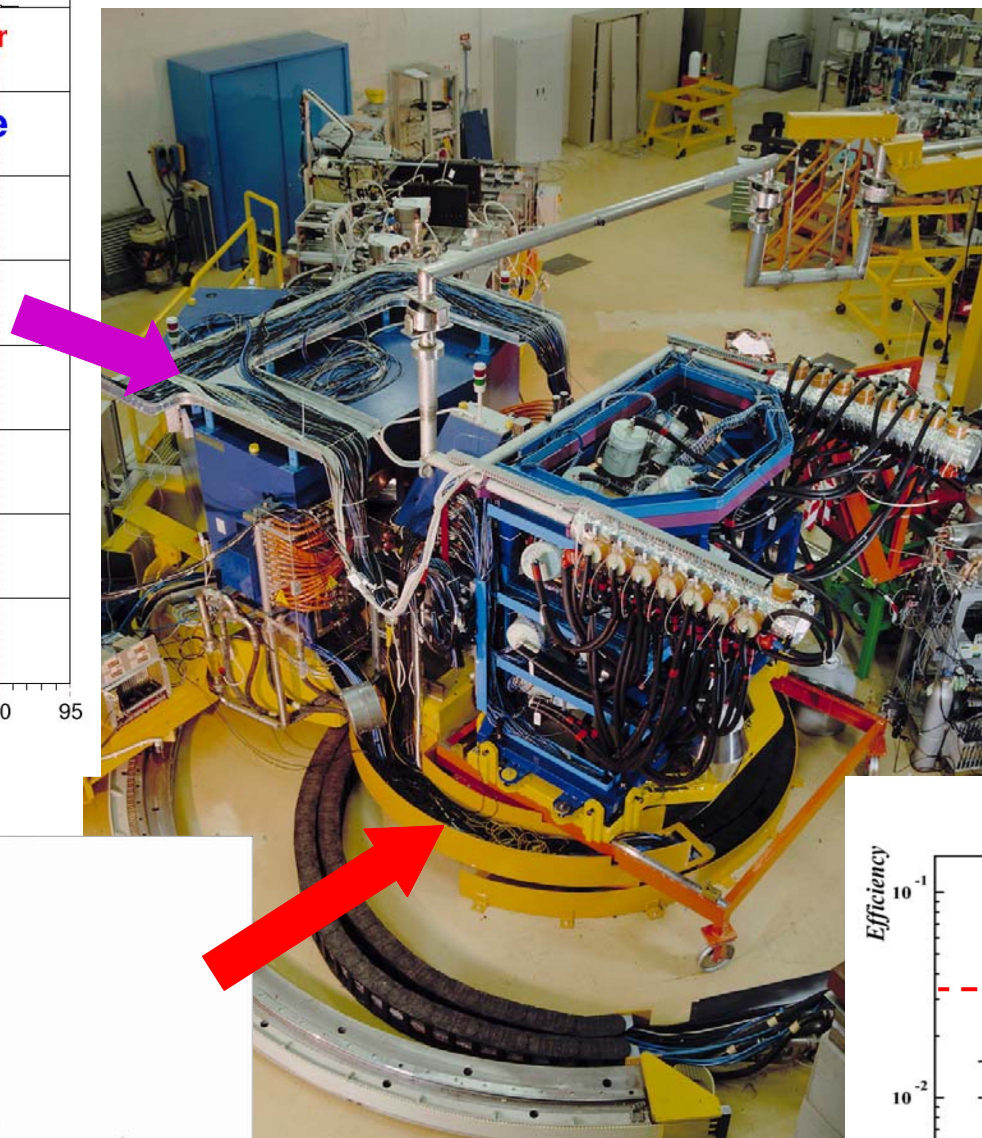
PRISMA: Large acceptance tracking Magnetic Spectrometer Q-D

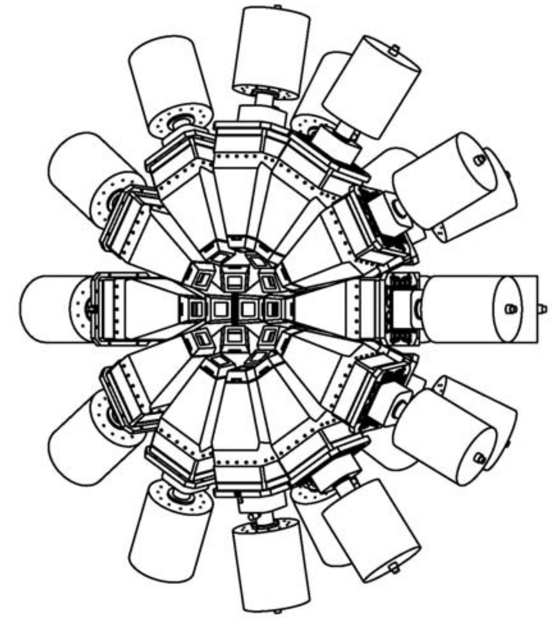
$\Omega = 80$ msr
$\Delta Z/Z \approx 1/60$ (Measured)
$\Delta A/A \approx 1/190$ (Measured) TOF
Energy acceptance ±20%
$B\rho = 1.2$ T.m

CLARA-PRISMA setup

A & Z identification







25 Euroball Clover detectors (from the EU GammaPool)

for Eγ= 1.3MeV

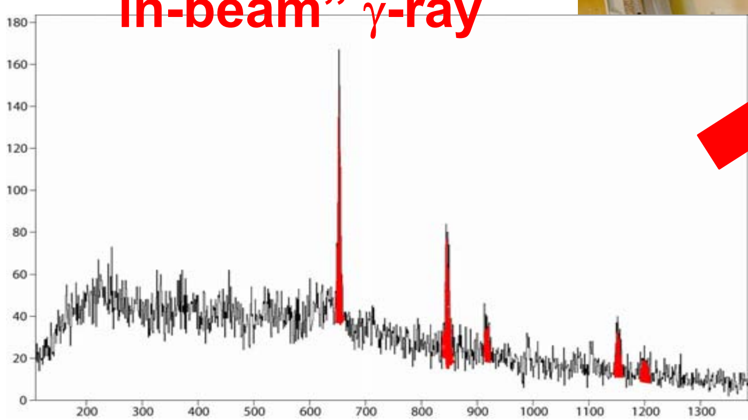
Efficiency ~ 3 %

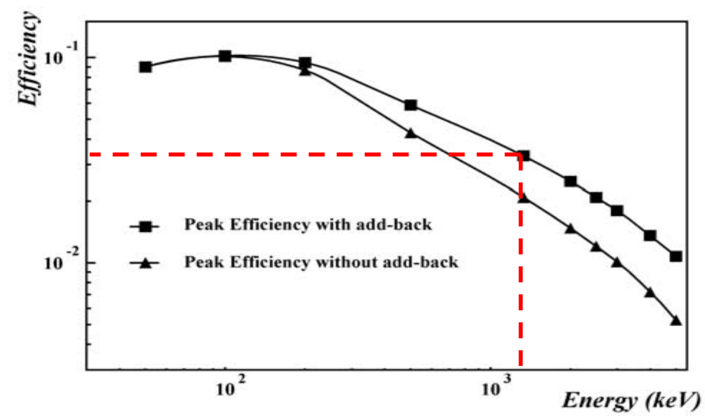
Peak/Total ~ 45 %

FWHM < 10 keV

(at v/c = 10 %)

"in-beam" γ-ray



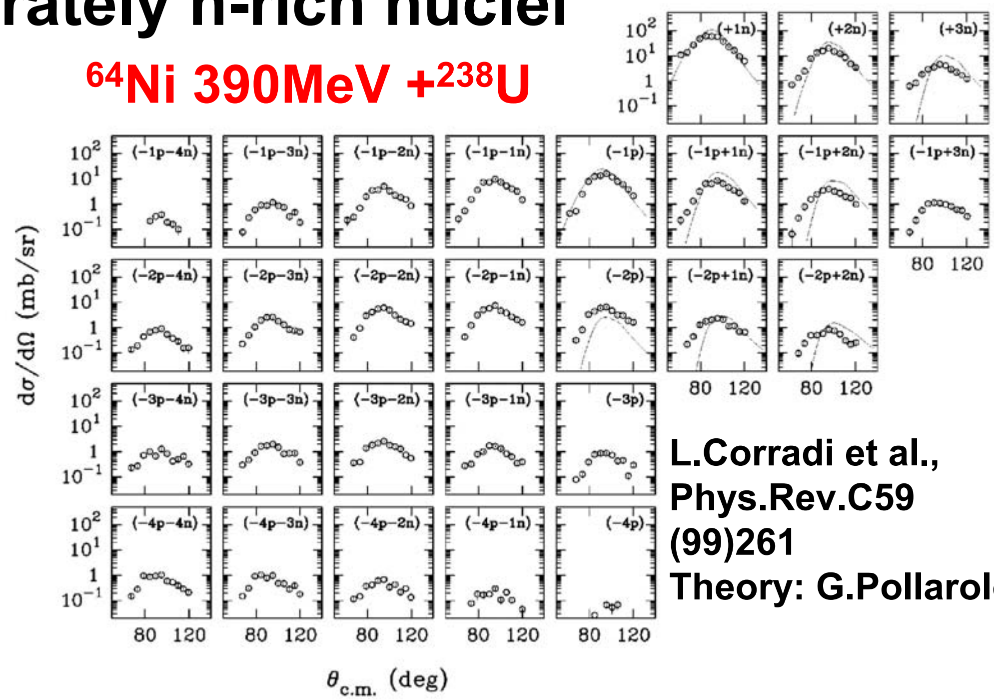


Multinucleon-Transfer and Deep Inelastic reactions as a tool to study moderately n-rich nuclei

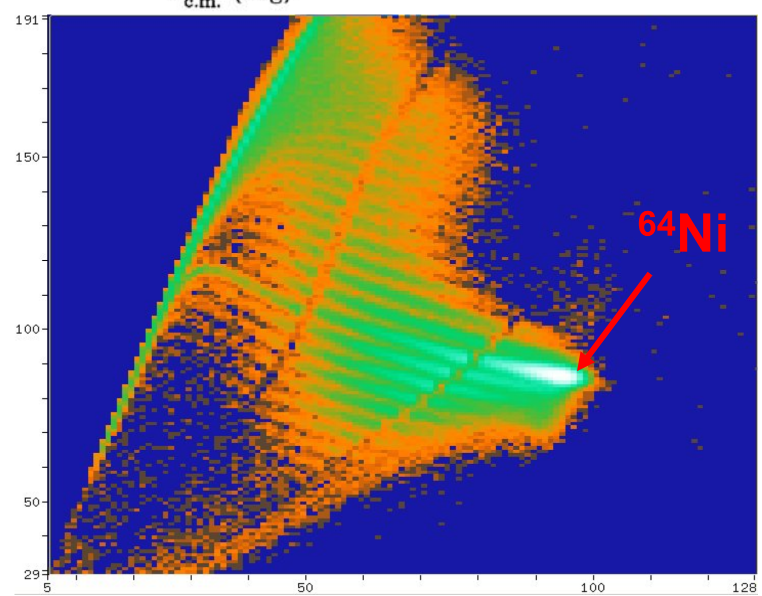
- •Shell evolution at N=20 and N=50
- •Collectivity in n-rich A~60 region (Cr and Fe isotopes)
- •Pairing vibration states populated with QE transfer (S.Szilner contribution)

- •Shell model in the 48Ca region
- •Quenching of the N=82 shell gap
- •Collectivity and critical-point symmetries in n-rich nuclei

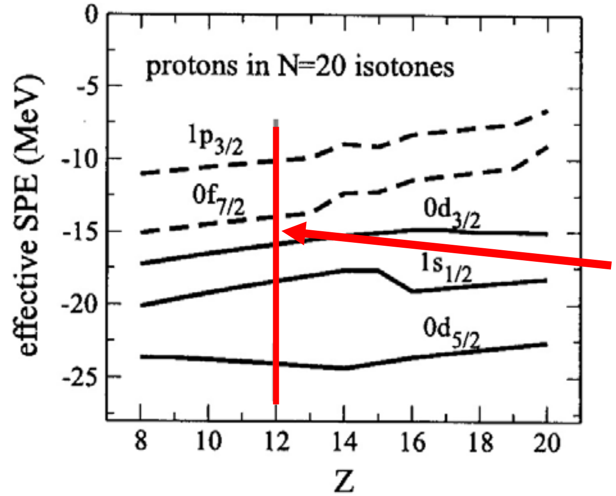
^{64}Ni 390MeV +^{238}U



L.Corradi et al., Phys.Rev.C59 (99)261
Theory: G.Pollarolo



N=20 and N=50 Shell Gaps



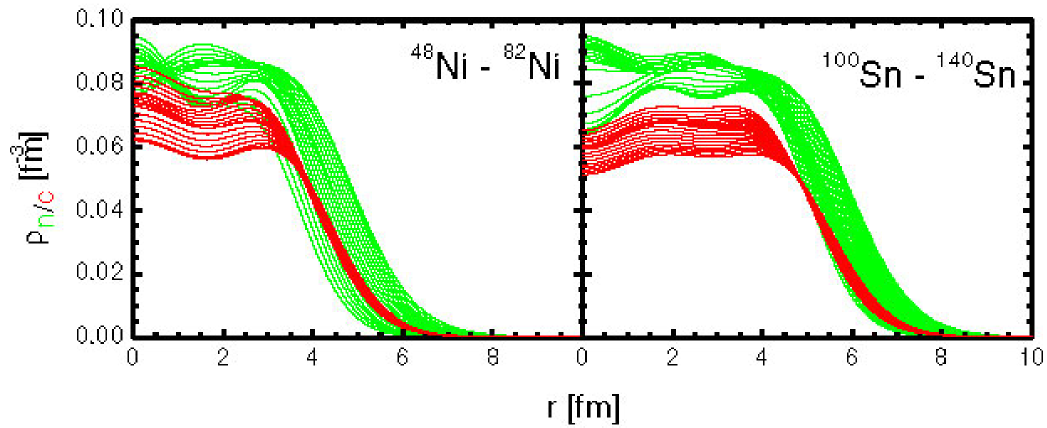
T. Otsuka et al.
/ Nuclear Physics A682 (2001) 155c–160c

N=20: ^{32}Mg

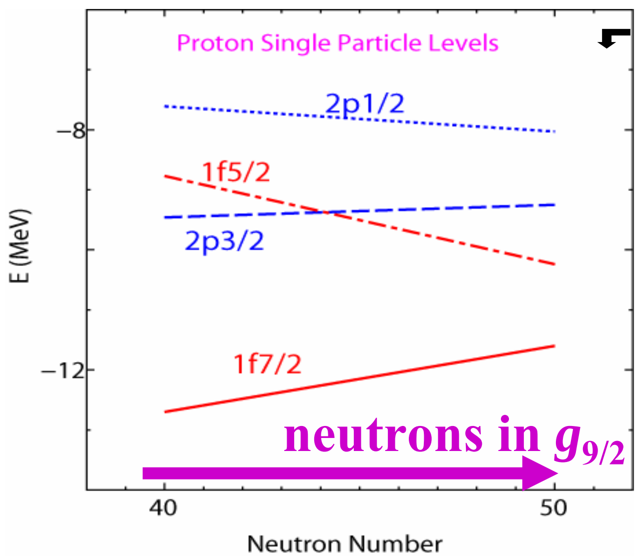
Island of inversion (due to residual interaction)

B(E2): GANIL, RIKEN, REX-ISOLDE, NSCL

weakening of the spin-orbit force?



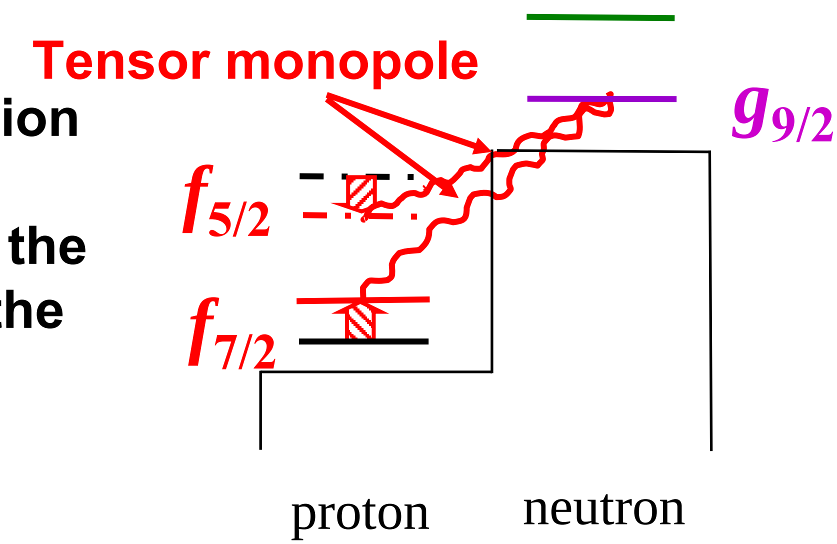
F.Hofmann, C.M.Keil, H.Lenske, Phys.Rev.C64(01)034314.



GXPF1 interaction

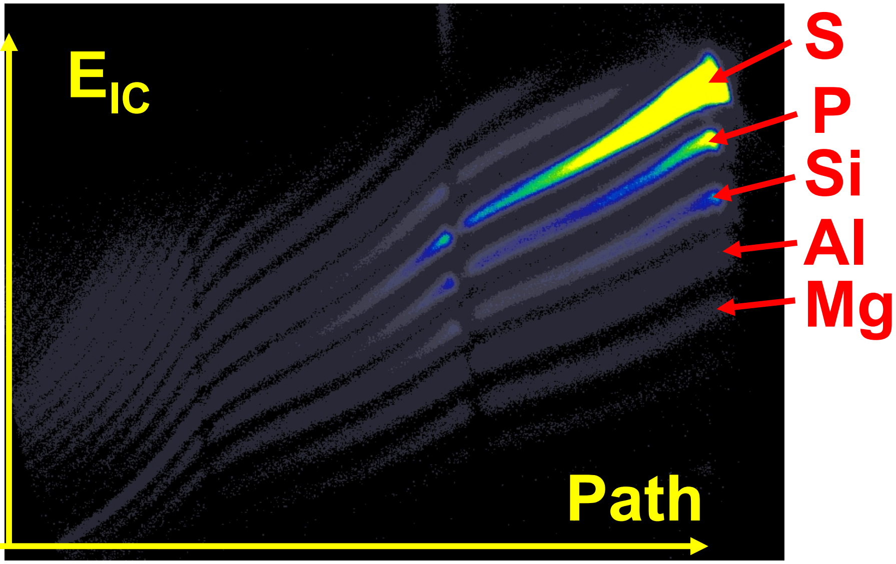
T. Otsuka et al. Zakopane 2004

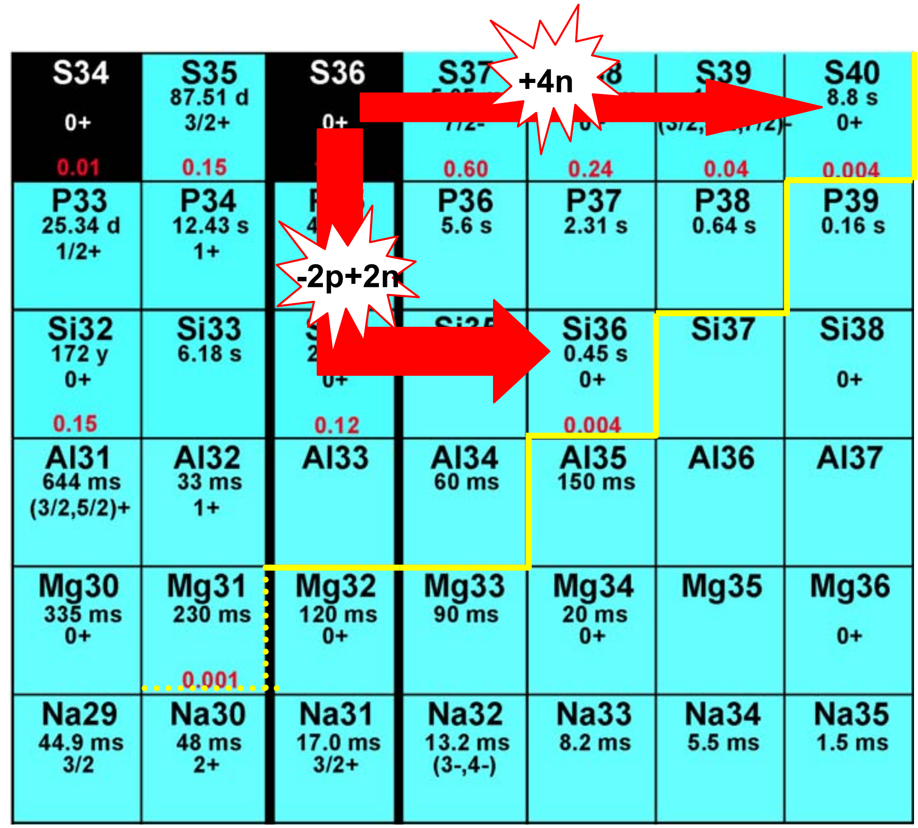
Tensor interaction may be also responsible for the weakening of the N=50 gap

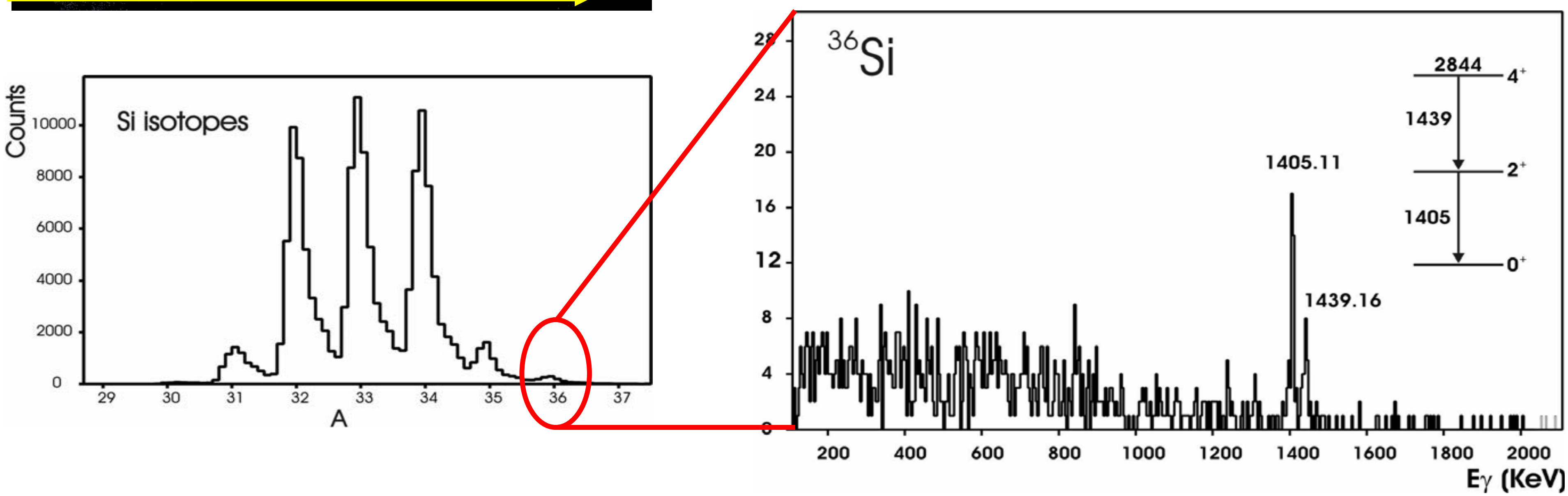


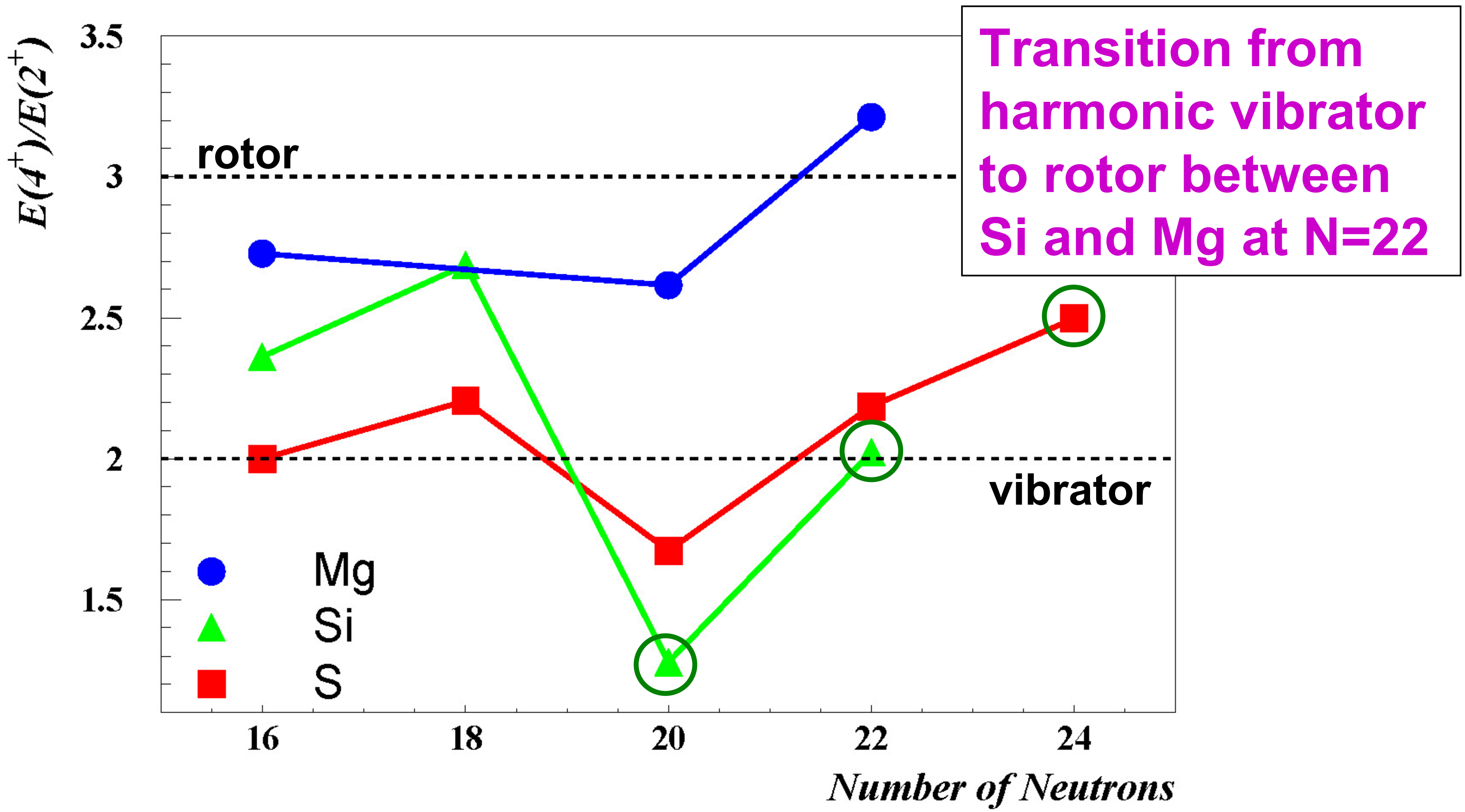
^{36}S 230MeV + ^{208}Pb $\theta_g=56^o$

M.Stanoiu, F.Azaiez IPN Orsay
X.Liang Manchester







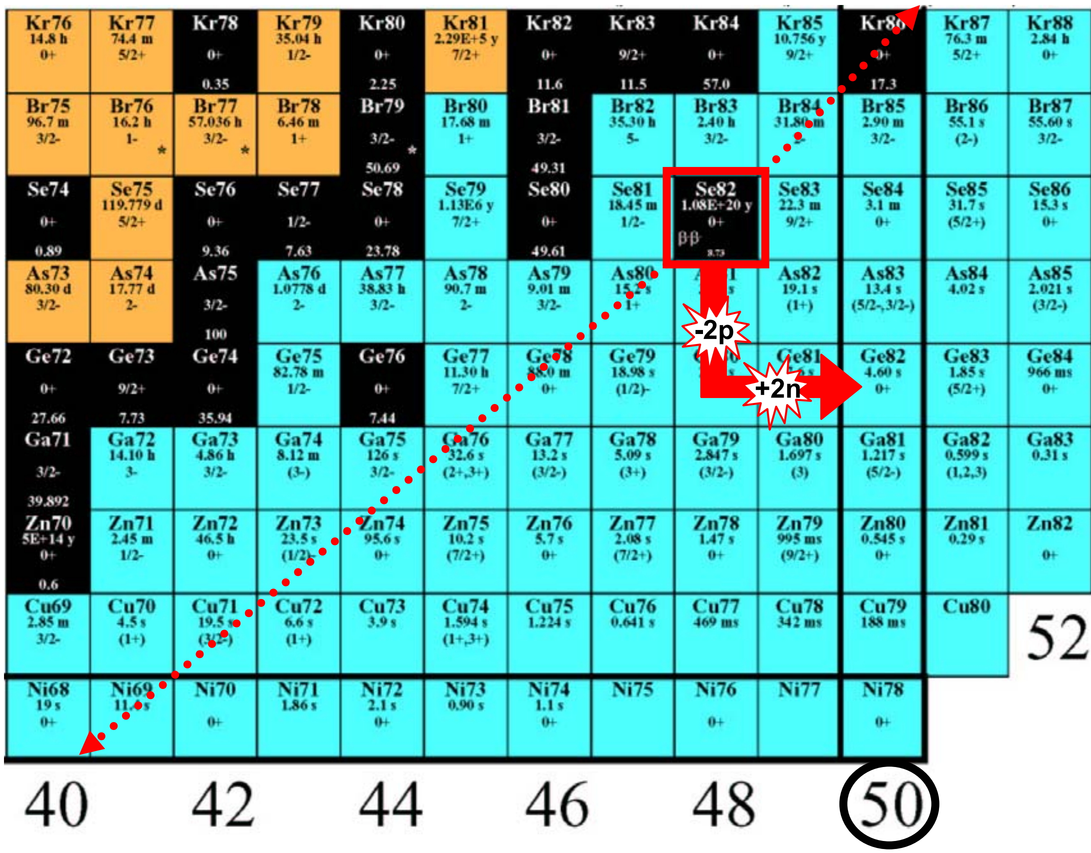


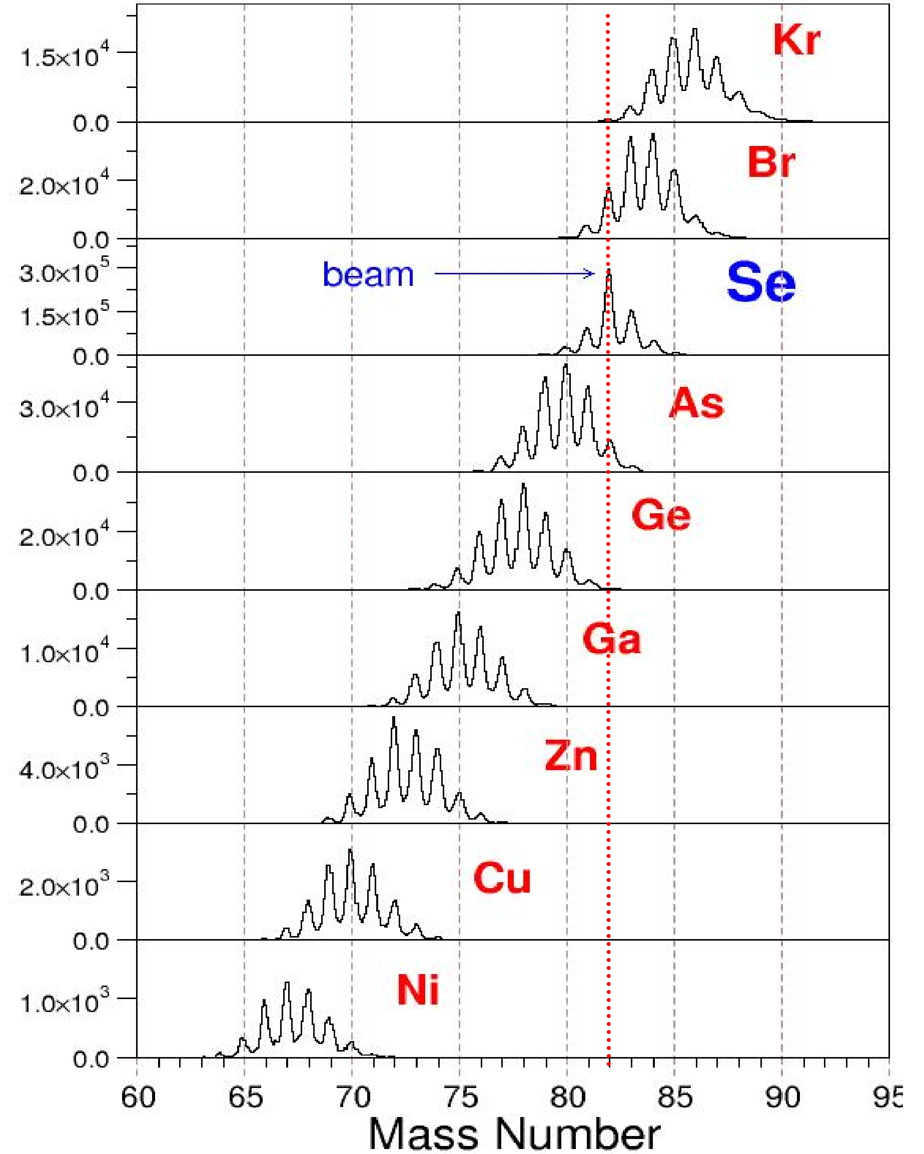
The spacing between the 2^+ and 4^+ can suggest, to good extent the shapes of the N~20 nuclei

M.Stanoiu, F.Azaiez (IPN Orsay) X.Liang (Manchester)

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

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



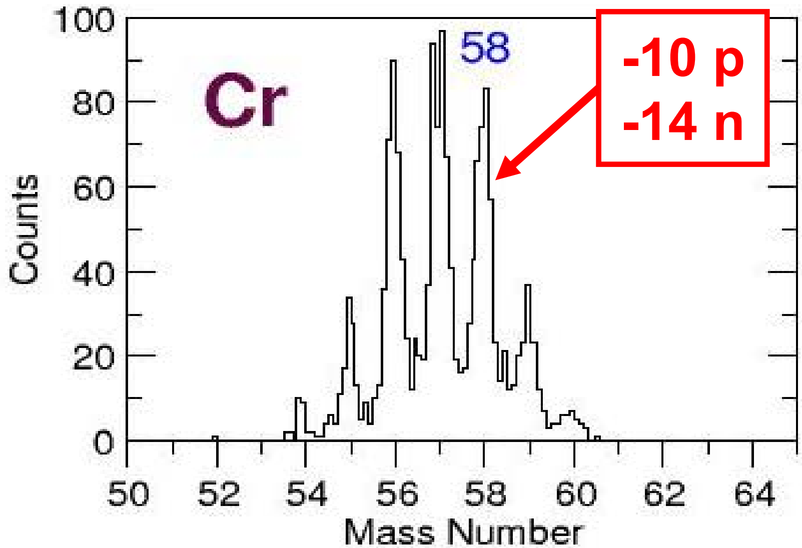


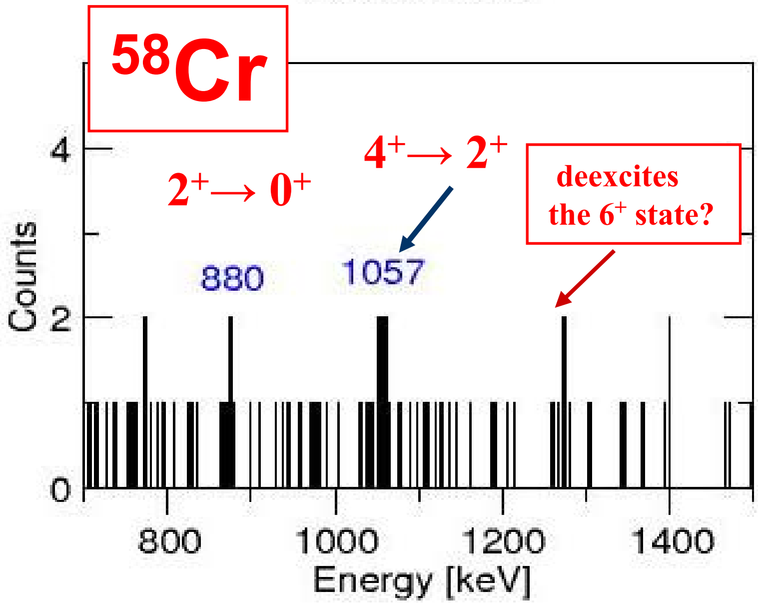
Evolution of the N=50 shell: Searching for the shell gap quenching (onset of deformation as in N=20 Z~12)

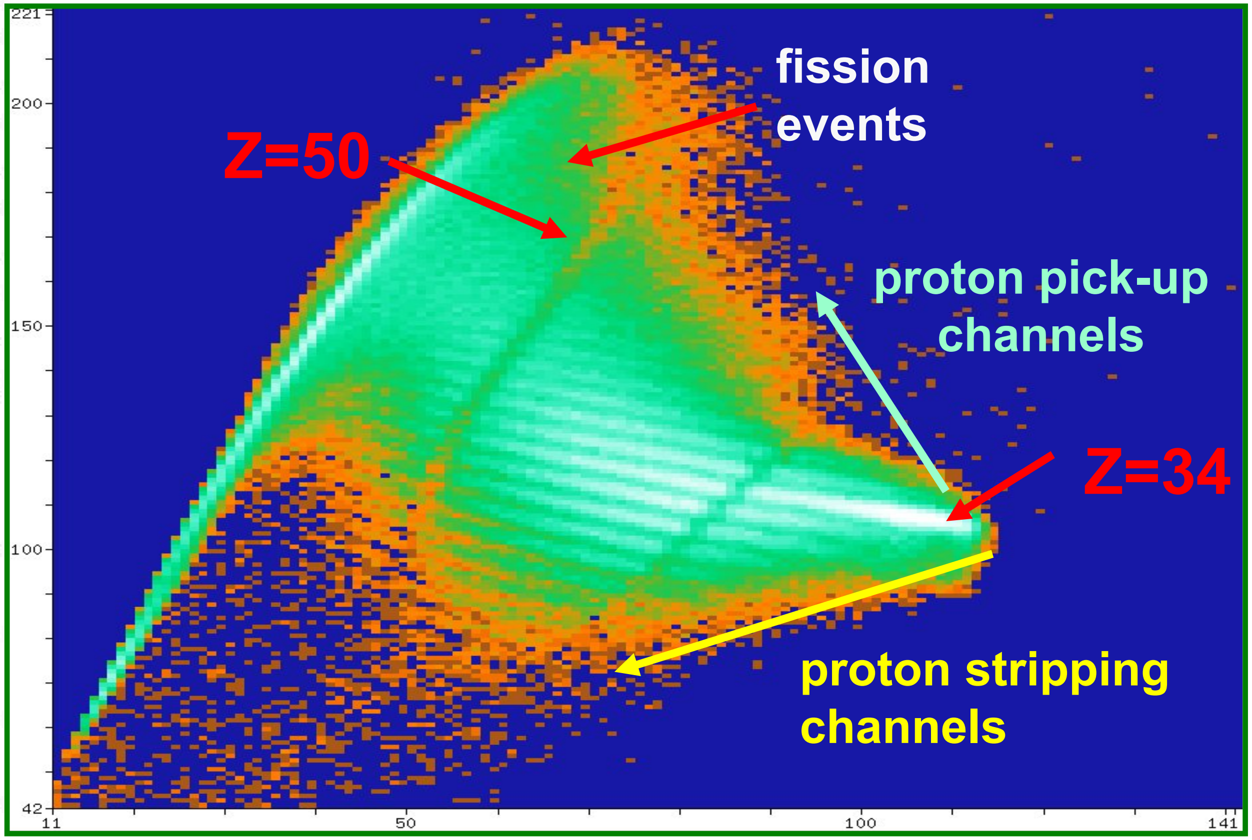
Z=32: INM, R.C.Nayak et al. PRC 60 (1999) 064305
Z=24-26: RMF, L.S.Geng et al. nucl-th/0402083

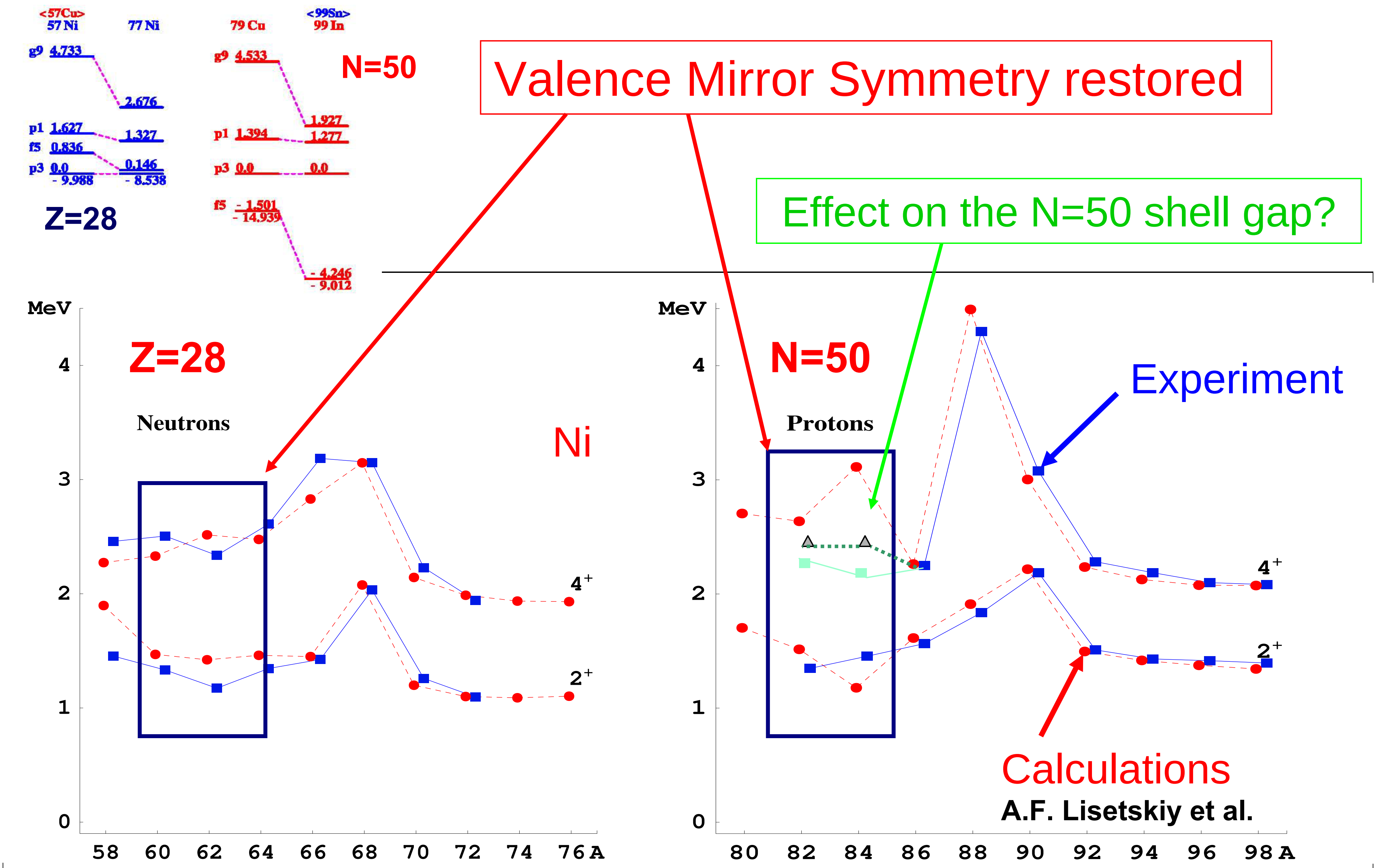
24 nucleons removed from projectile

$^{82}Se + ^{238}U$ E=505 MeV
θ_G=64° IC E-ΔE Matrix



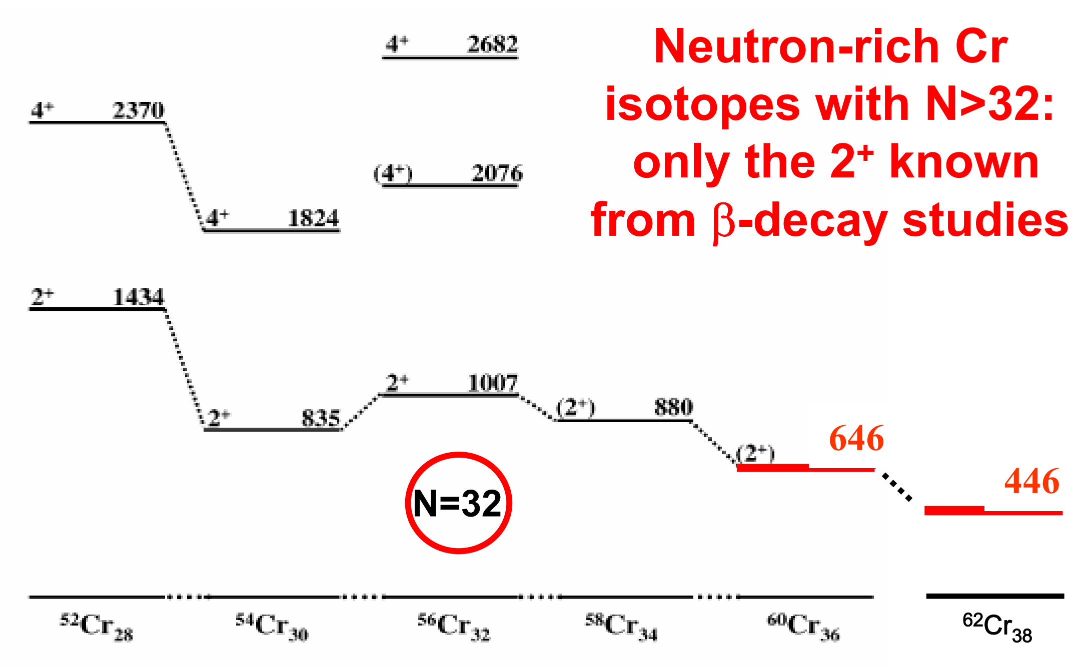




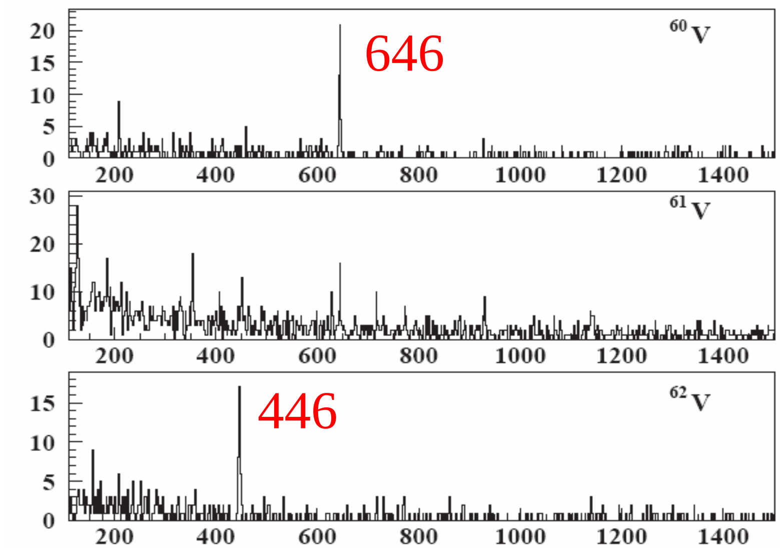


A.F. Lisetskiy, B.A.Brown, M. Horoy, H. Grawe nucl-th0402082 (G-Matrix based on Bonn-C)

Collectivity in n-rich A~60 nuclei



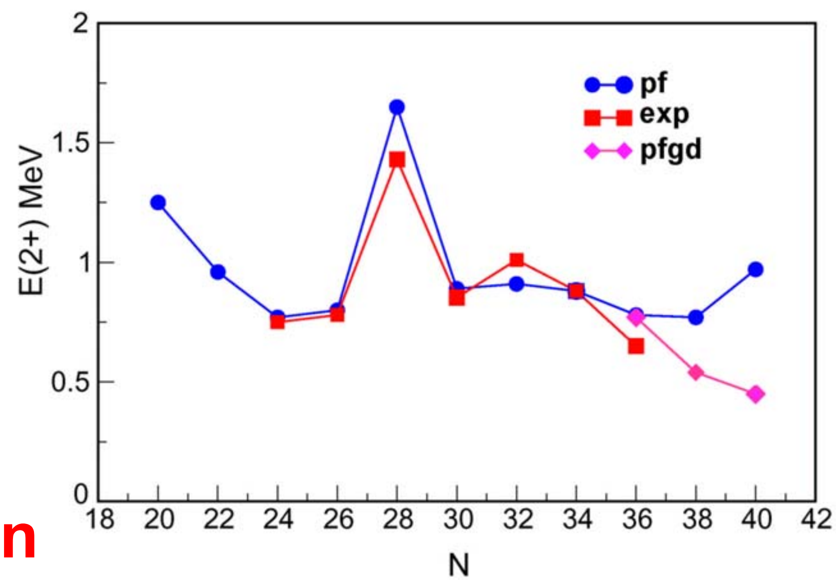
Neutron-rich Cr isotopes with N>32: only the 2^+ known from β-decay studies



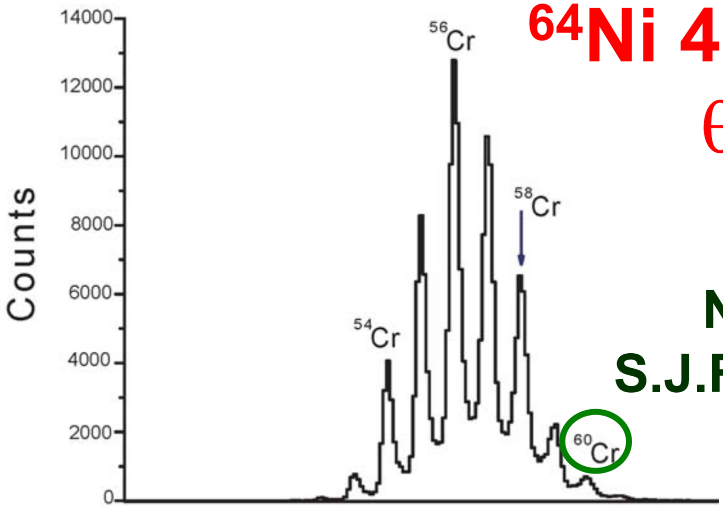
GANIL: O.Sorlin et al., Eur. Phys. J. A 16 (2003) 55
MSU: P.F.Mantica et al., Phys. Rev. C 67 (2003) 014311

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

LSSM Calculations



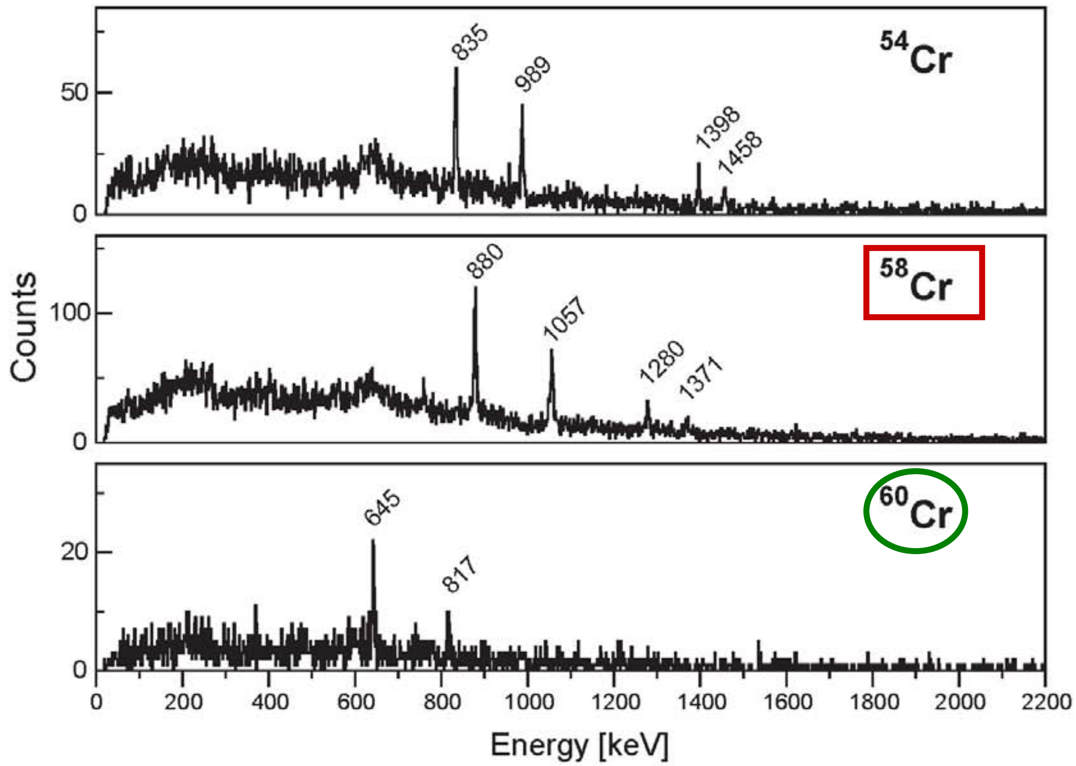
N=32 Shell closure: B.Fornal
Onset of deformation N>32: S.Freeman

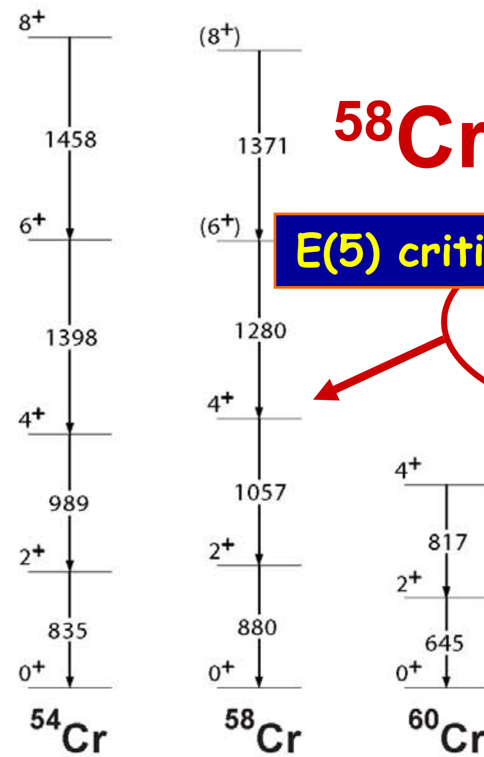


^{64}Ni 400MeV + ^{238}U

$\theta_{GR} = 64^o$

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





^{58}Cr

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

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

E(5) critical point symmetry?

vibrator to γ-unstable rotor

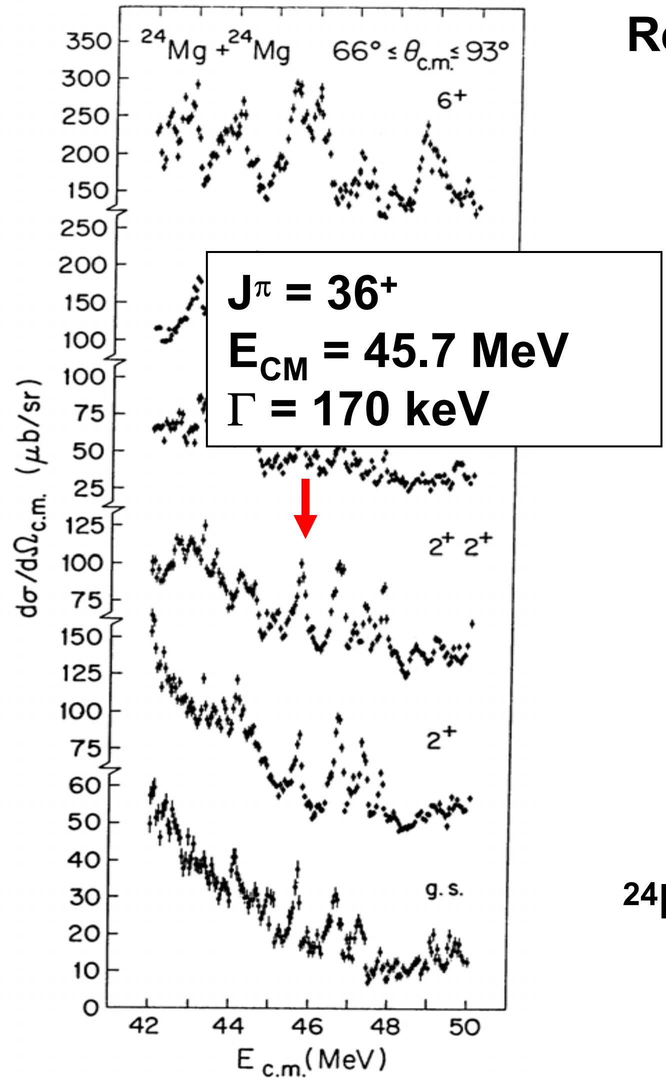
F.Iachello Phys.Rev.Lett. 85 (2000)3580

Lifetime masurements

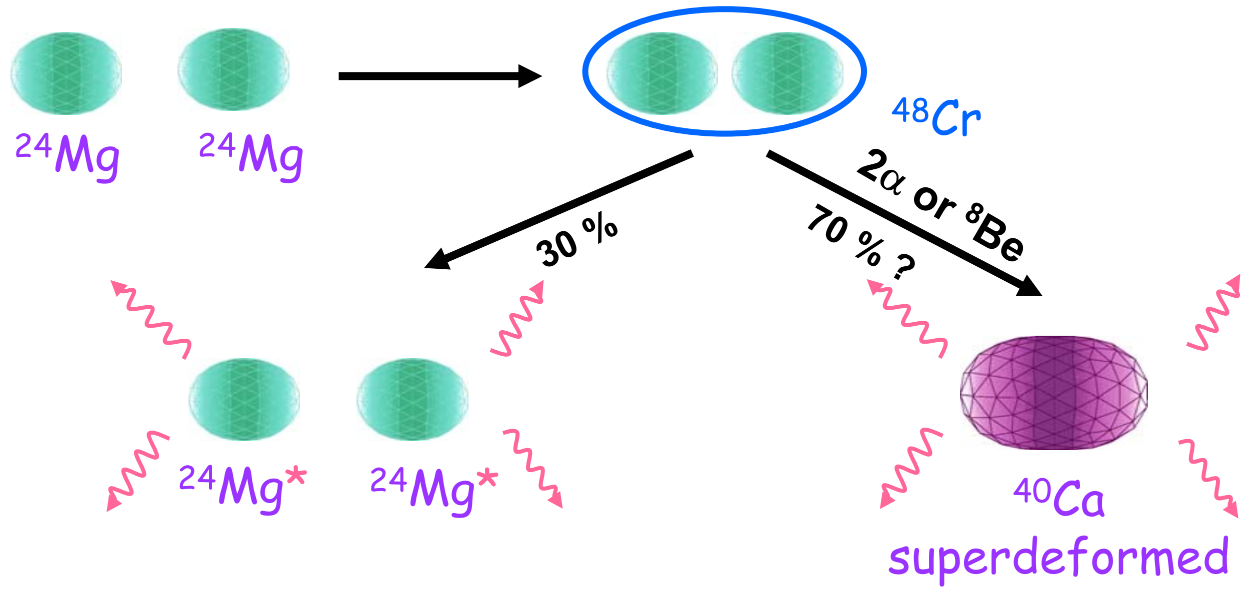
From our data the 1057 keV transition is the $4^+ \rightarrow 2^+$ member of the yrast cascade. Therefore ^{58}Vg.s. is probably 3^+, also predicted at low energies.

Experimental Study of Nuclear Molecular States

Inelastic decay of the $J^{\pi} = 36^{+}$ resonance in the 24Mg + 24Mg reaction



Resonance as molecular state in the composite system

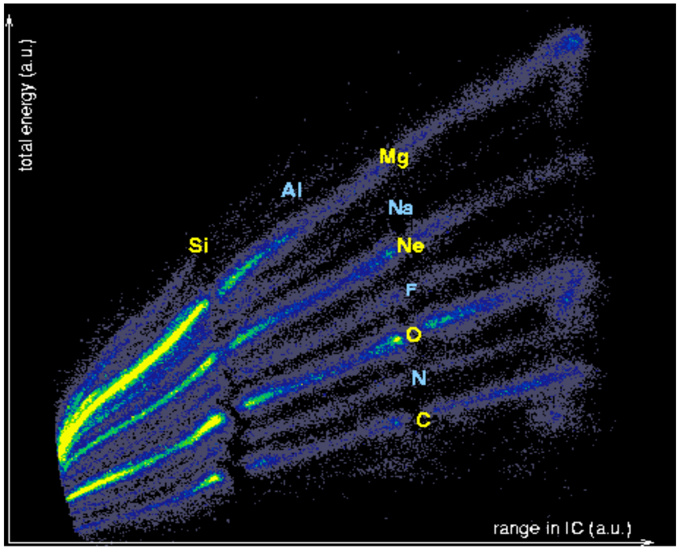


CLARA-PRISMA
(θ_g= 43°± 5°)

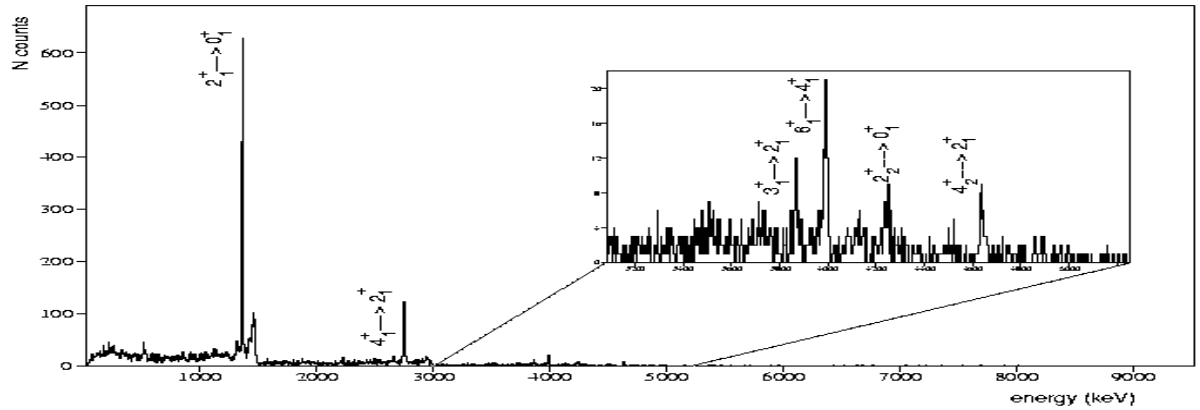
GASP+EUCLIDES

^{24}Mg+^{24}Mg E_L = 91.72 MeV (ON) and E_L = 92.62 MeV (OFF) resonance measurements to study the decay into the inelastic channels

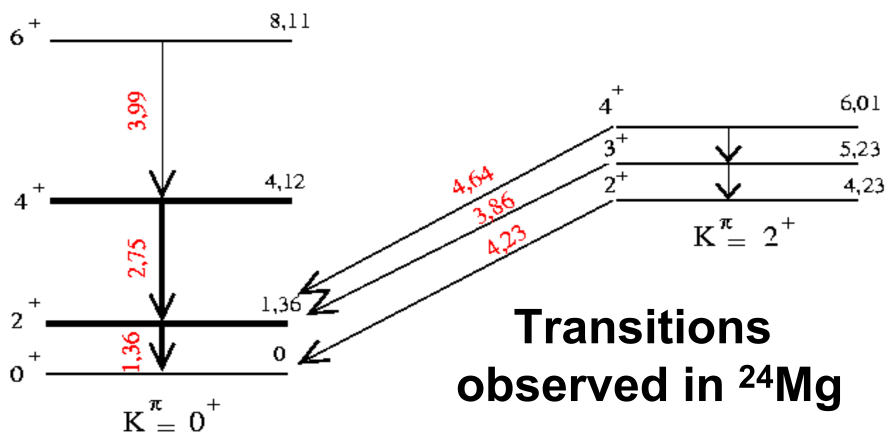
M.-D. Salsac, F. Haas, S. Courtin (IReS, Strasbourg) et al.



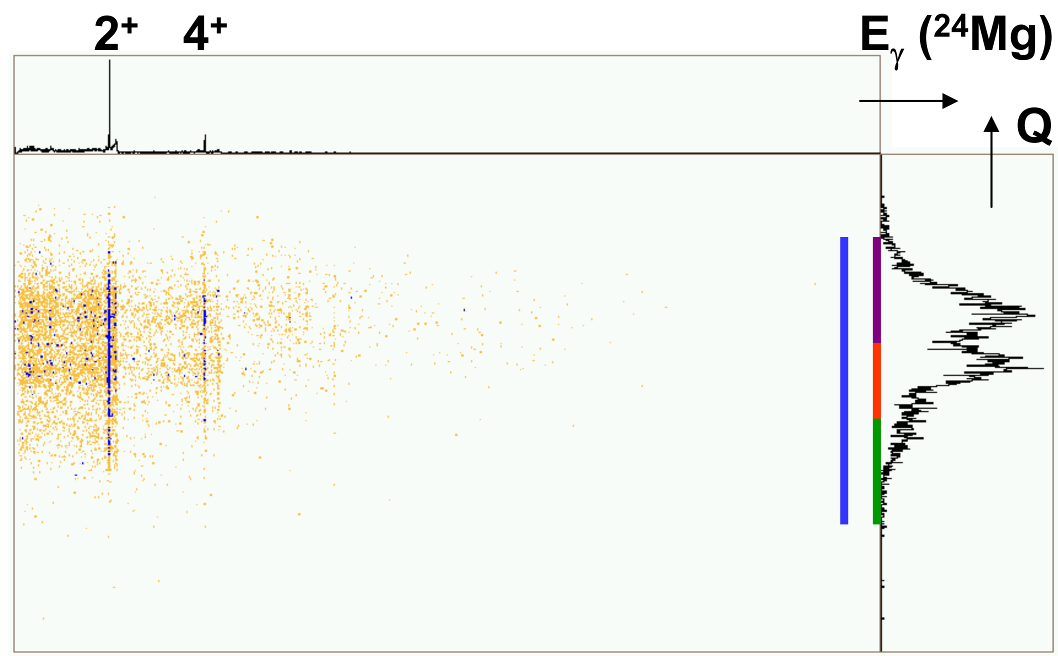
Z selection



^{24}Mg total gamma ray spectrum



Transitions observed in ^{24}Mg



E_{γ} versus Q

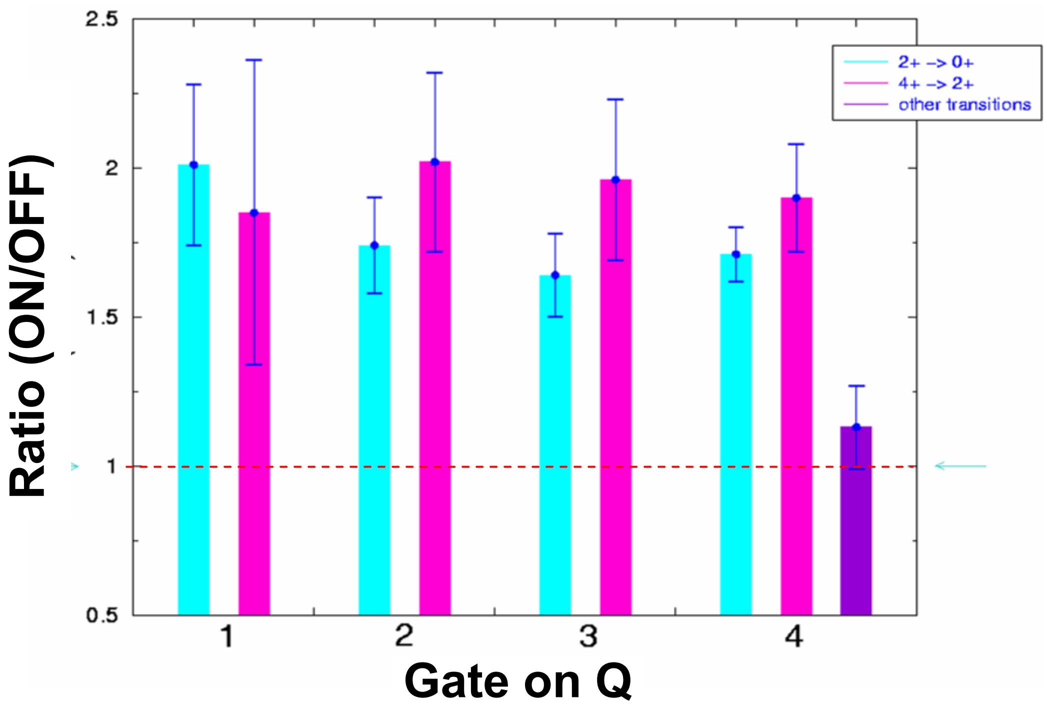
Gate 1 E_{ex} = 1 – 4.6 MeV

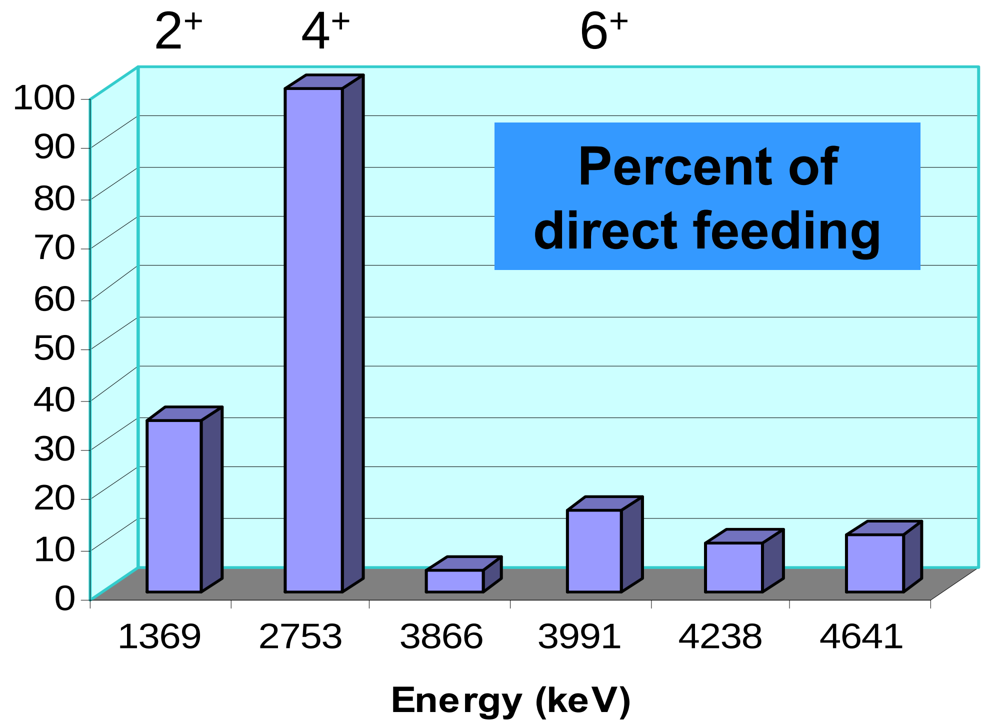
Gate 2 E_{ex} = 4.7 – 7.3 MeV

Gate 3 E_{ex} = 7.3 – 11 MeV

Gate 4 E_{ex} = 1 – 11 MeV

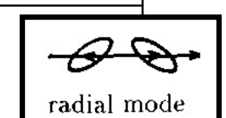
Direct feeding of the ^{24}Mg states:





- Resonance is seen in the 2+, 4+ g.s band members and also in the 0+ g.s (from other measurements) . In the inelastic channels, the ^{24}Mg + ^{24}Mg resonance flux is essentially observed in the 2+ and 4+ states of the ^{24}Mg g.s band.

- This is in agreement with the molecular model proposed by Abe and Uegaki *(Phys. Lett.231B (1989) 28)* to describe the ^{24}Mg + ^{24}Mg high spin resonances.

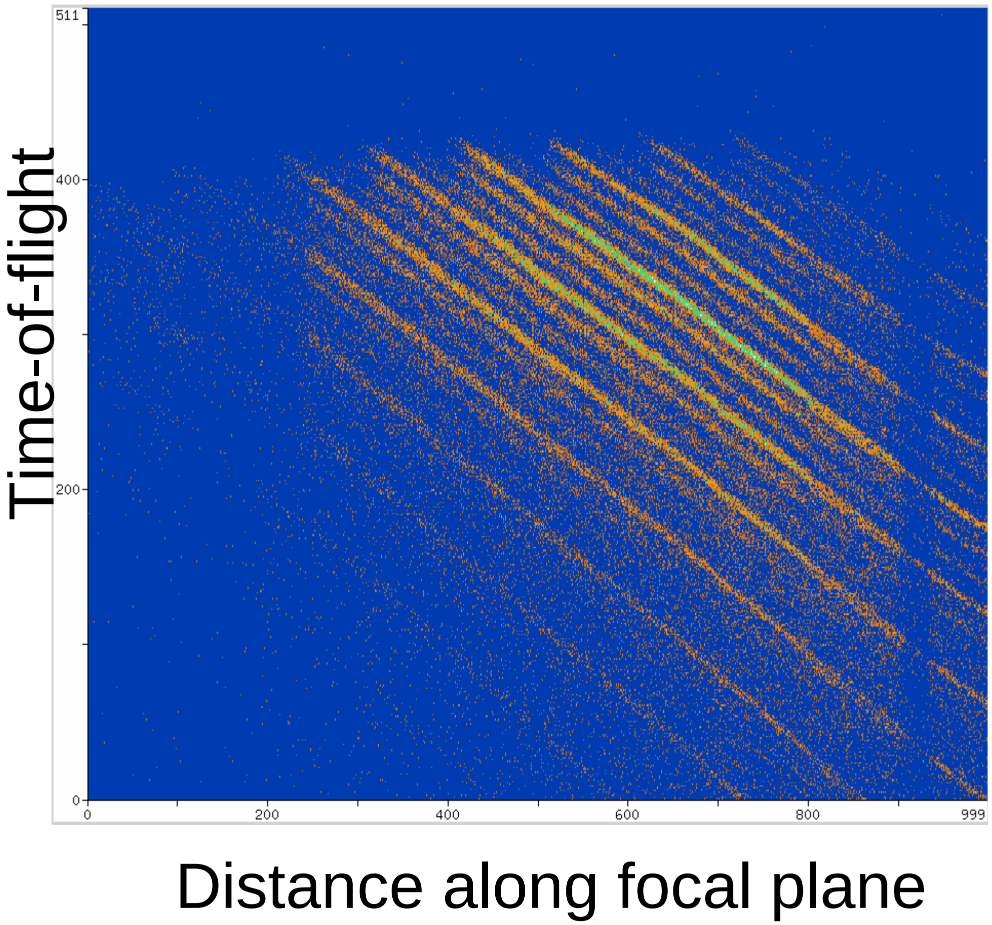


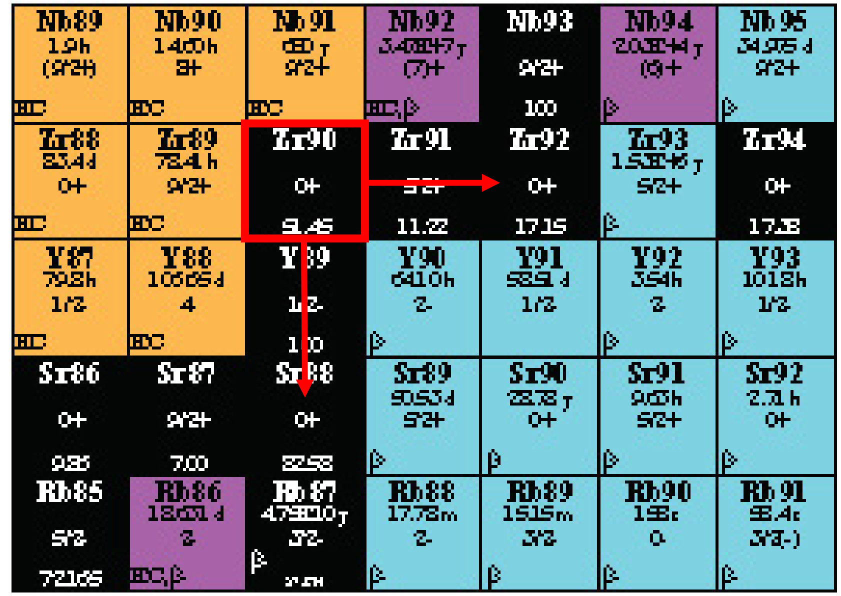
- All the direct channels absorb only ~30% of the resonance flux. CN ~70%? Experiment GASP-EUCLIDES

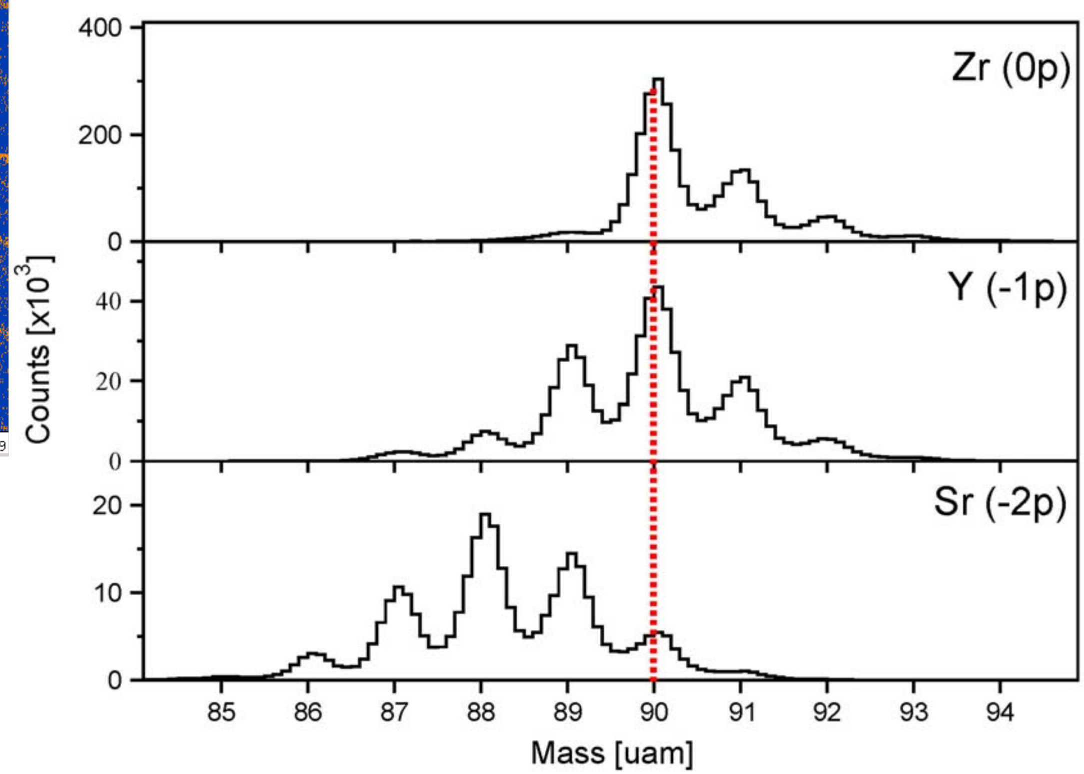
M.-D. Salsac, F. Haas, S. Courtin (IReS, Strasbourg) et al.

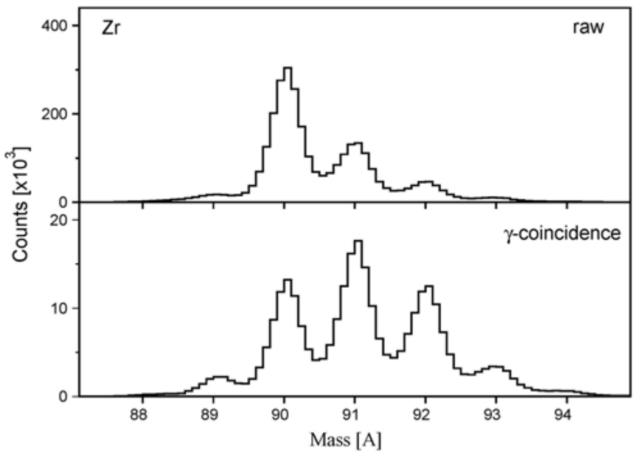
^{90}Zr 560MeV + ^{208}Pb

1 day beam time
L.Corradi, C.A.Ur, et al.



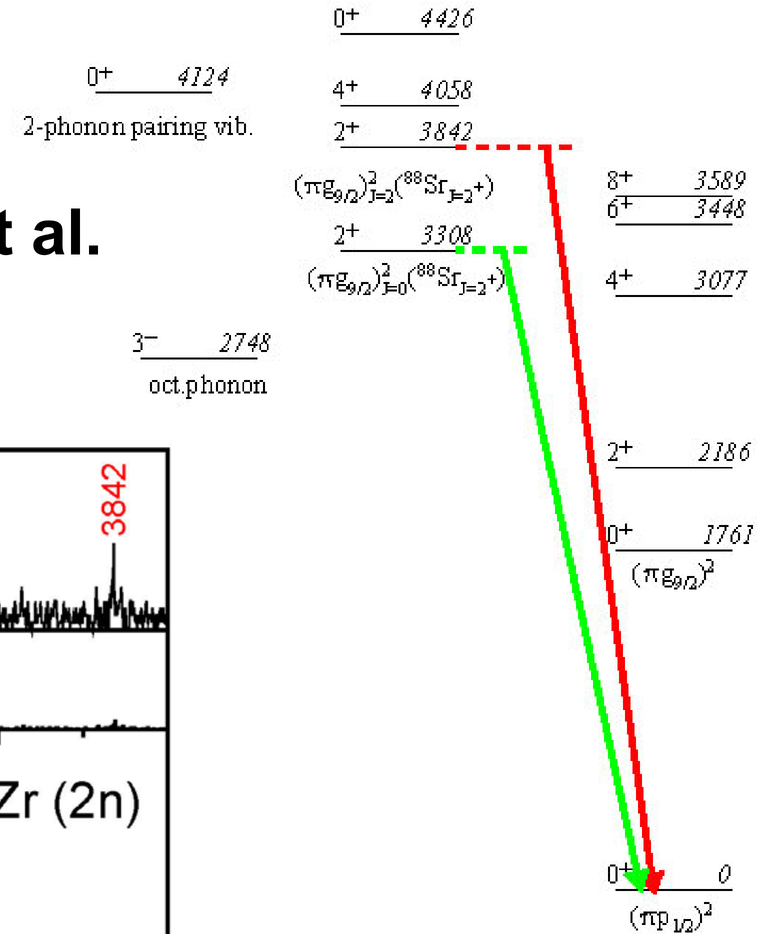


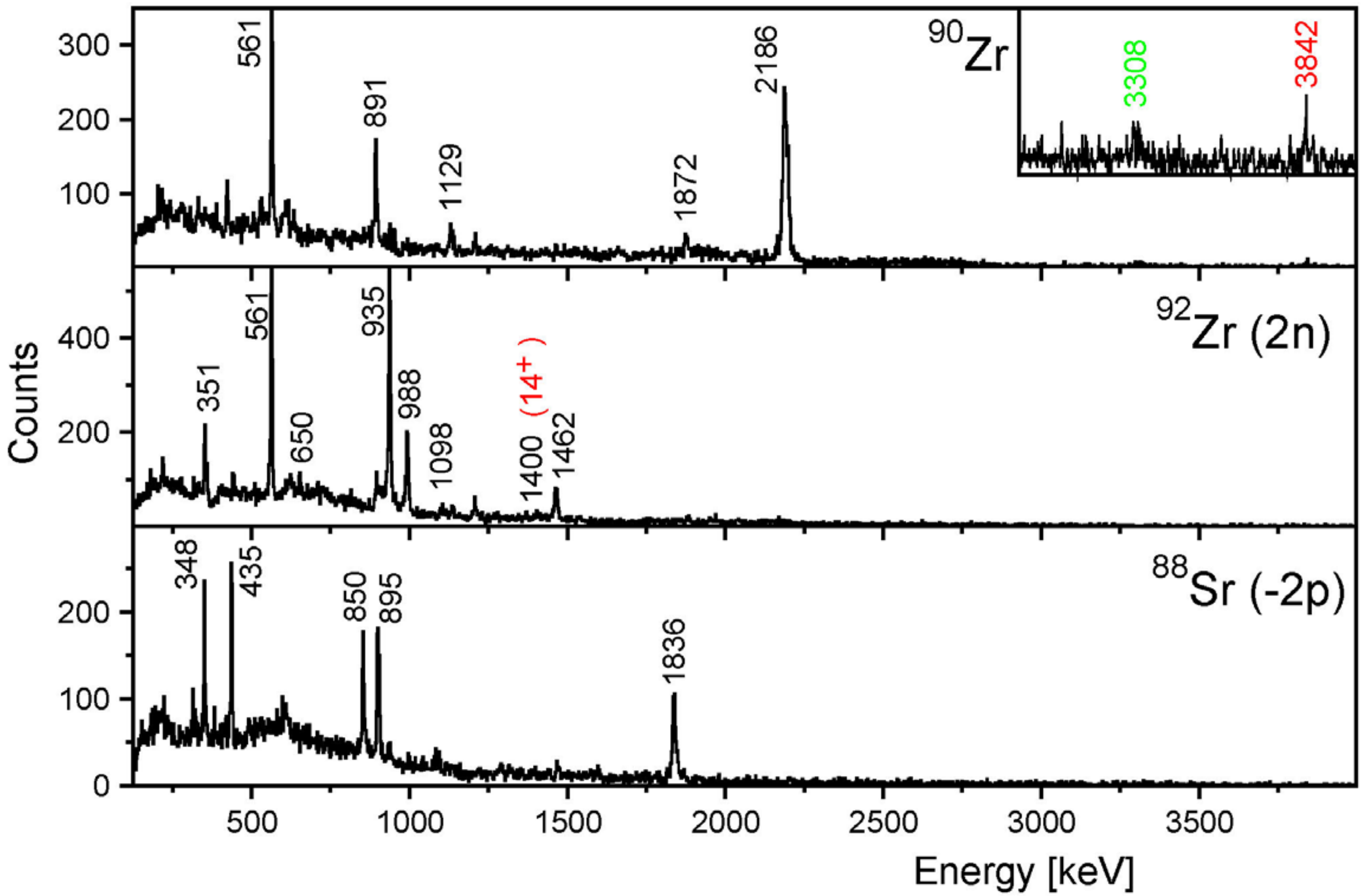




^{90}Zr 560MeV + ^{208}Pb

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

Short-term perspectives for CLARA-PRISMA:

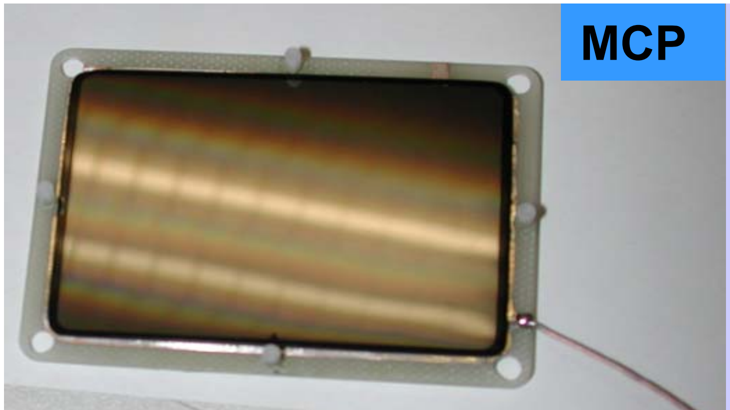
Drawback of the setup: low efficiency for $\gamma-\gamma-$PRISMA coincidences: Development of complementary ancillary devices for Doppler correction.

Measurement of $\gamma-$PRISMA coincidences (Identification) and $\gamma-\gamma-$ancillary coincidences ($\gamma-\gamma-$coincidences with Doppler correction).

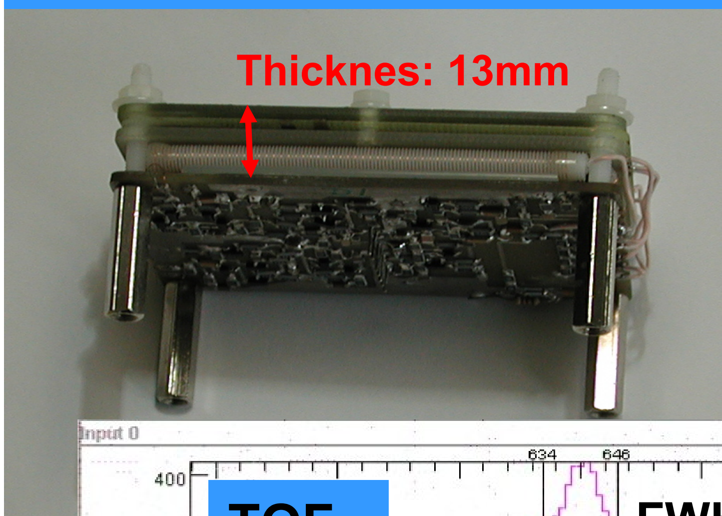
DANTE: MCP array under development in collaboration with FLNR Dubna

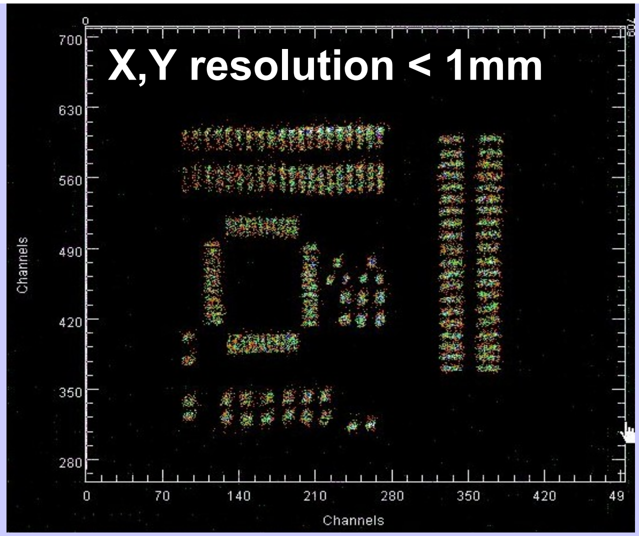
Development of the Differential Plunger RDDS technique for CLARA-PRISMA (IKP-Koeln)

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



first prototype of DANTE



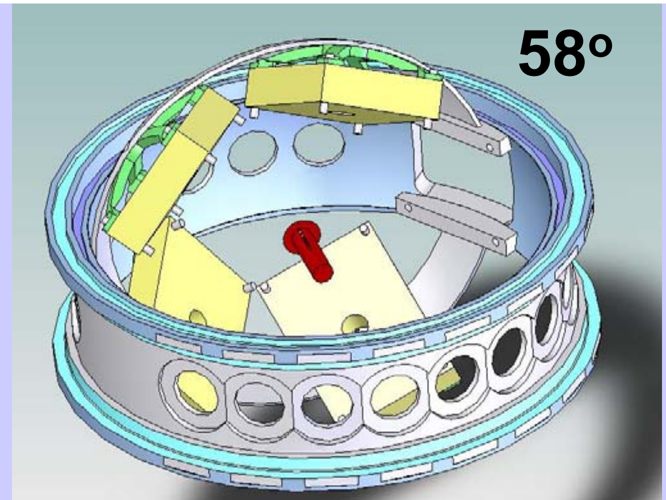


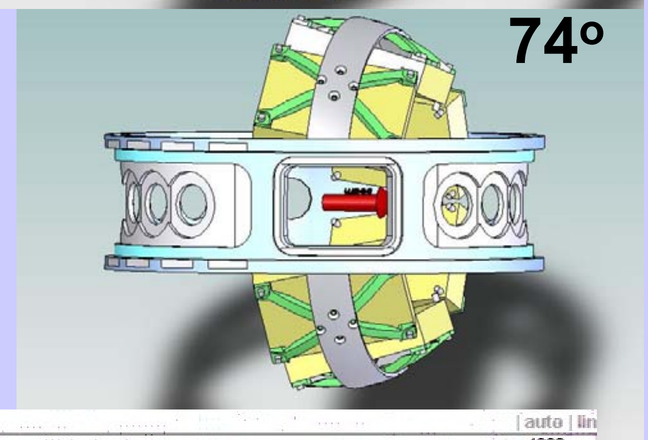
DANTE

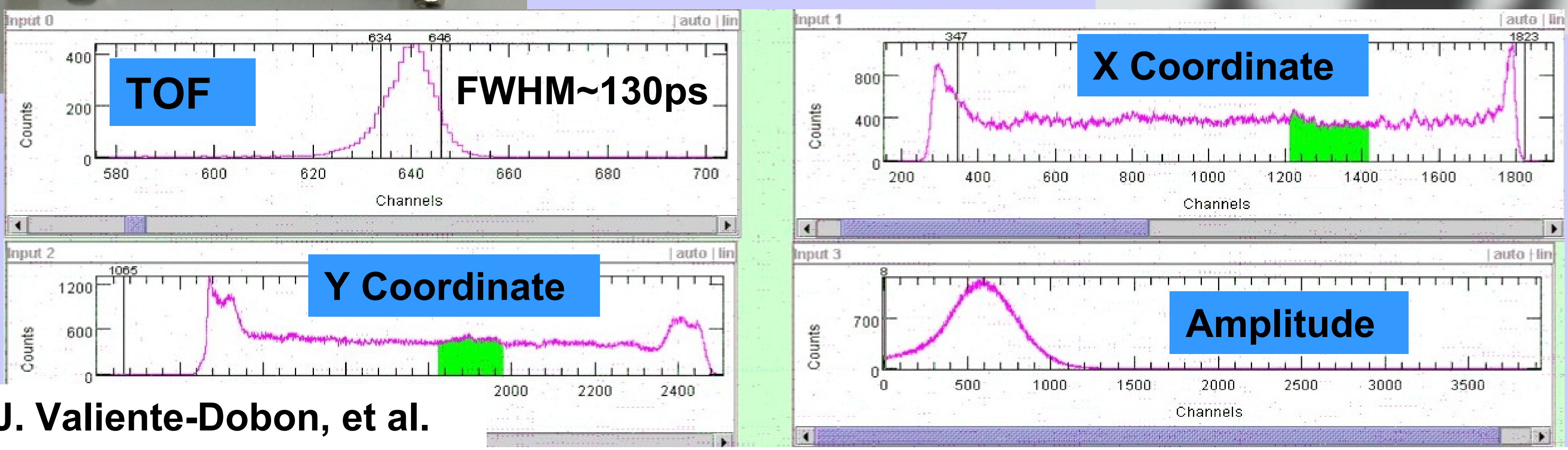
MCP Detector array

γ–PRISMA: identification

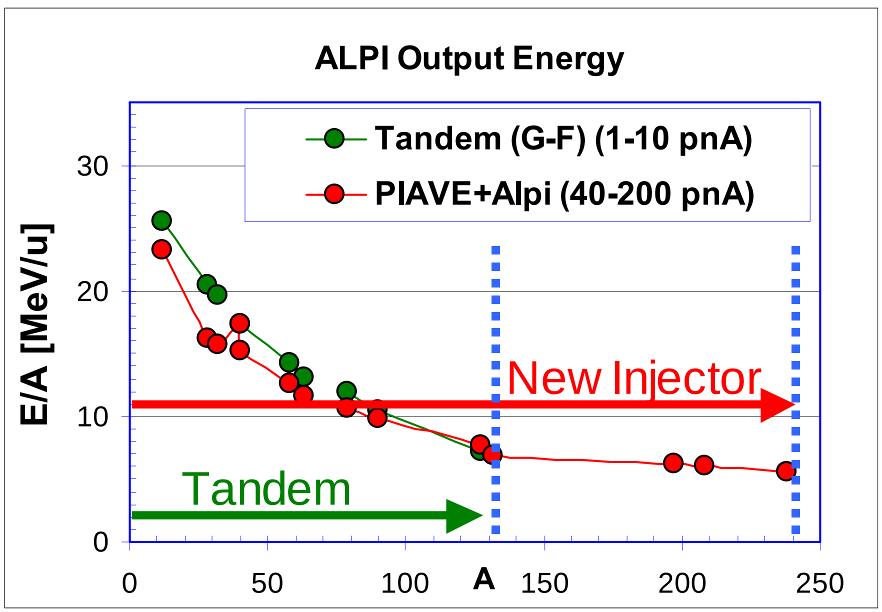
γ–γ–DANTE: coincidences







J.J. Valiente-Dobon, et al.



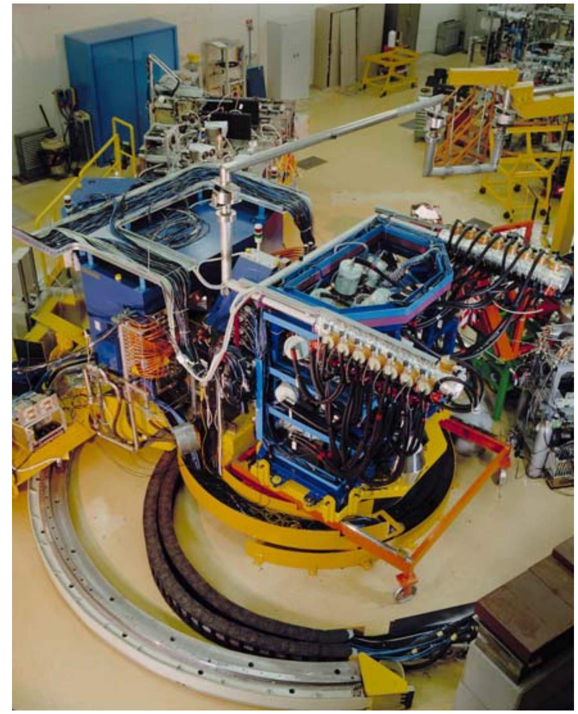
Positive ion injector ECRIS + PIAVE commissioned beginning 2005 with O and Kr beams. July 2005 PIAVE beam accelerated by ALPI.

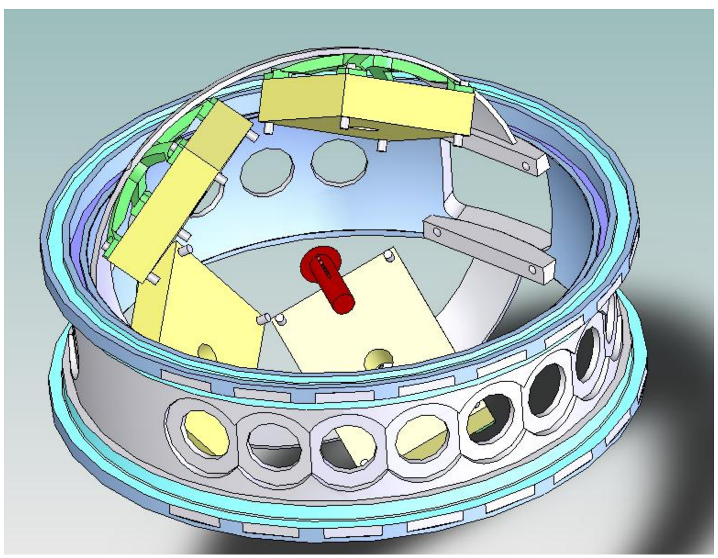
PIAVE beams for users expected spring 2006.

Summary:

-Spectroscopy with quasi-elastic multinucleon transfer and deep-inelastic collisions, using the CLARA-PRISMA setup and the medium-mass and heavy beams from LNL, provides valuable structure information on moderately n-rich nuclei.

-Differential RDDS technique is been developed in collaboration with IKP-Koeln, first experimental effort in the next months.





-CLARA is being upgraded with an ancillary array to perform "in beam" $\gamma-\gamma$ coincidences with Doppler correction.

-Is foreseen to start the use of the CLARA-PRISMA setup with the medium-mass and heavy beams from PIAVE by spring 2006.

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

Fusion06

International Conference on Reaction Mechanisms and Nuclear Structure at the Coulomb Barrier

March 19-23, 2006 - S. Servolo, Venezia - Italy

URL: http://www.lnl.infn.it/~fusion06/
E-mail : fusion06@lnl.infn.it

Topics

Near-barrier fusion reactions
Fusion-fission dynamics
Reaction dynamics with weakly bound nuclei
Nuclear reactions of astrophysical interest
Production and spectroscopy of heavy and superheavy elements
Quasi-elastic and deep-inelastic reactions
Nuclear structure explored in binary reactions
Clusters in nuclear structure and dynamics

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M.G. Itkis (Dubna, Russia)
R. Julin (Jyväskylä, Finland)
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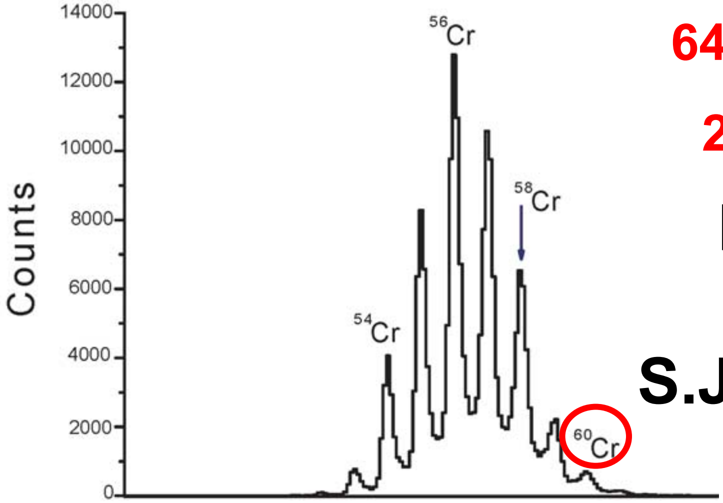
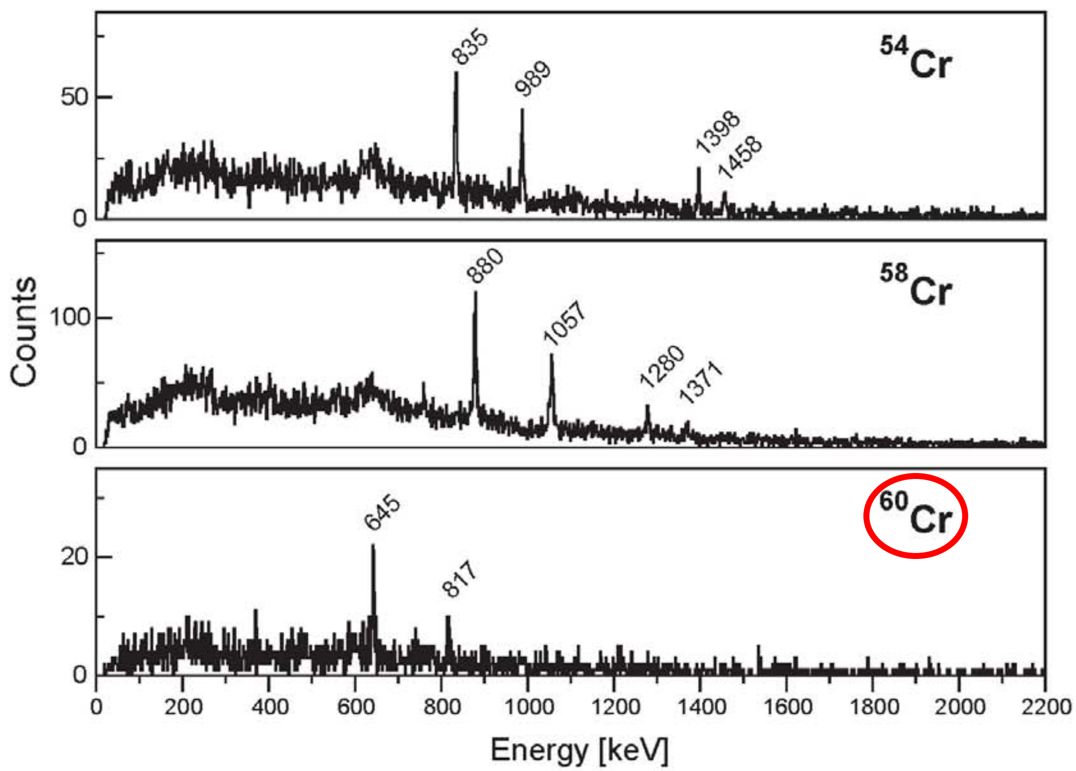
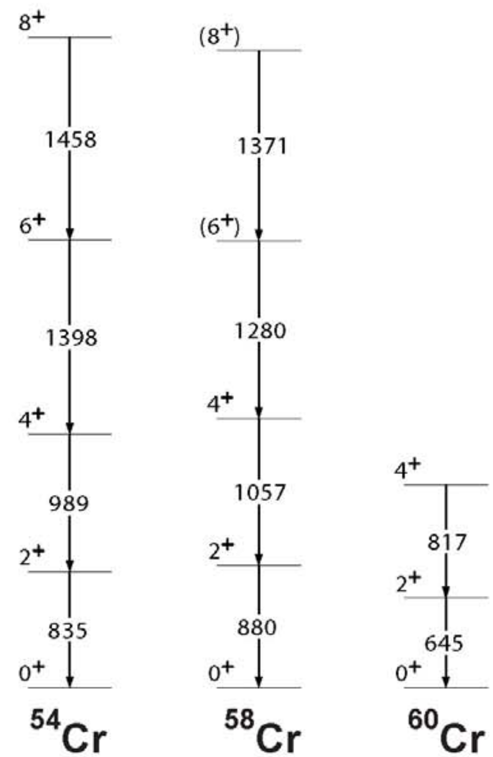
J.M.W.Turner, Tate (London)



^{64}Ni 400MeV + ^{238}U $\theta_{GR}=64^{o}$

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

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

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

E(5) critical point symmetry

vibrator to
γ-unstable rotor

^{58}Cr

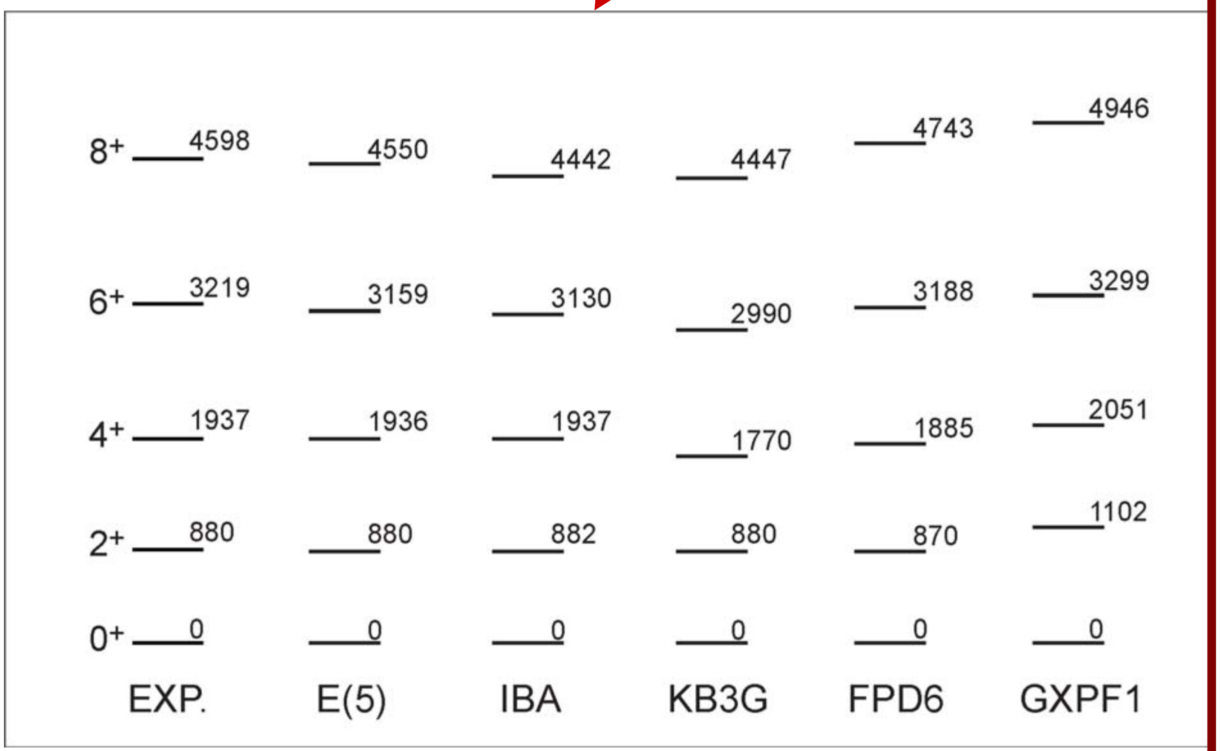


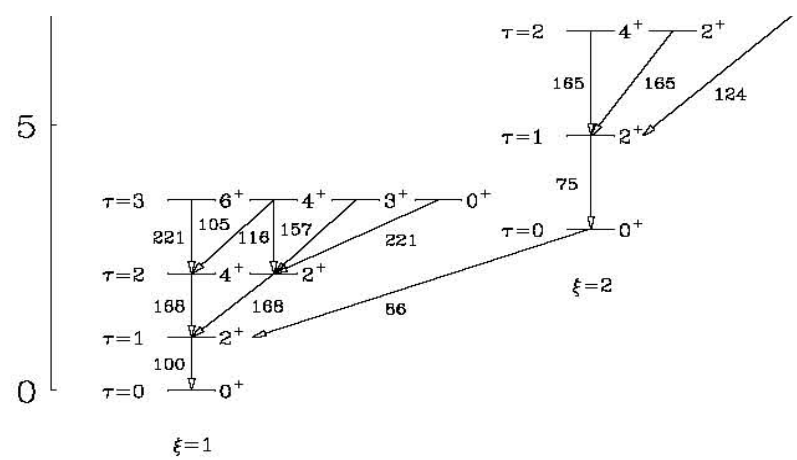
TABLE 1. Excitation energies of the E(5) symmetry.

	$\xi = 1$	$\xi = 2$	$\xi = 3$	$\xi = 4$
$\tau = 0$	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)



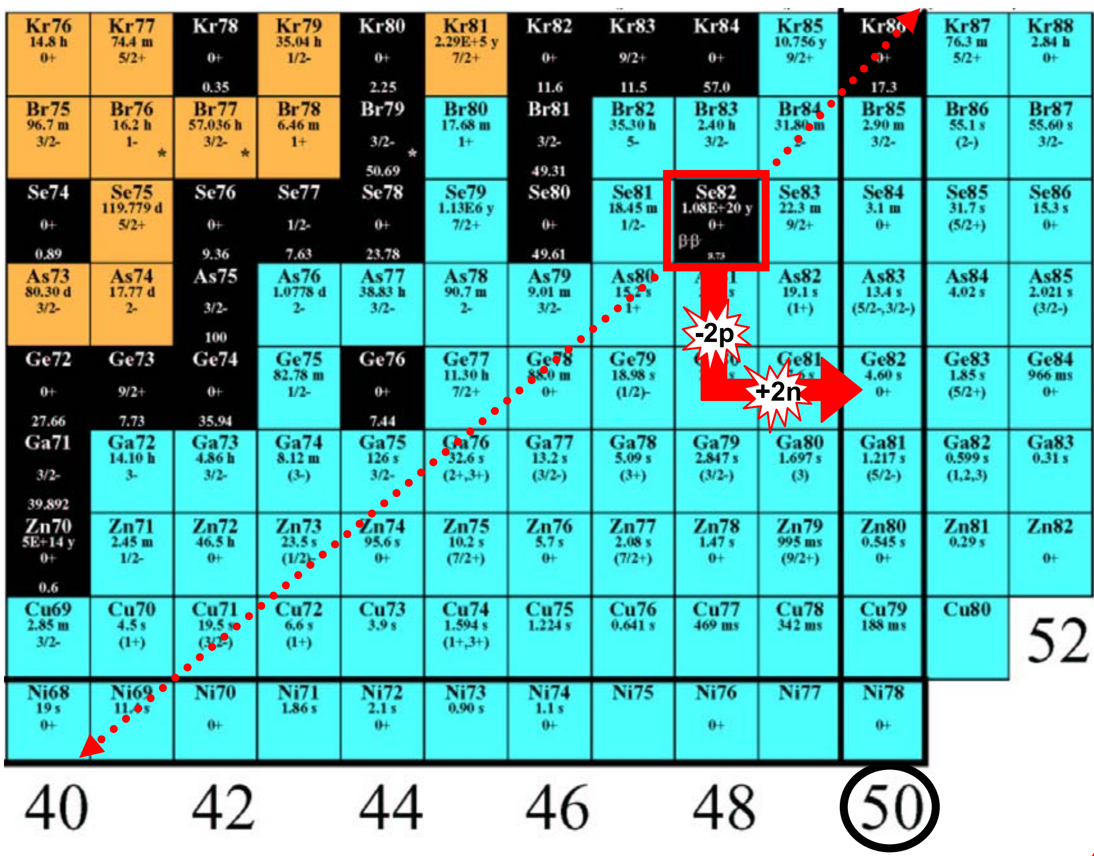
N.Marginean et al., to be published

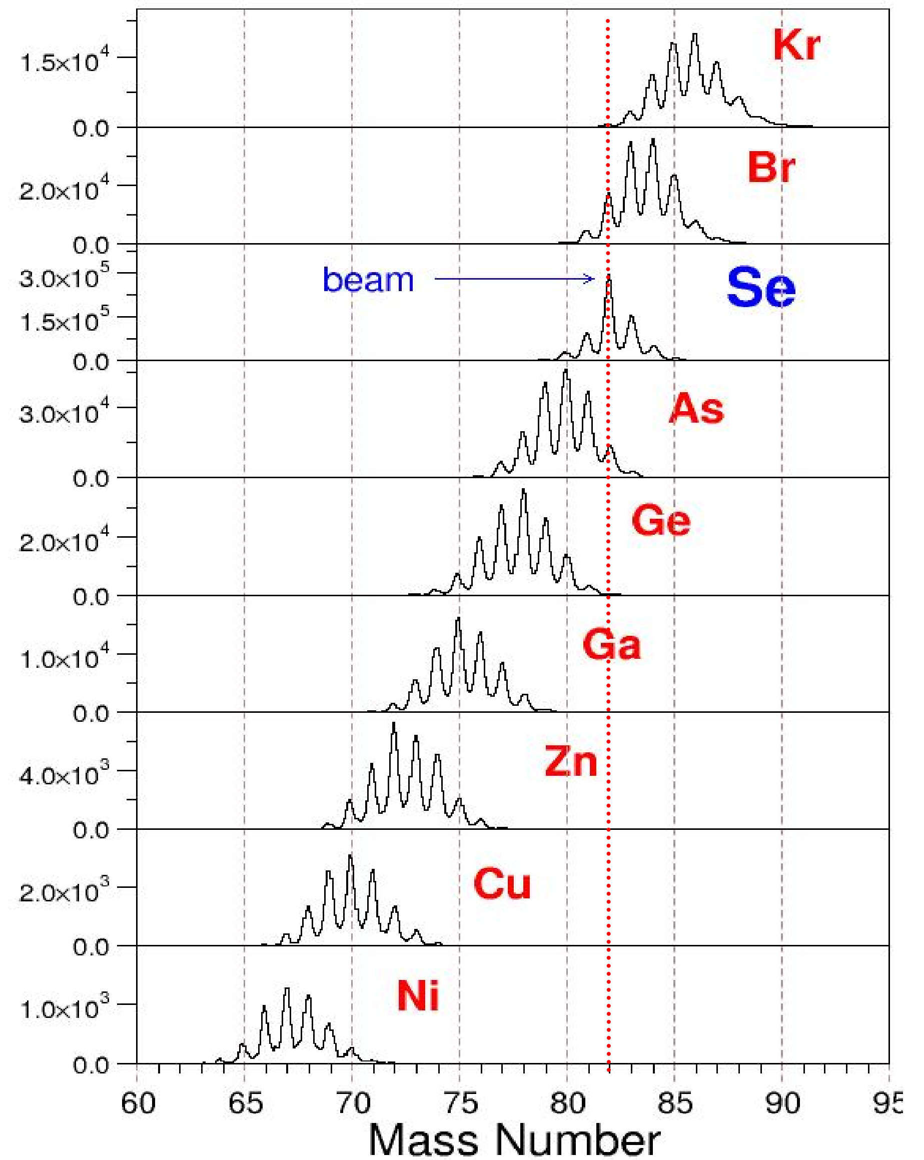
Experiments performed: March-November 2004

- *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

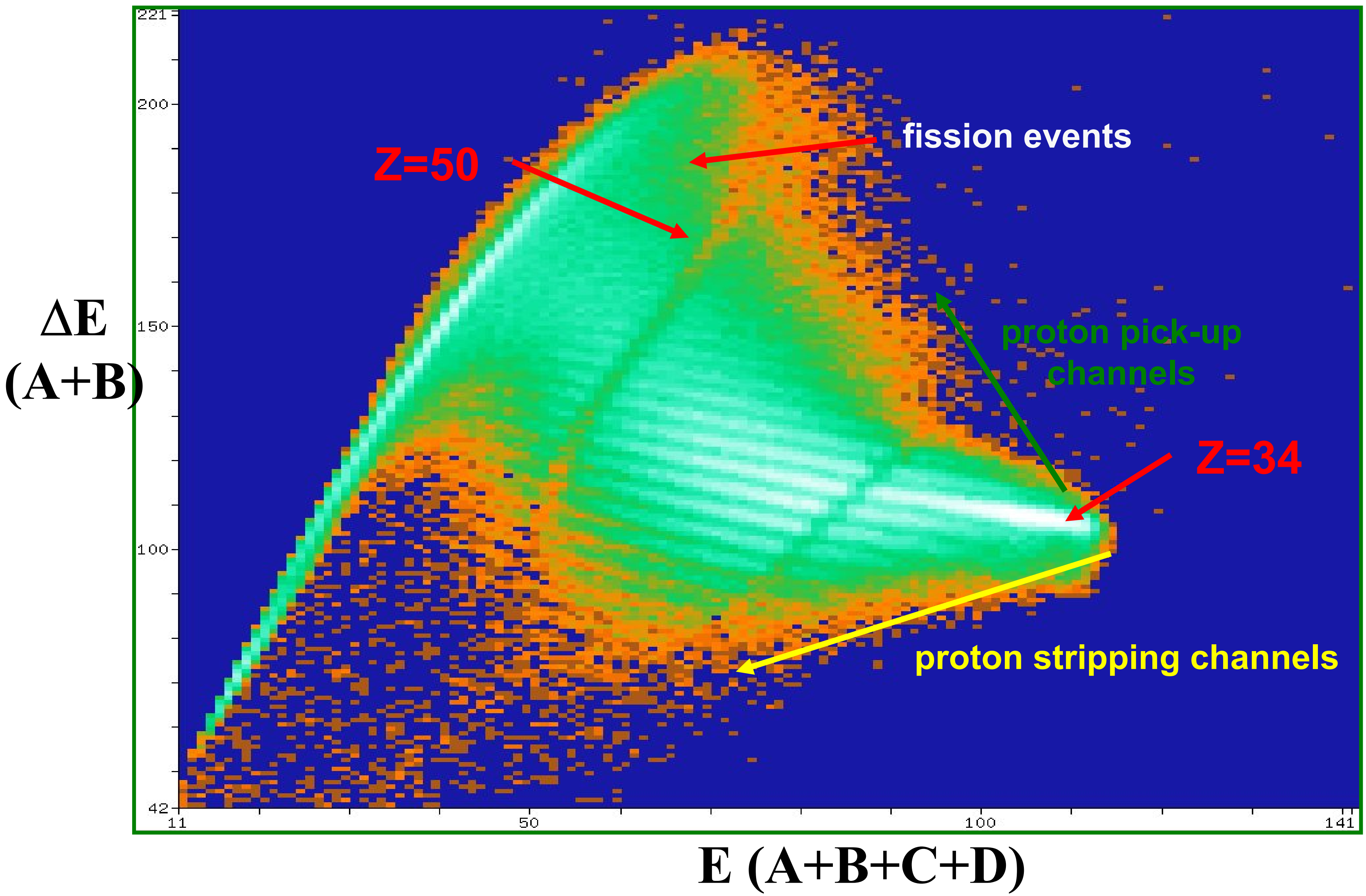


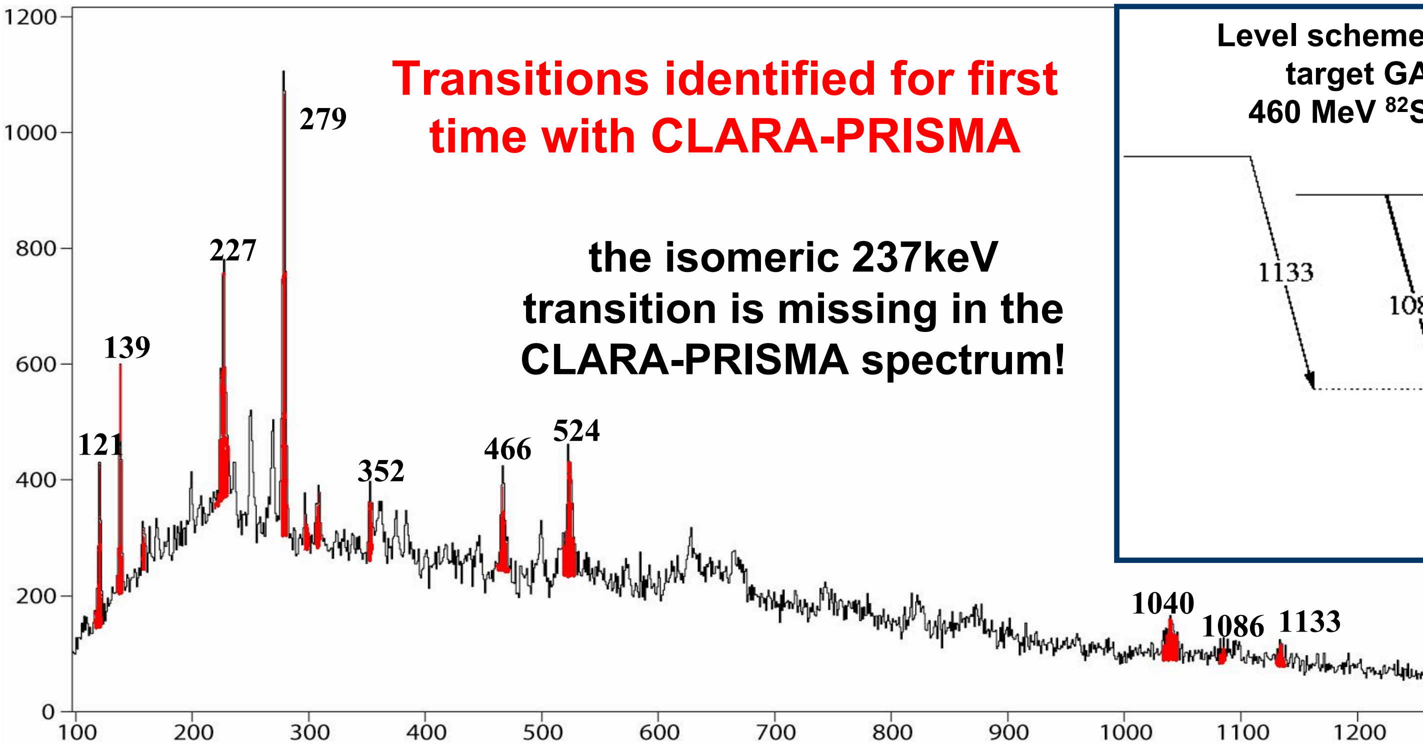


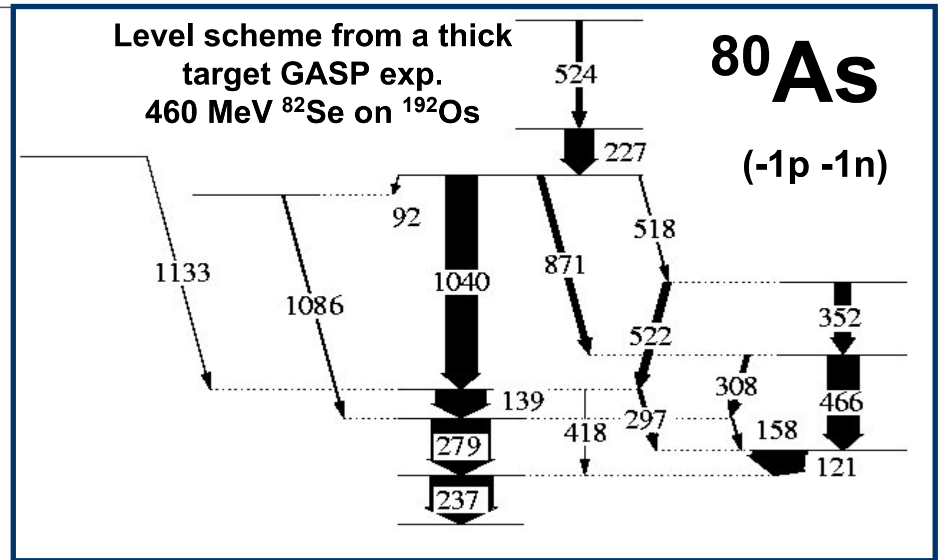
Evolution of the N=50 shell: Searching for the shell gap quenching (onset of deformation as in N=20 Z~12)

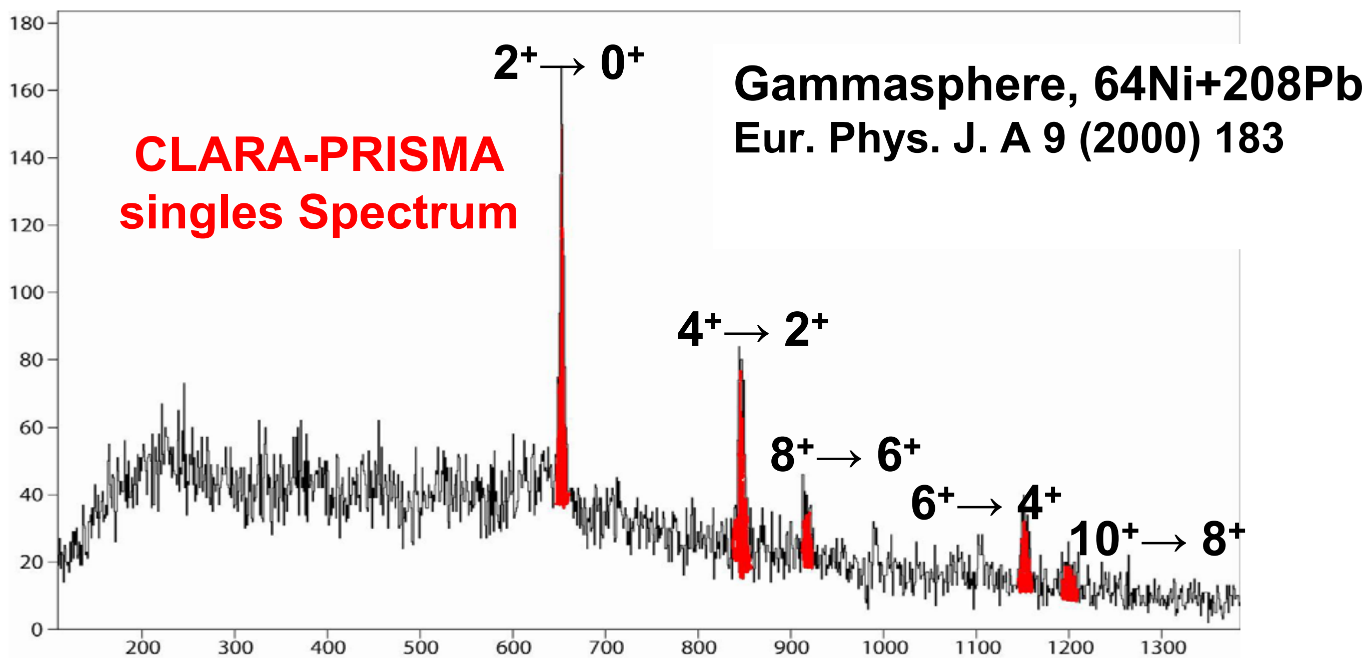
Z=32: INM, R.C.Nayak et al. PRC 60 (1999) 064305
Z=24-26: RMF, L.S.Geng et al. nucl-th/0402083

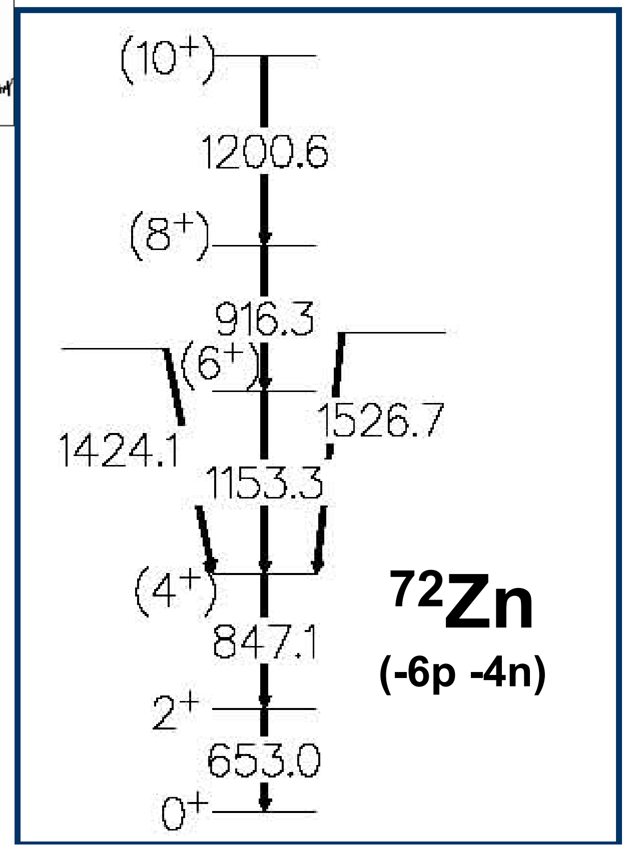
$^{82}Se + ^{238}U$ E=505 MeV $\theta_G=64^o$ IC ΔE-E Matrix



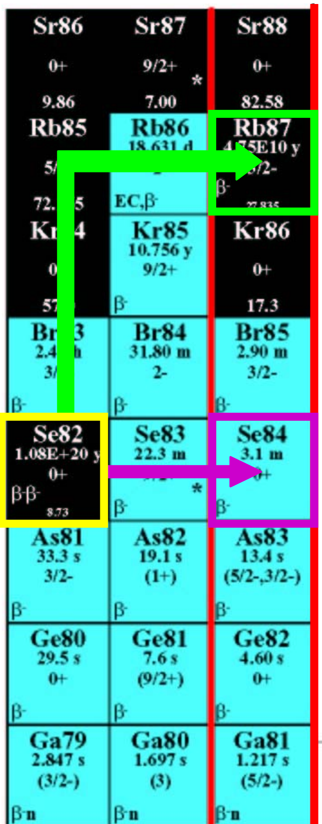

Transitions identified for first time with CLARA-PRISMA
the isomeric 237keV transition is missing in the CLARA-PRISMA spectrum!
121
139
227
279
352
466
524
1040
1086
1133
0
200
400
600
800
1000
1200
100
200
300
400
500
600
700
800
900
1000
1100
1200

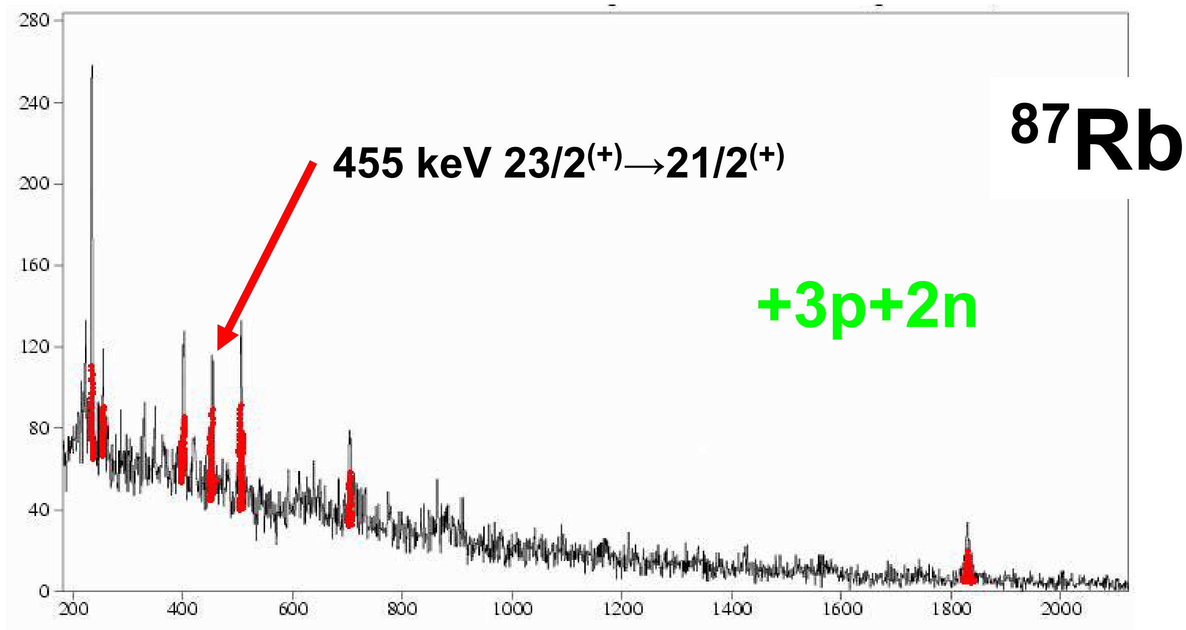

Level scheme from a thick target GASP exp.
460 MeV ^{82}Se on ^{192}Os
^{80}As
(-1p -1n)
524
227
92
1040
871
518
1133
1086
352
522
466
308
139
297
418
158
279
121
237

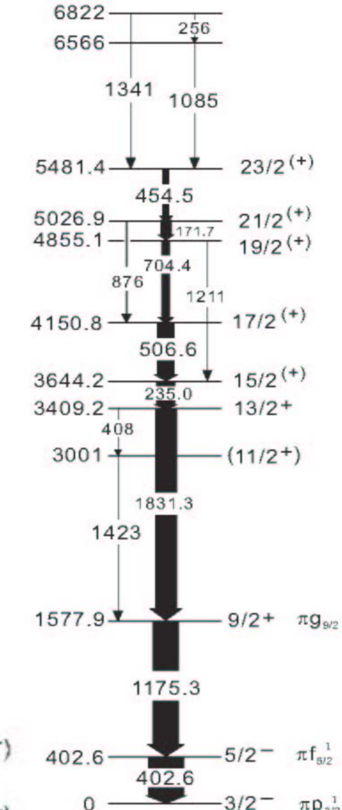

CLARA-PRISMA singles Spectrum
Gammasphere, 64Ni+208Pb
Eur. Phys. J. A 9 (2000) 183
$2^+ \rightarrow 0^+$
$4^+ \rightarrow 2^+$
$8^+ \rightarrow 6^+$
$6^+ \rightarrow 4^+$
$10^+ \rightarrow 8^+$
0
20
40
60
80
100
120
140
160
180
200
300
400
500
600
700
800
900
1000
1100
1200
1300

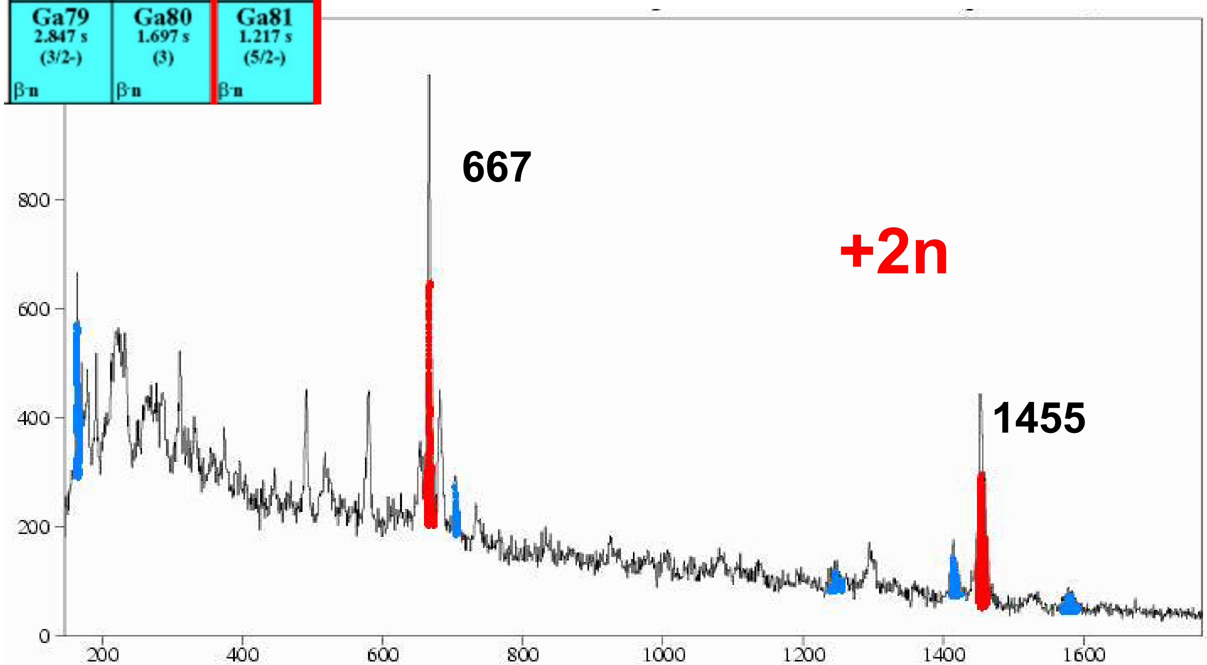

(10^+)
1200.6
(8^+)
916.3
(6^+)
1424.1
1526.7
1153.3
(4^+)
847.1
2^+
653.0
0^+
^{72}Zn
(-6p -4n)

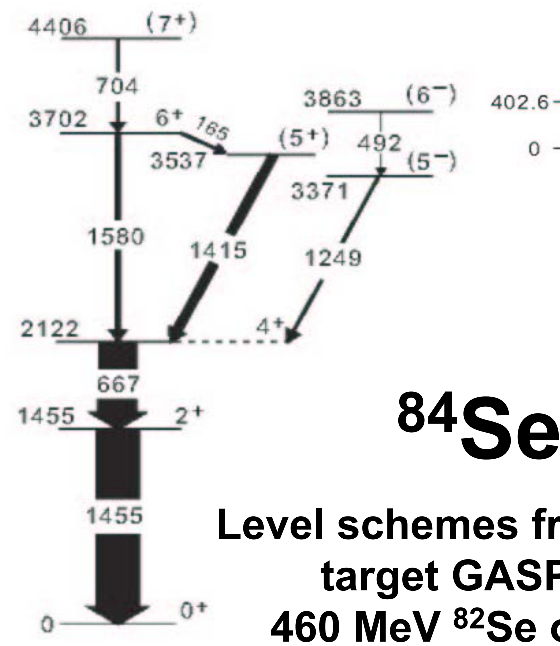
$^{82}Se + ^{238}U$ E=505 MeV











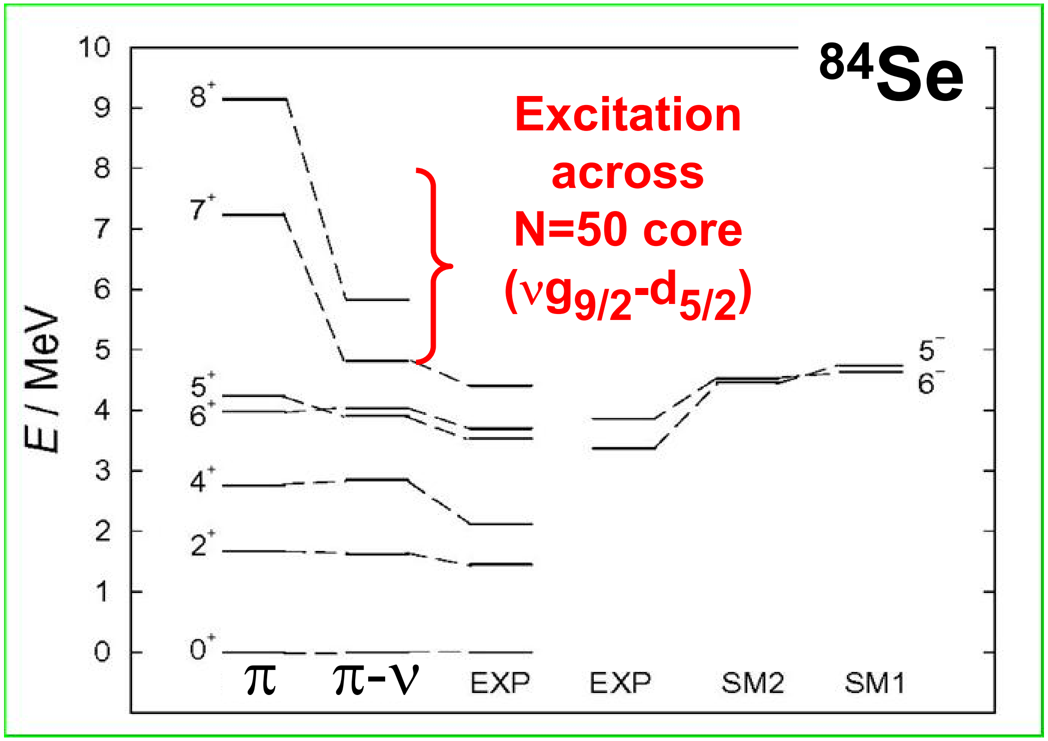
Level schemes from a thick target GASP exp. 460 MeV ^{82}Se on ^{192}Os

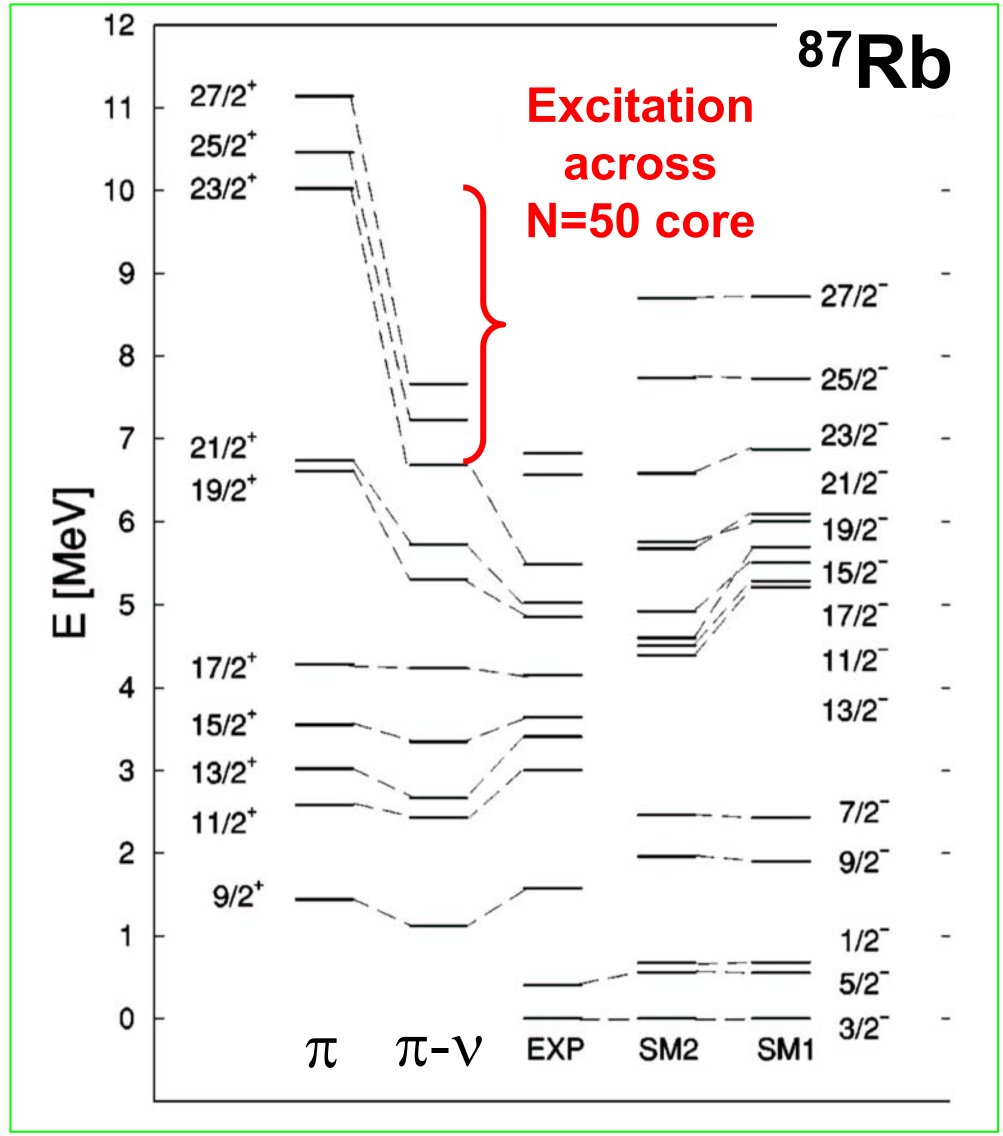
Stability of the N=50 Shell down to Z~32

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



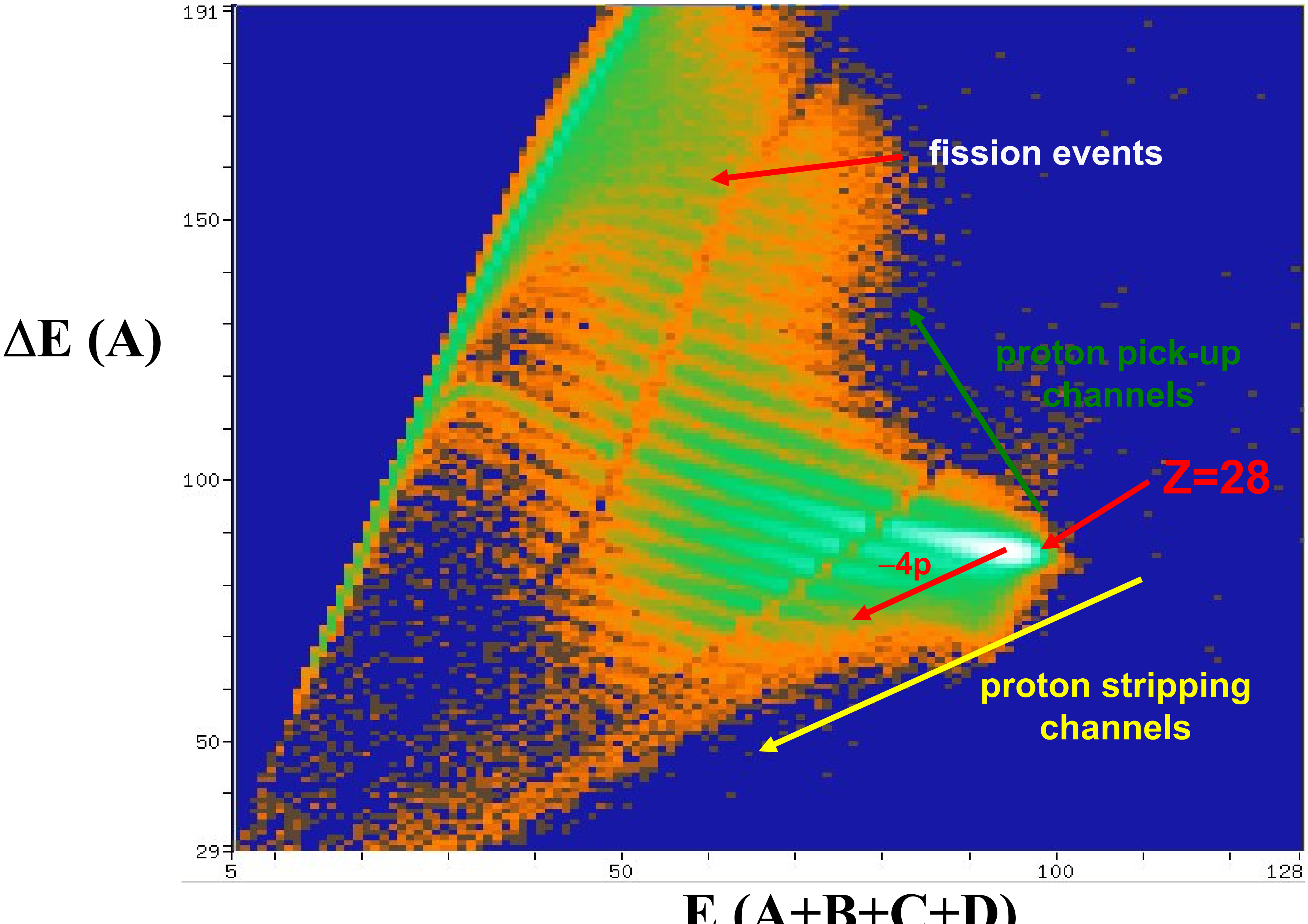


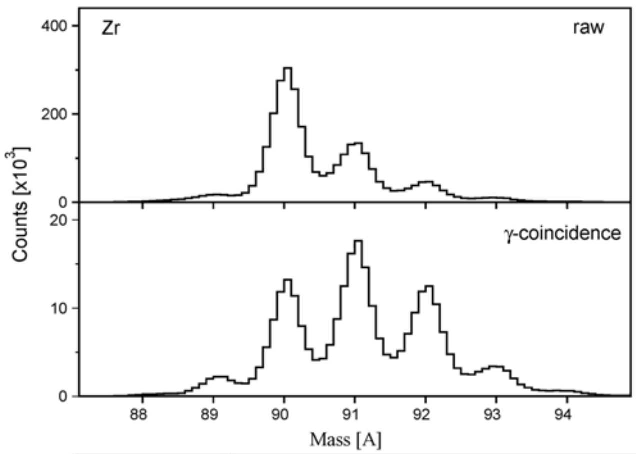
Space: $\pi f_{5/2}\ p_{3/2}\ p_{1/2}\ g_{9/2}\ \ \nu p_{1/2}\ g_{9/2}\ d_{5/2}$

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

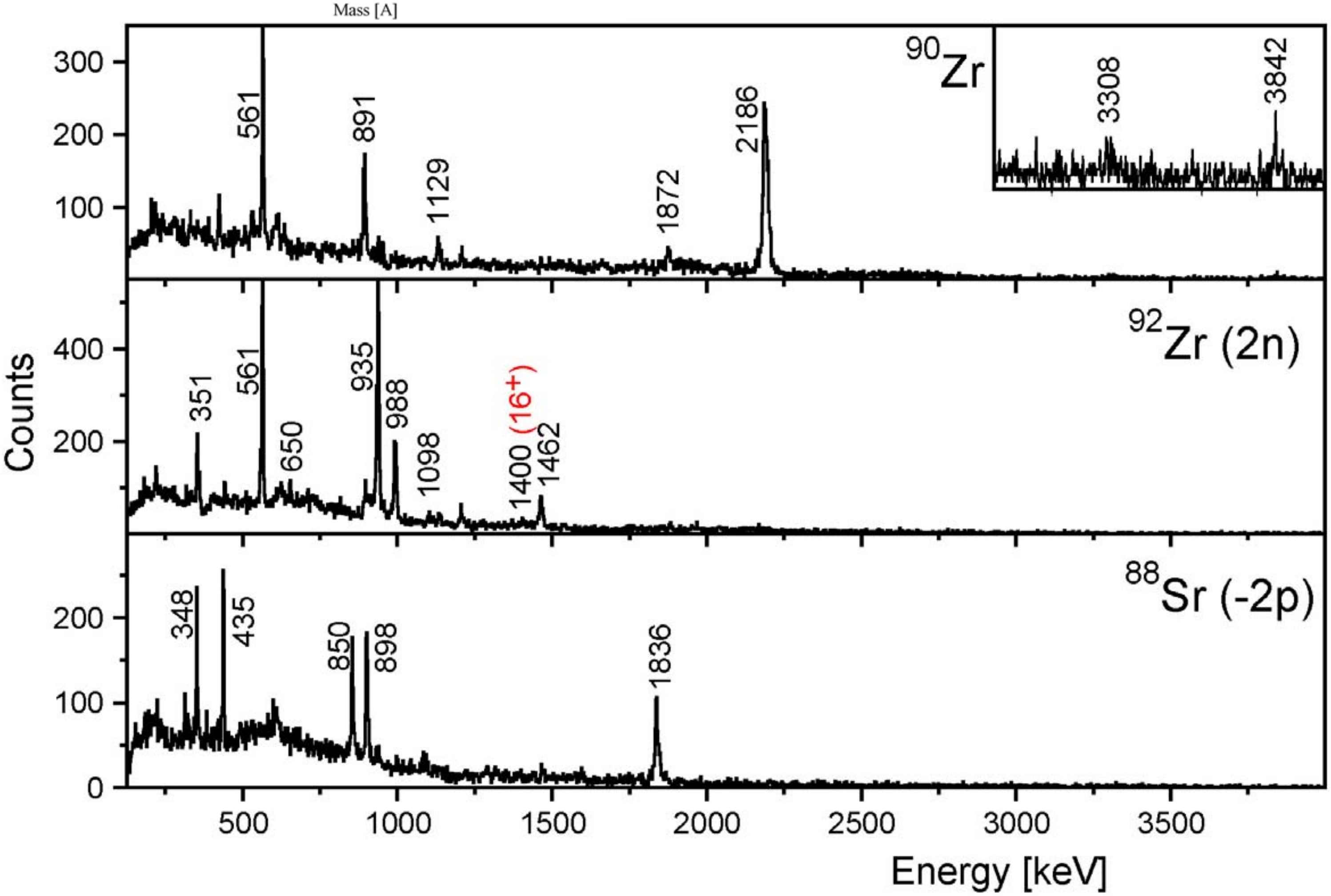
^{64}Ni 400MeV + ^{238}U IC ΔE-E matrix

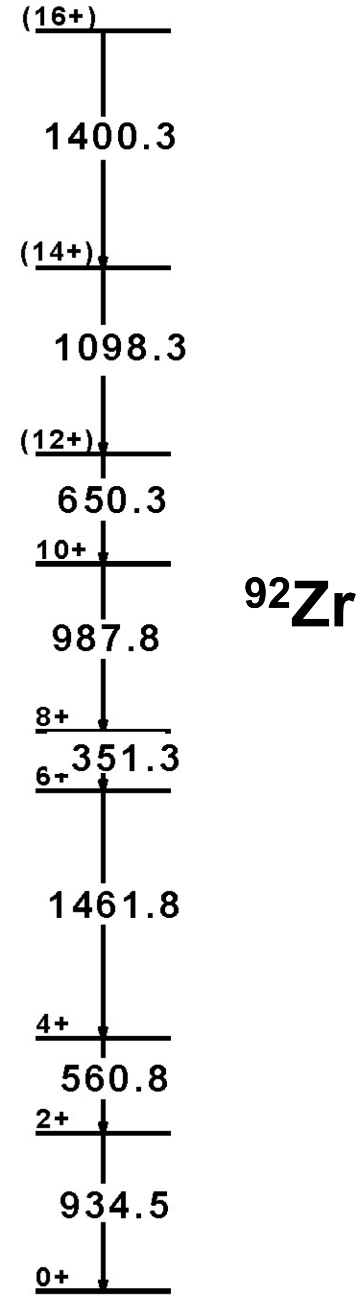




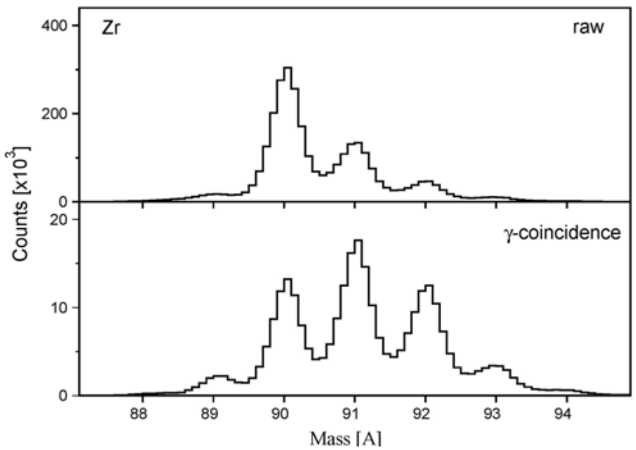
^{90}Zr 560MeV + ^{208}Pb

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



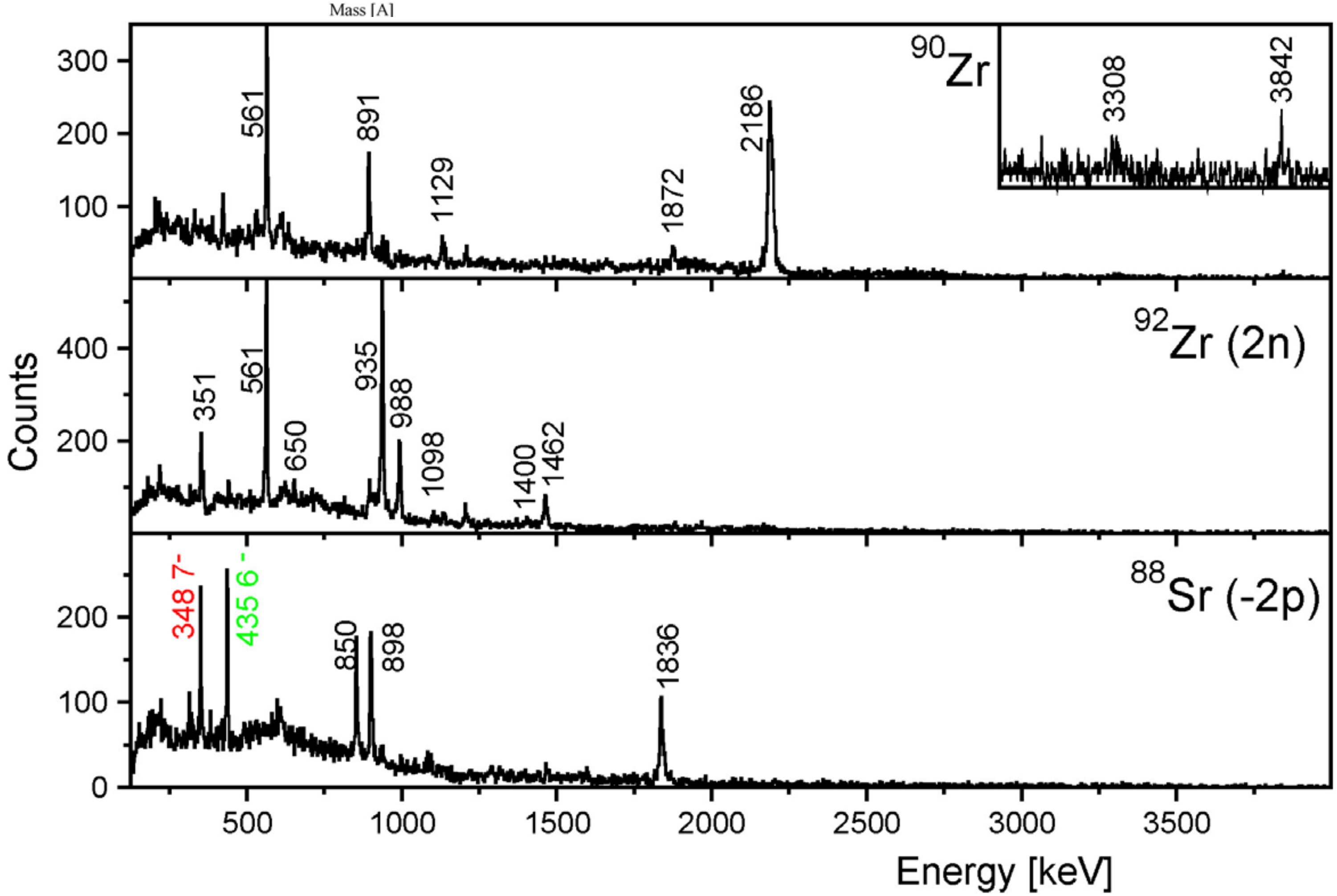


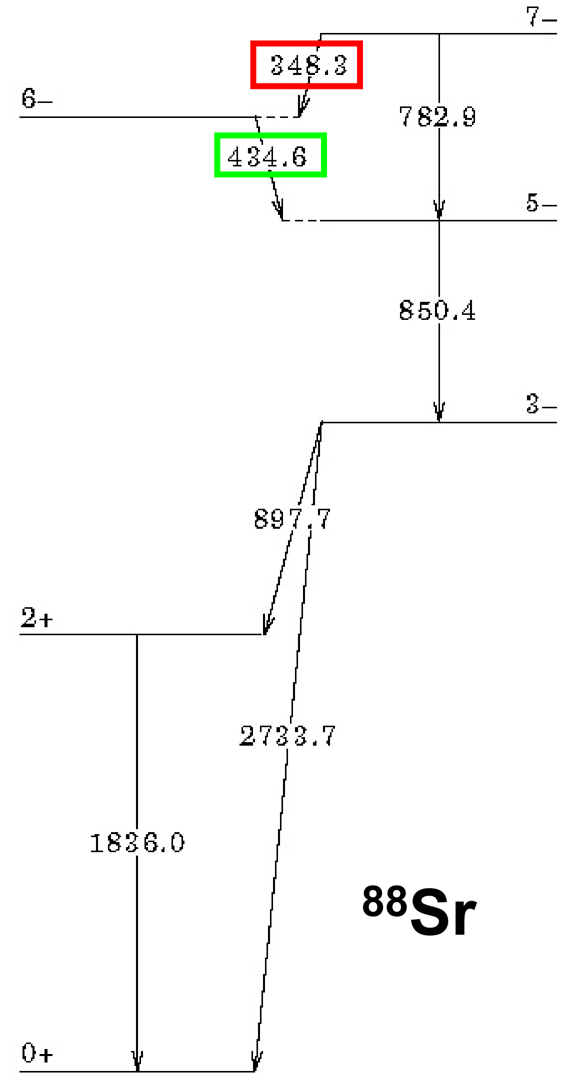
Adopted NNDC Level Scheme



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

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



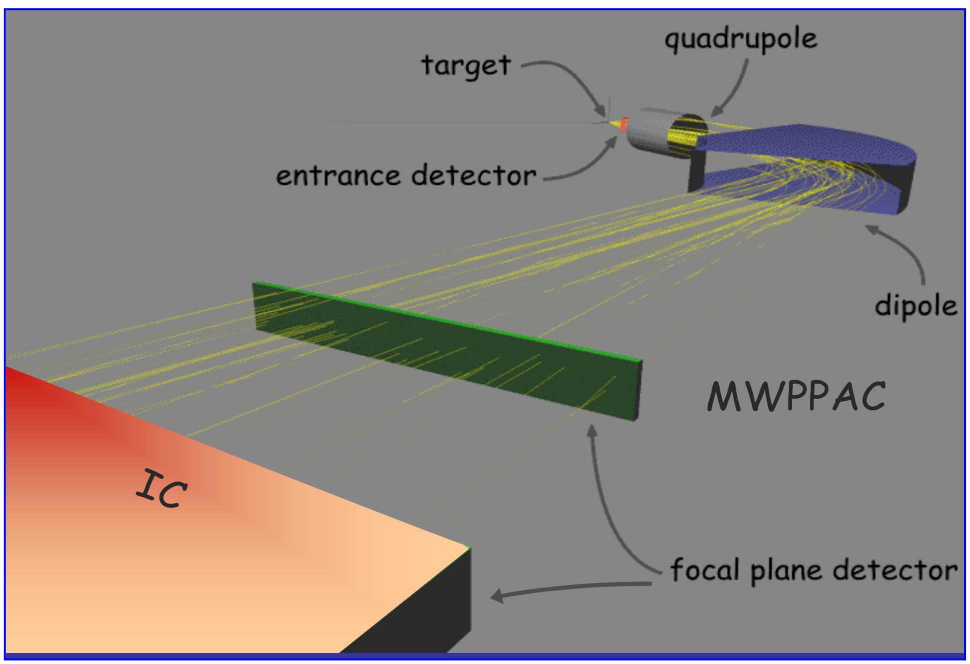


Adopted NNDC Level Scheme

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 (ΔE/E) from IC



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

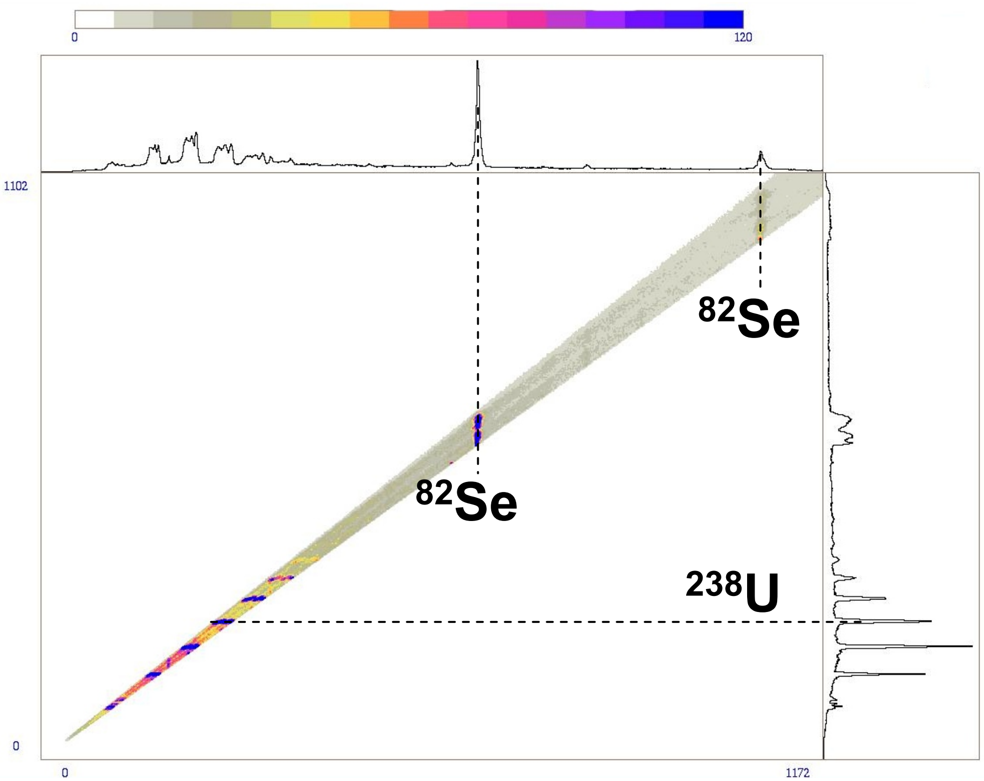
A/q

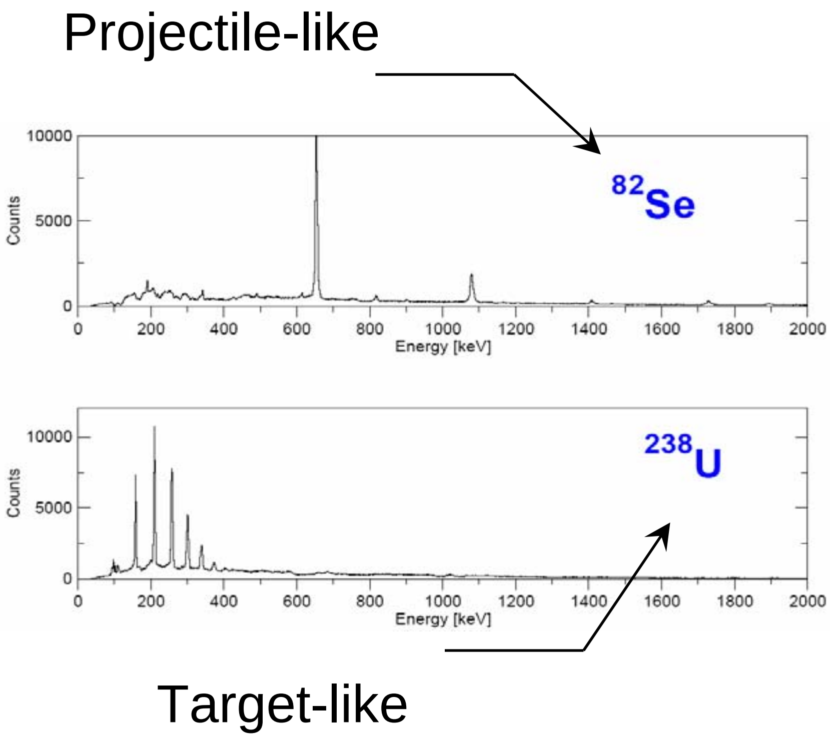
Charge state
- trajectory in dipole
- total energy

CLARA Doppler correction

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

$^{82}Se+^{238}U$ with <u>^{82}Se</u> selected in PRISMA

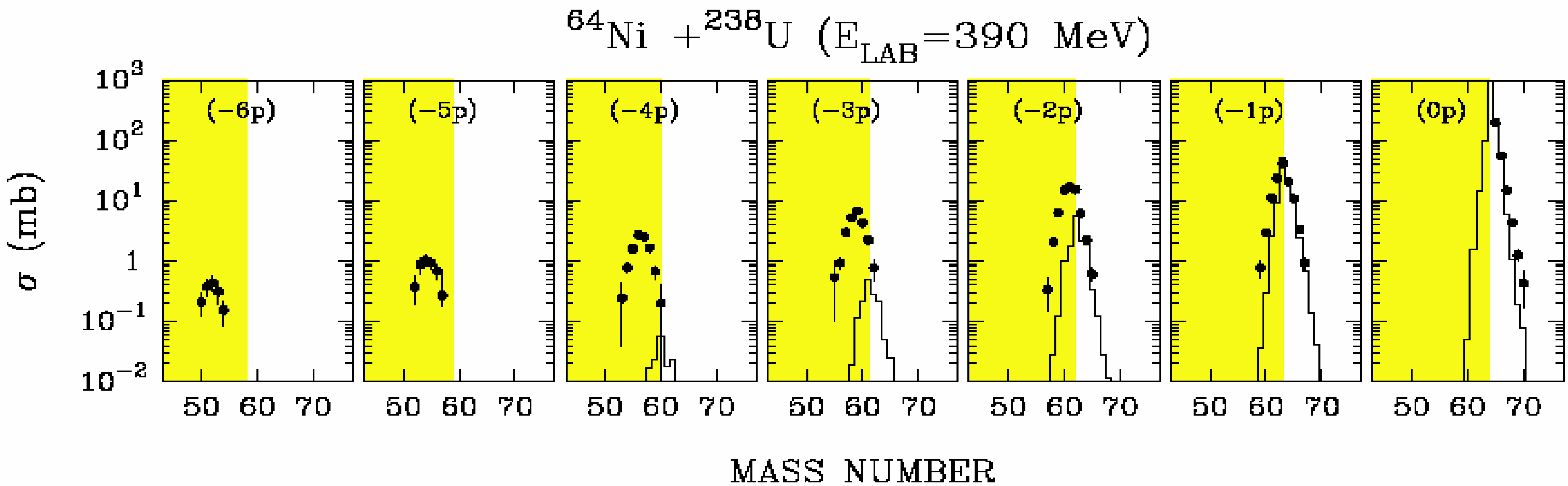




PHYSICAL REVIEW C VOLUME 59, NUMBER 1 JANUARY 1999

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



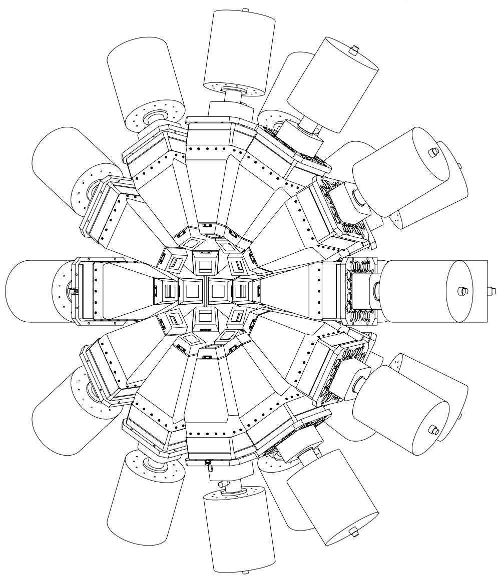
Lifetime measurements with the Clover array at Prisma

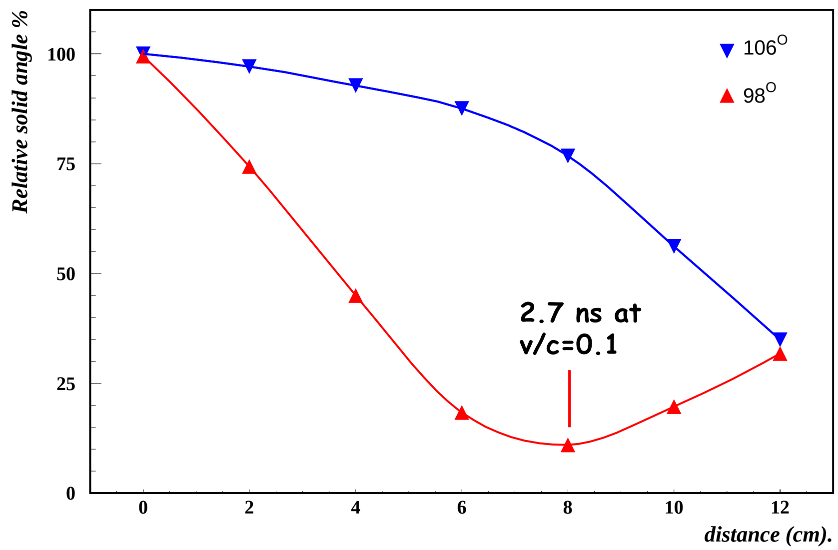
- Recoil Shadow anisotropy method:
  Based on the array-collimator geometry.
  Lifetimes ranging from ~0.5 to ~20 ns.
  E.Gueorguieva et al. NIM A 474 (2001) 132.

- 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

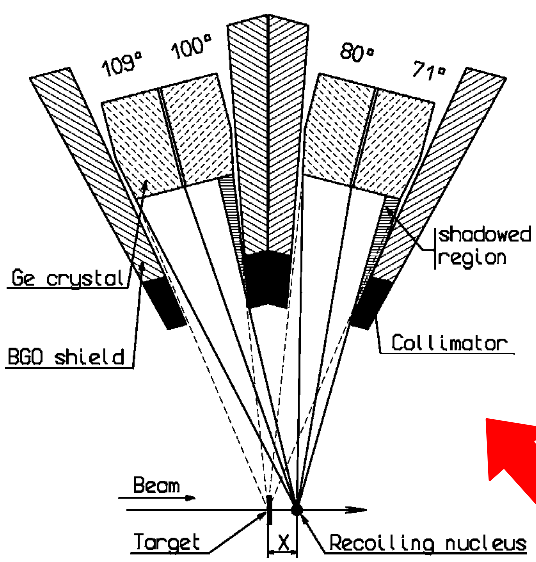


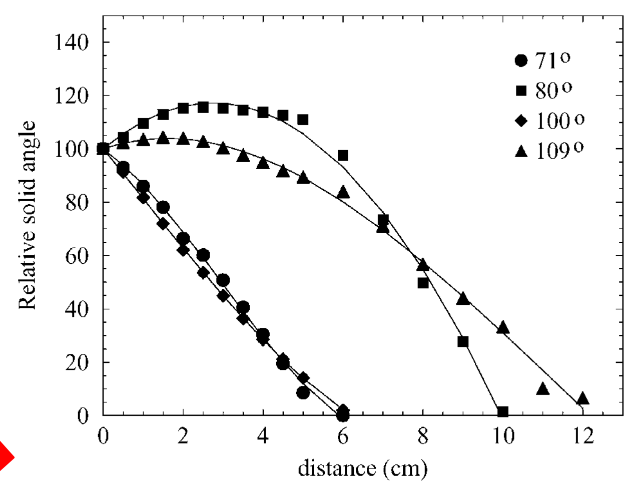


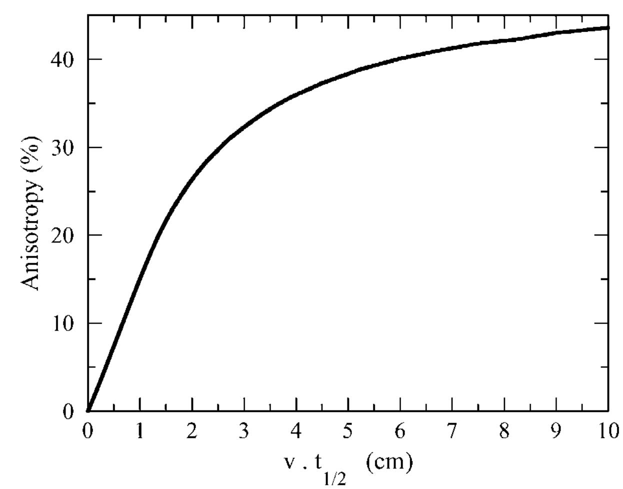
Angles for the Ge crystals of the Clover array ring:

θ = 106 °

θ = 98 °

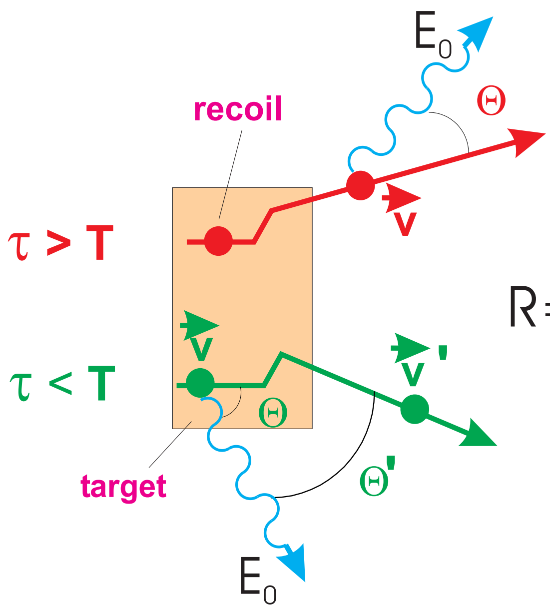




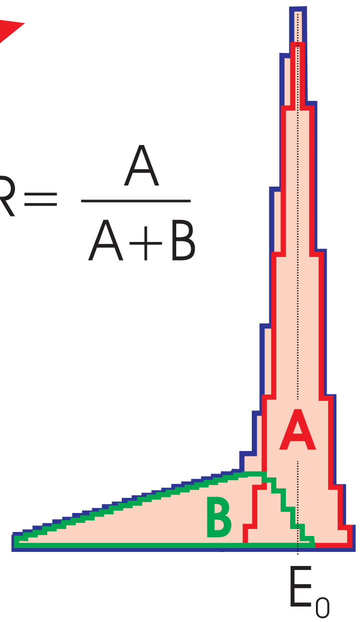


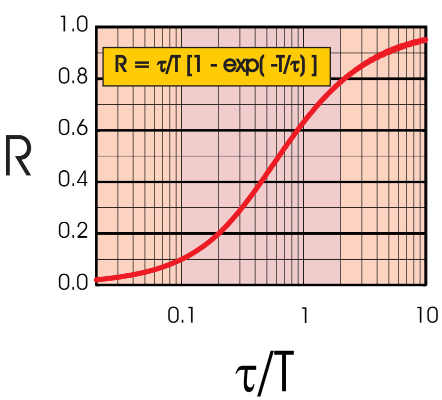
For EUROBALL: **E.Gueorguieva et al. NIM A 474 (2001) 132**

A short lifetime determination with RFD

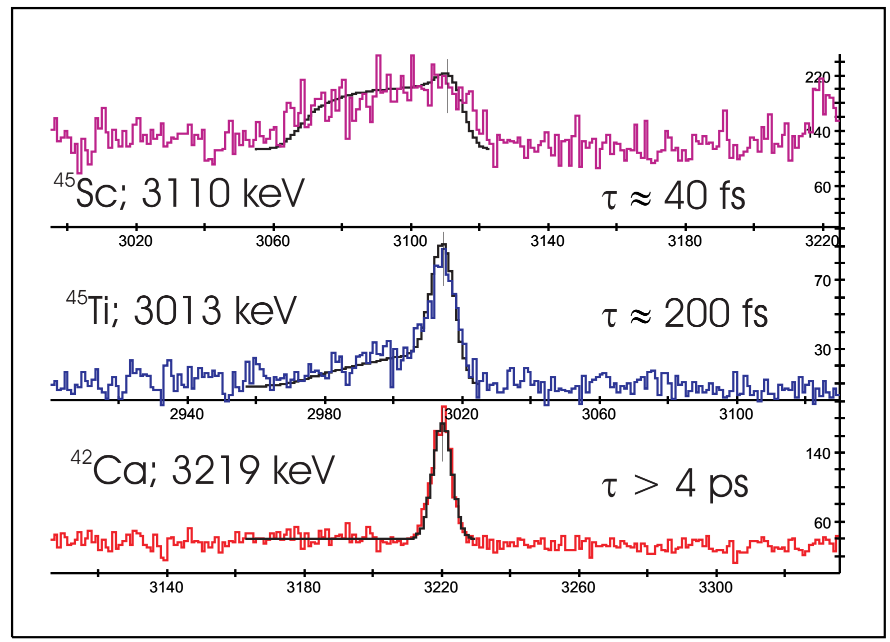


$$R = \frac{A}{A+B}$$





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



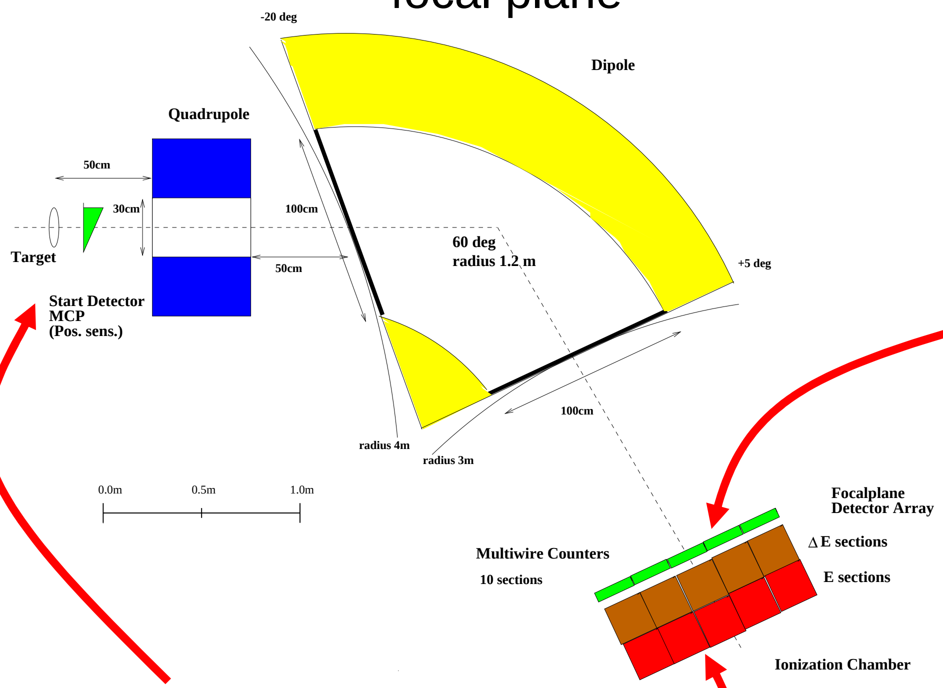
The range of measured lifetimes can be chosen by a selection of the target thickness.

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

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

The PRISMA Spectrometer Detectors

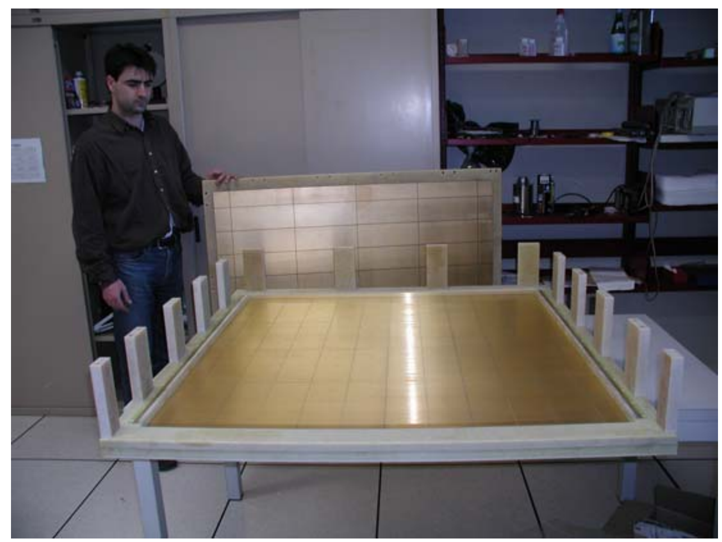
Large dispersion dipole: 4cm / % at the focal plane



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