γ spectroscopy with Clara and Prisma at LNL

Daniel R. Napoli

On behalf of the
Prisma – Clara collaboration

Laboratori Nazionali di Legnaro

INFN

γ spectroscopy with Clara and Prisma at LNL

Outline of the presentation

- *Laboratori Nazionali di Legnaro dell'INFN*
- *Nuclear spectroscopy at LNL*
- *γ- ray spectroscopy of neutron rich nuclei populated in transfer and deep inelastic reactions*
- *Clara* - *Prisma* setup
- *Recent results*

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Laboratori Nazionali di Legnaro

User oriented facility – EURONS (FP6)

Nuclear Physics

Fundamental Interactions

Interdisciplinary Physics

Applications of Nuclear Techniques

Accelerator Design

Accelerator Technology

Superconductivity

Basic research and applications

Laboratori Nazionali di Legnaro

Facilities

+

ALPI - PIAVE

46% INFM, ENEA, ISS, Universities

Interdisciplinary activities and applications

10.000 hours of beam on target

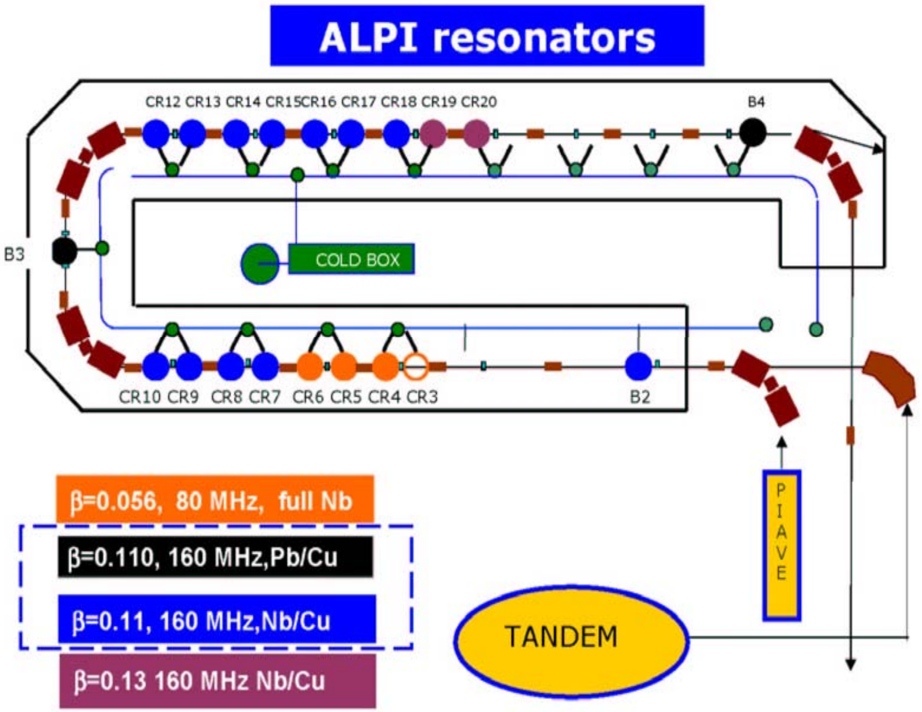
5500 4500

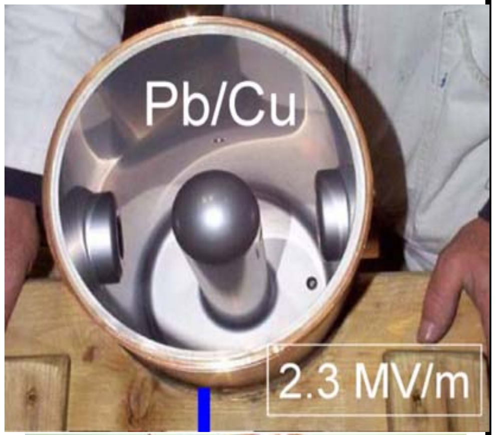
p → Au, from AkeV → 20 AMeV, from few pnA → few pμA

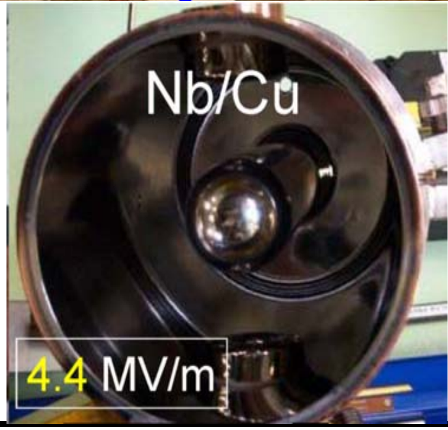
Tandem – ALPI beams

Tandem XTU-Tandem, 15MV. Beams from H (30Mev/amu) up to Au (1.5MeV/amu)

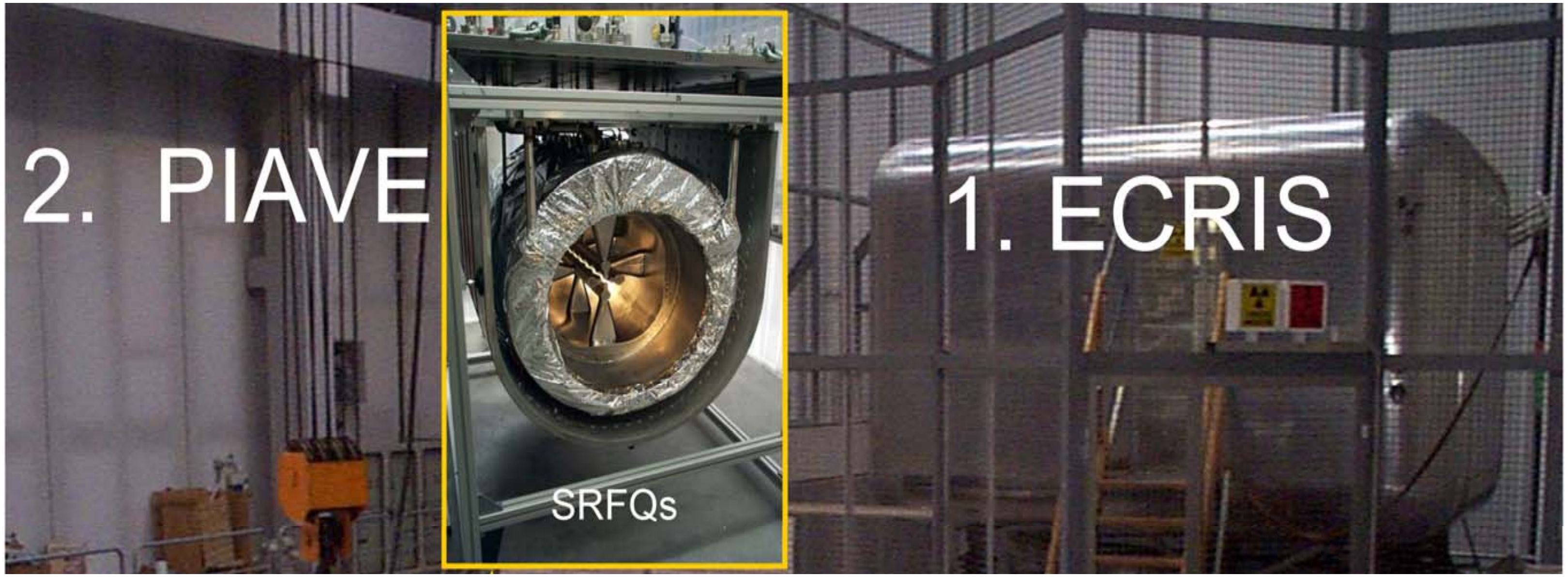
Alpi after the upgrade
Superconductive Linac. Beams from Si to Au.
Beam intensities increased up to few pnA (6pnA for ^{82}Se, 4pnA for ^{90}Zr)
Accelerator equivalent potential up to ~ 32MV.
Heavier beams available with the low β cavities.

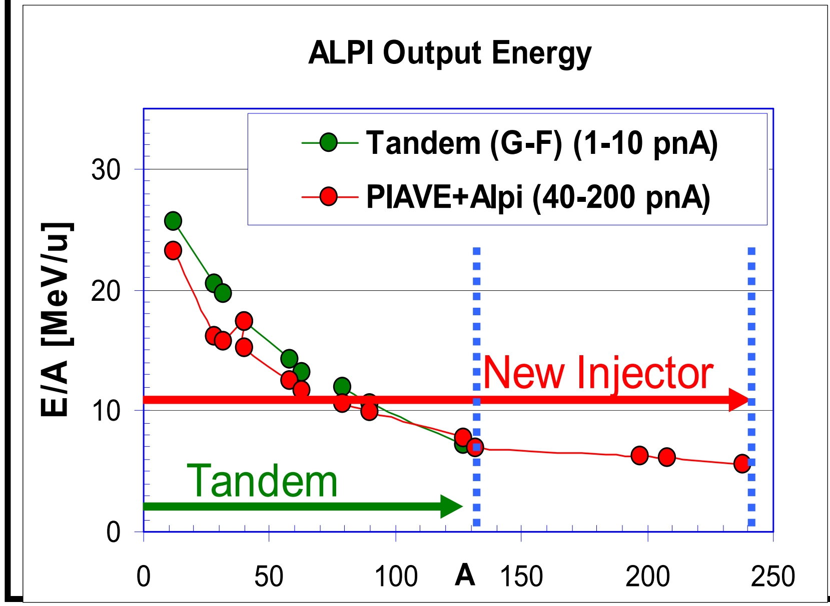






Piave – Ecris injector





Positive ion injector ECRIS + PIAVE commissioned with O and Kr beams.

Transmission 40%.

Next step: beam test with heavier beams.

Operational from February 2006 (next PAC period).

ECR beams: Ar, Kr, Xe, Ag and Cu

Program to develop Sn, Cd, Sm and Pb

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Nuclear spectroscopy at LNL

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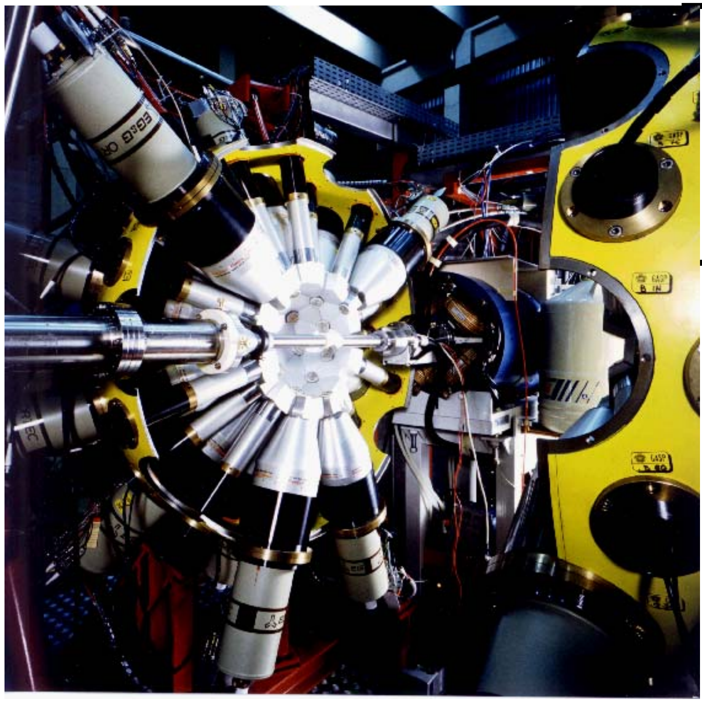
GASP Operational again…

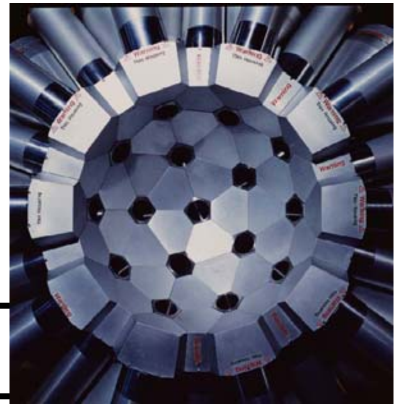


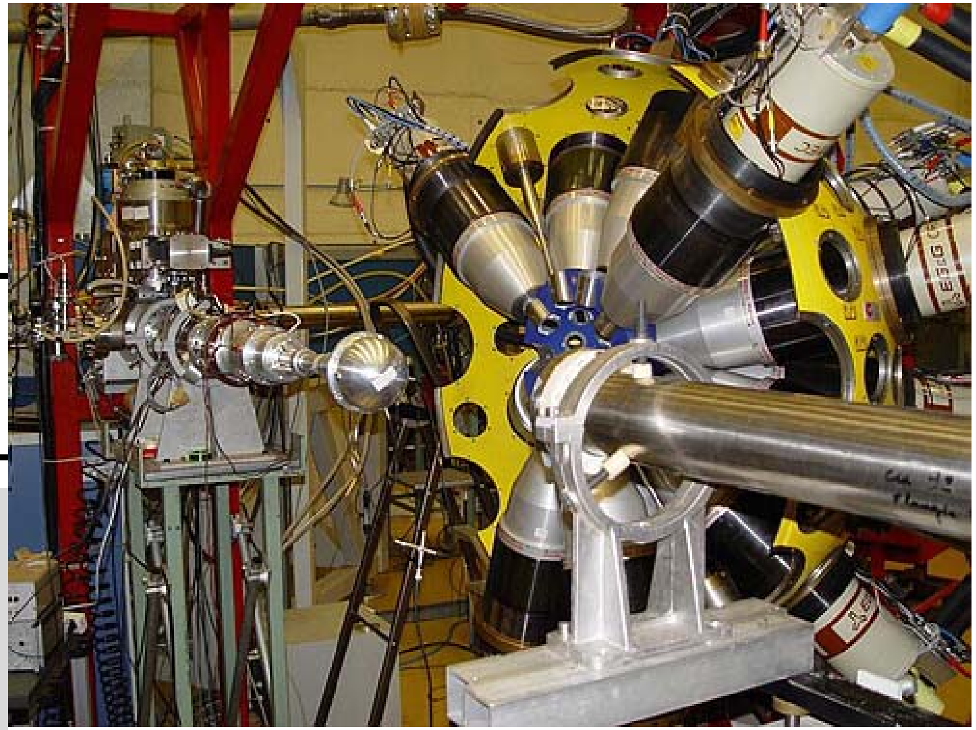
Configuration 1

40 Ge detectors

at 27 cm, ε_{tot} = 3%

BGO innerball 80 elements





Configuration 2 Ge detectors

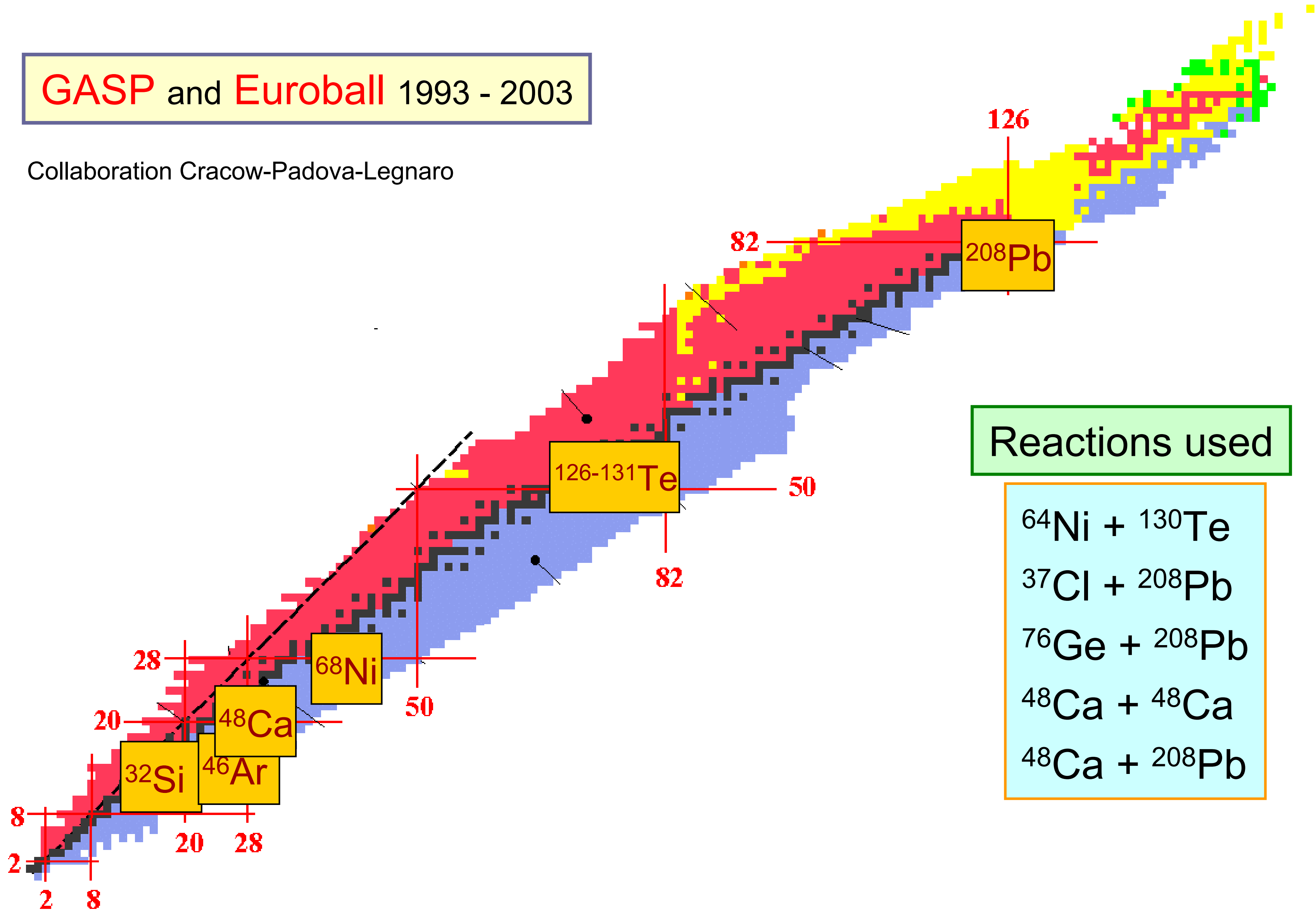
at 20 and 24 cm, ε_{tot} ~ 5.8%

And in combination with:
ISIS, Euclides, neutron detectors, plunger, RFD, Miniorange, Corset, etc…

γ-ray studies of Neutron Rich Nuclei Produced in Deep-Inelastic collisions

GASP and Euroball 1993 - 2003

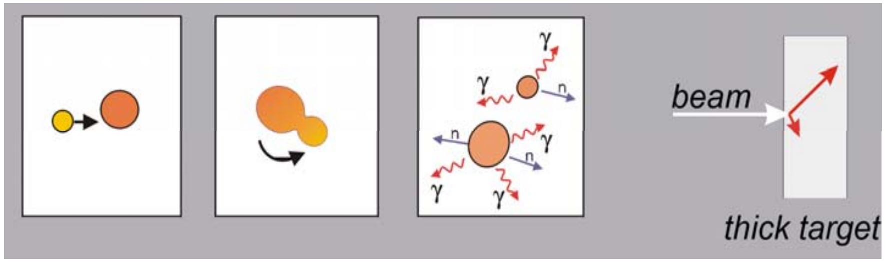
Collaboration Cracow-Padova-Legnaro



Reactions used

$^{64}Ni + ^{130}Te$
$^{37}Cl + ^{208}Pb$
$^{76}Ge + ^{208}Pb$
$^{48}Ca + ^{48}Ca$
$^{48}Ca + ^{208}Pb$

Deep inelastic reactions



a tool for nuclear spectroscopy

Populate high spin states

Rolling limit:

$$L_{TLF} = \frac{2}{7}\left(\frac{1}{1+\left(A_B / A_T\right)^{1/3}}\right)L_{MAX}$$

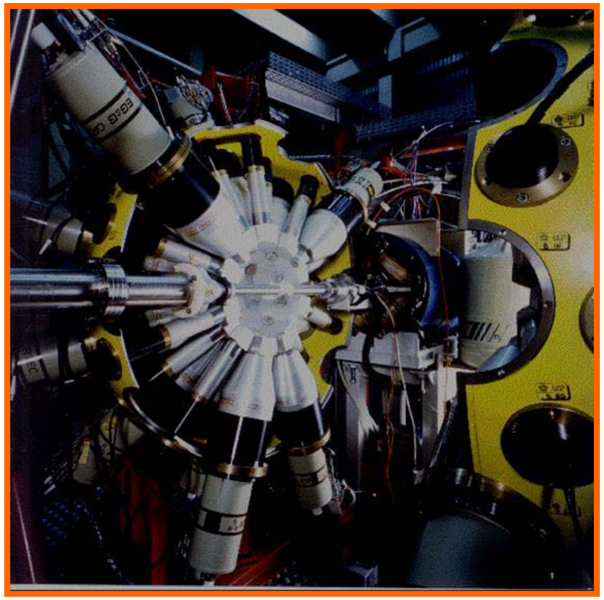
$$L_{MAX} = \sqrt{\frac{2\mu R^2}{\hbar^2}\left(E_{CM} - V_C\right)}$$

Detecting γ-rays emitted at rest
- no Doppler correction is needed!
- sensitive to the decay of levels which live longer than the stopping time

Identification of new states based on γ-coincidences between the two binary products (cross-coincidences)

Neutron rich heavy projectiles would allow to use transfer reactions as a ΔN-ΔZ filter for driving the multi-nucleon transfer flux to exotic regions

Neutron-rich radioactive beams or beams of heavy ions plus a detection system with good selectivity are needed



γ spectroscopy with Clara - Prisma at LNL

Large acceptance tracking magnetic spectrometer PRISMA

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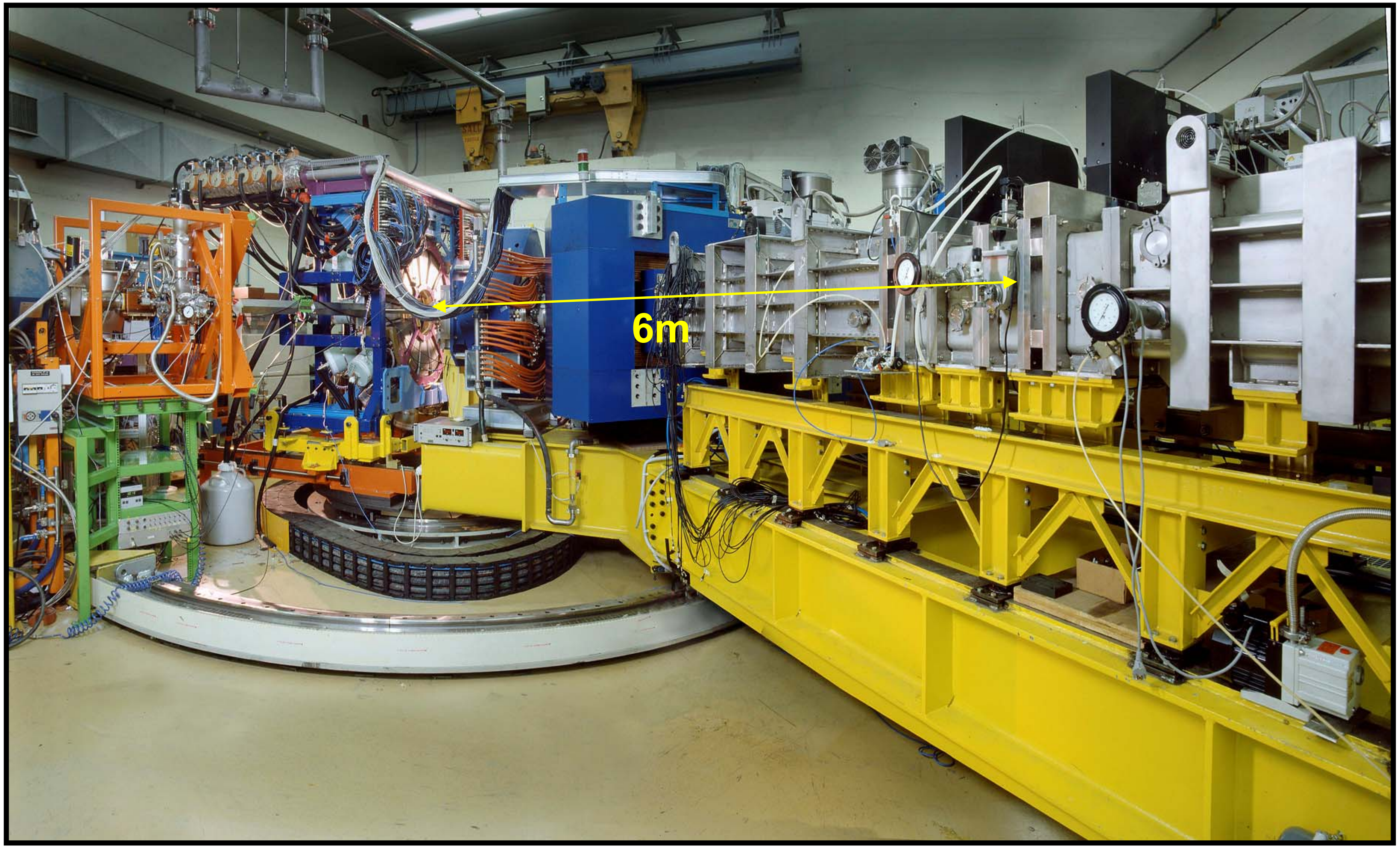
PRISMA, A.M.Stefanini et al

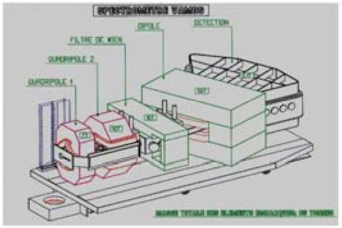
Large acceptance tracking magnetic spectrometer Q-D

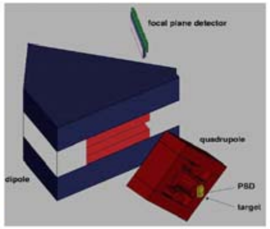


Ω = 80 msr, ΔZ / Z ≈ 1 / 60, ΔA / A ≈ 1 / 190, ***Energy acceptance*** *± 20%* ***Br*** *= 1.2 Tm*

Design Characteristics of PRISMA

Other magnetic spectrometers

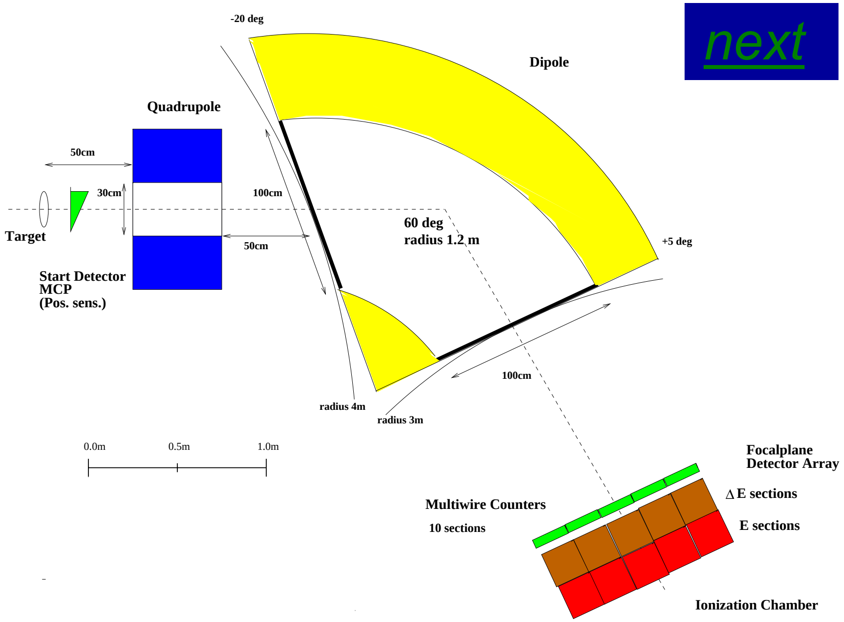




	PRISMA	VAMOS	MAGNEX
Solid Angle (msr)	80	100	52
Target-FPD (m)	7	7.3	5.8
Dispersion (cm/%)	4	2.5	3.8
Momentum acceptance	±10%	±5%	±10%
Max Rigidity T•m	1.4	1.6	1.8

particle identification with PRISMA

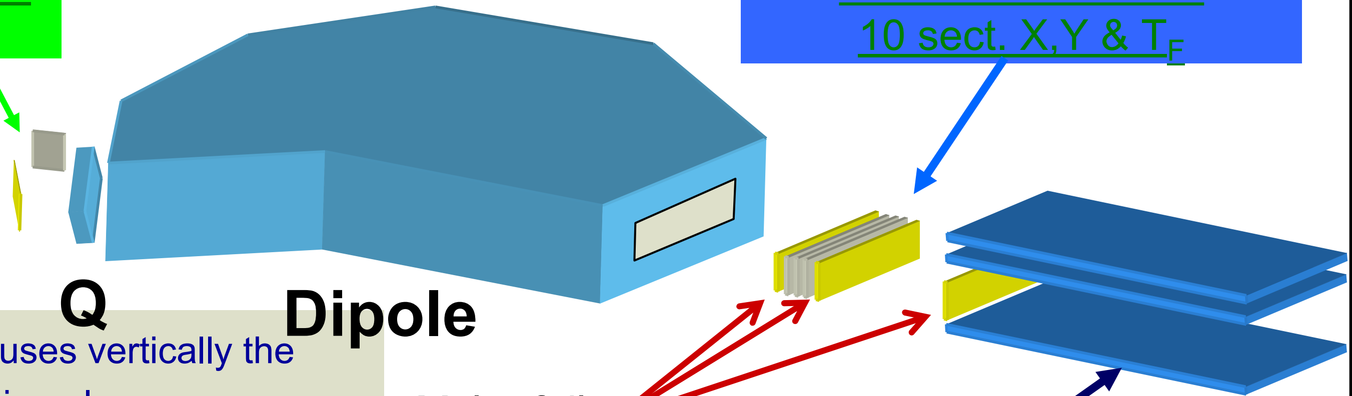
next



MCP Start Detector
$X,Y \; \& \; T_I$

MWPPAC Detector
10 sect. $X,Y \; \& \; T_F$

C foil
20 $\mu g/cm^2$ thick



Mylar foils
1.5 μm thick

Ionisation Chamber
10x4 sect. DE - E

Singlet quadrupole focuses vertically the ions towards the dispersion plane.

Magnetic dipole bends horizontally the ions with respect of their magnetic rigidity $B\rho$

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CLARA

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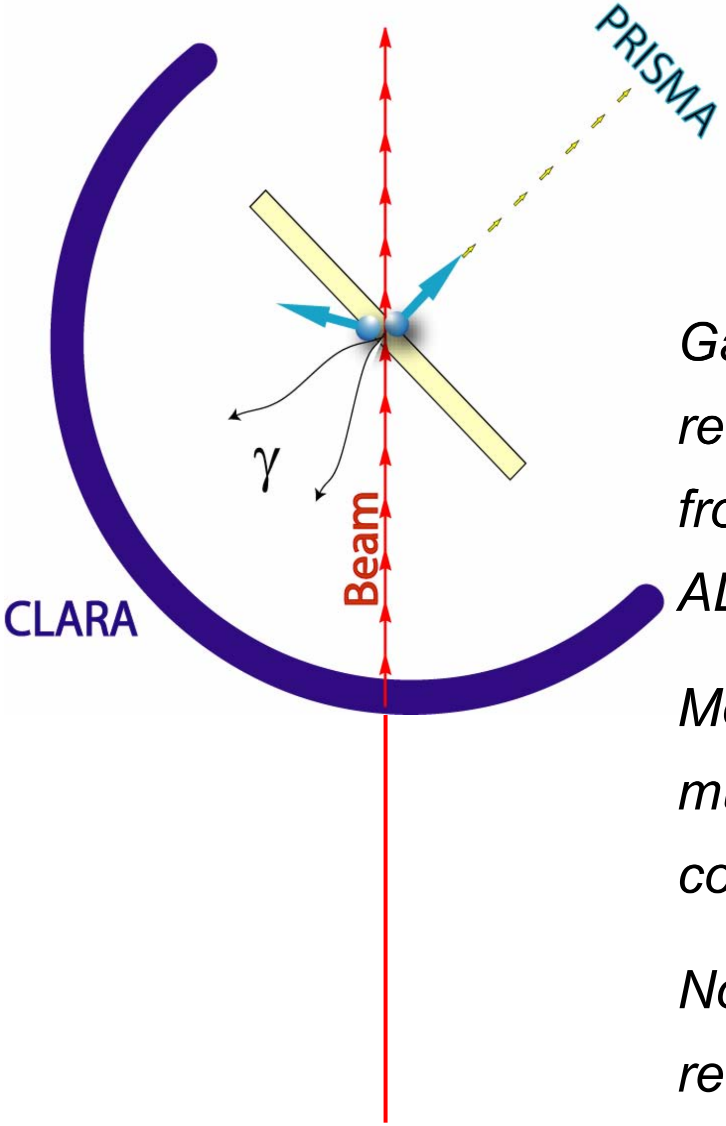
CLARA – PRISMA proposal

A.Gadea (INFN-LNL Legnaro) et al.



Gamma Spectroscopy in products of binary reactions with the “intense” stable beams from the LNL Tandem-ALPI and PIAVE-ALPI

Moderately neutron rich nuclei produced by multi-nucleon transfer or deep inelastic collisions

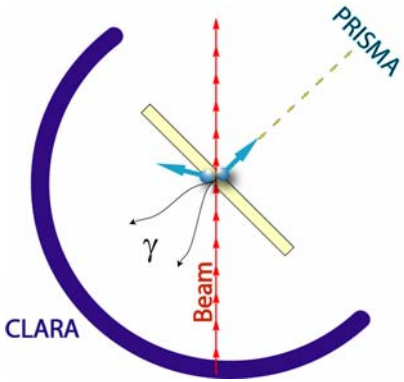
Non-Yrast states populated in quasi-elastic reactions

CLARA

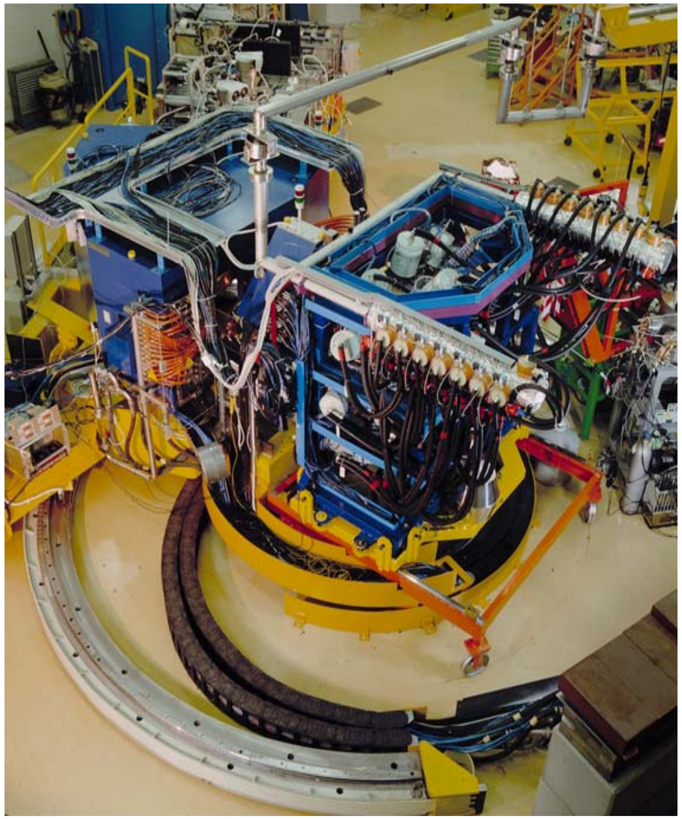
2π coverage

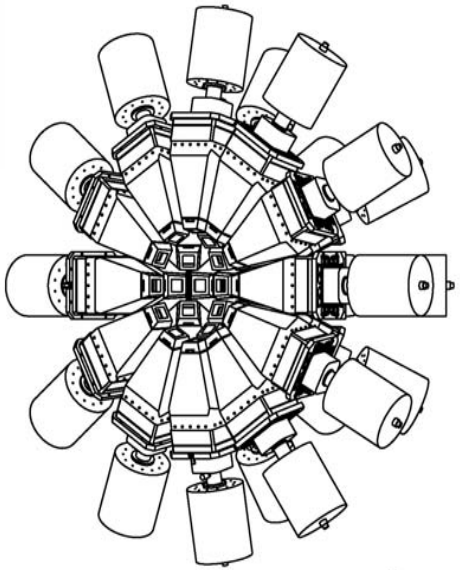
AC BGO shields

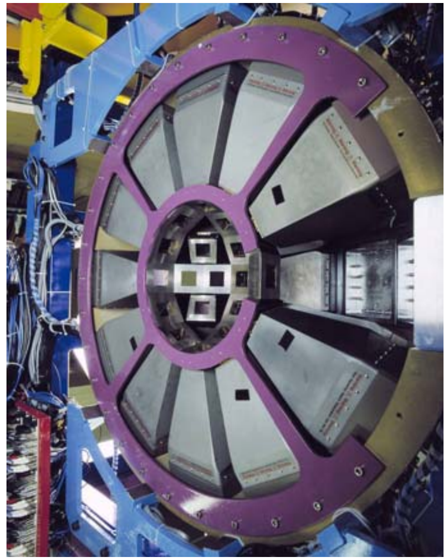
High granularity



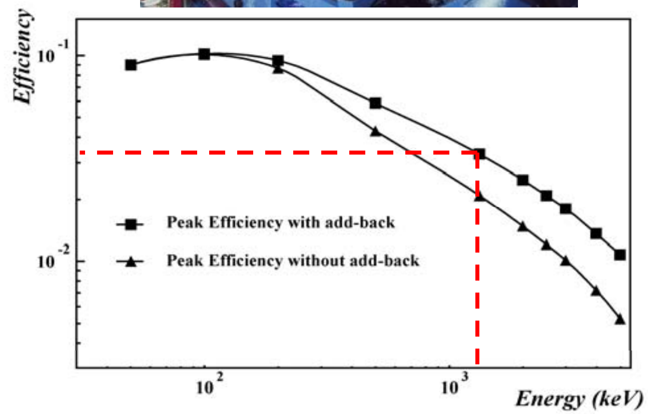
25 Euroball Clover detectors placed at backward angles respect to the optical axis of PRISMA







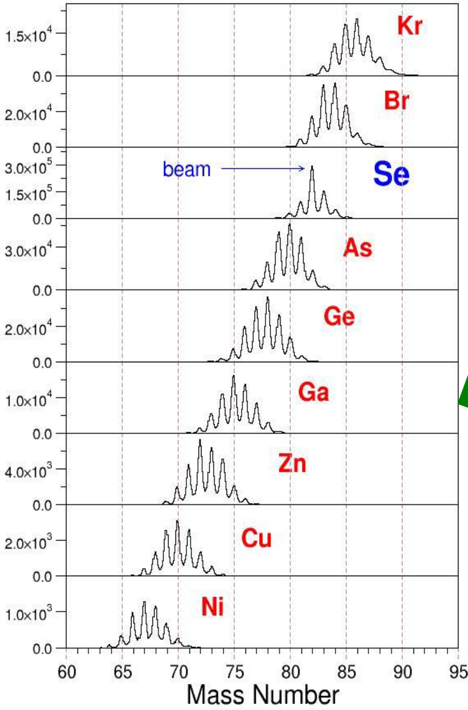
Italy
France
Germany
UK
Romania
Spain

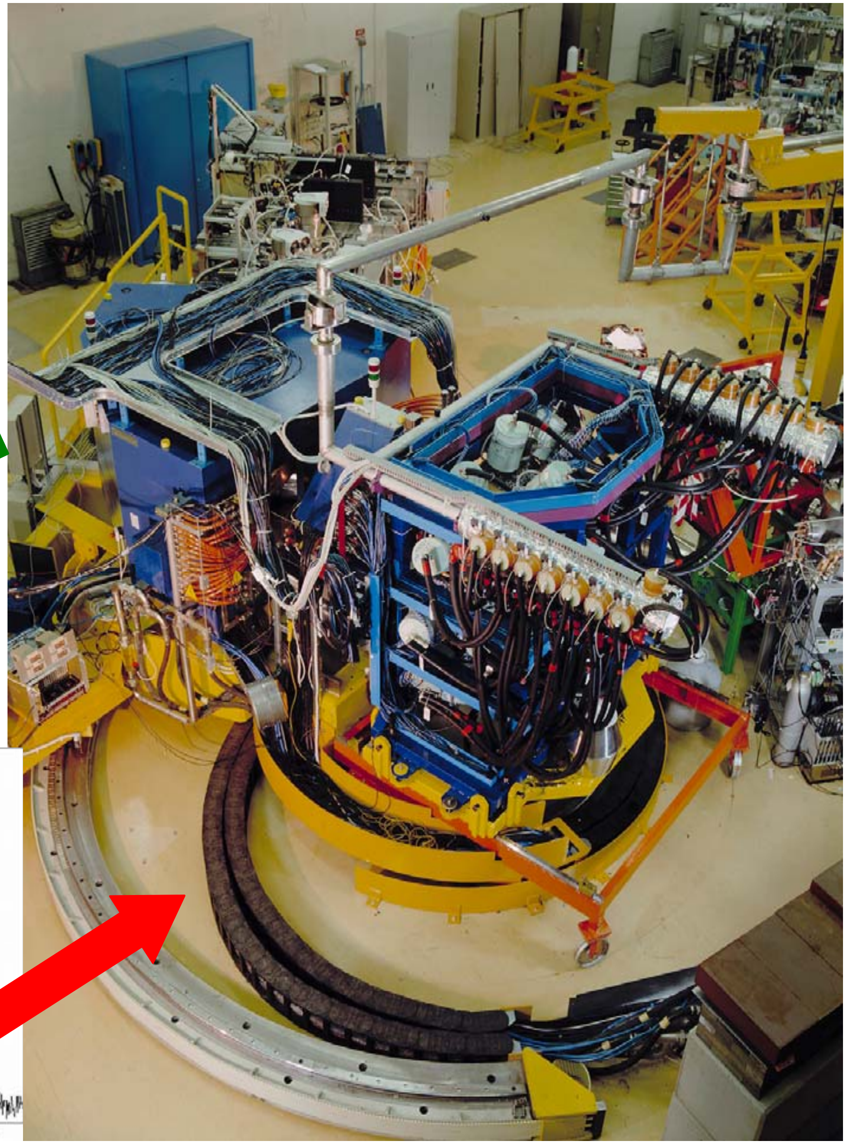


for $E\gamma$ = 1.3 MeV: Efficiency ~ 3 %, Peak / Total ~ 45 %, FWHM ~ 0.8% at v/c = 10 %

For mass and Z identification in coincidence with γ - ray

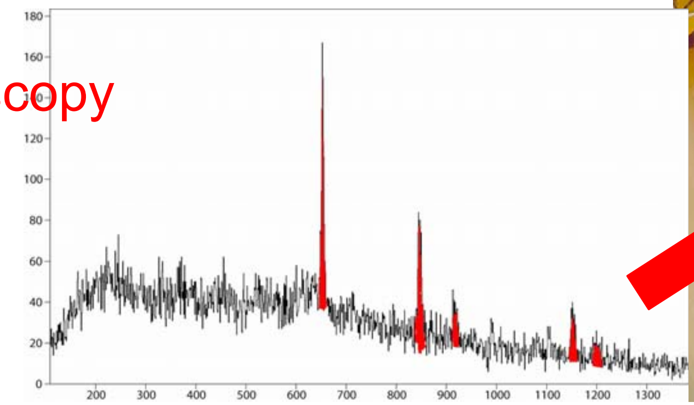
Mass and Z identification





In beam

γ spectroscopy



Analysis of PRISMA/CLARA data

A complete tracking algorithm for PRISMA was developed

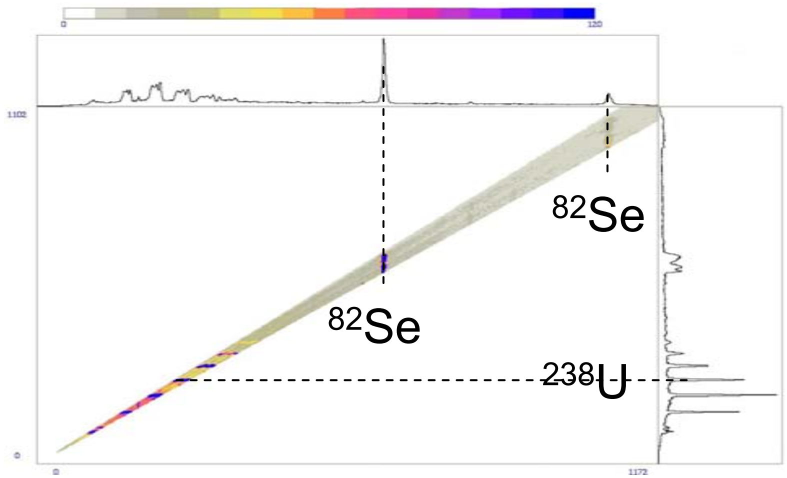
Doppler correction
- precise position on entrance detector
- true recoil velocity

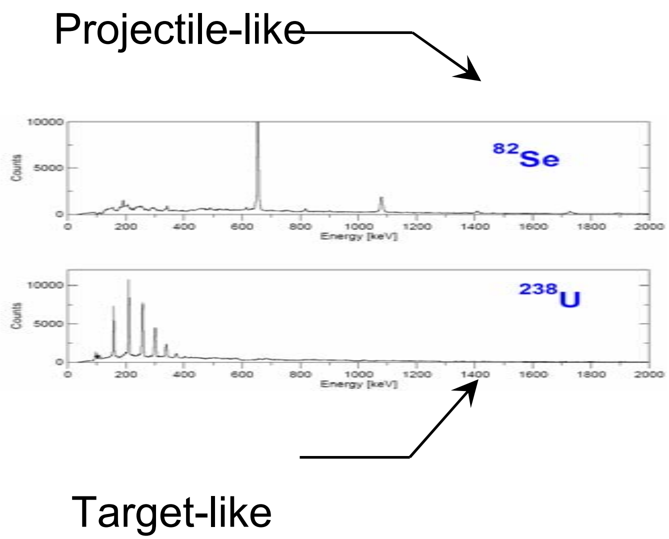
A/q

Charge state
- radius of the trajectory in the dipole
- total energy

Energy resolution < 0.8% at recoil velocity v/c = 10%

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





next

γ spectroscopy with Clara - Prisma at LNL

Recent results

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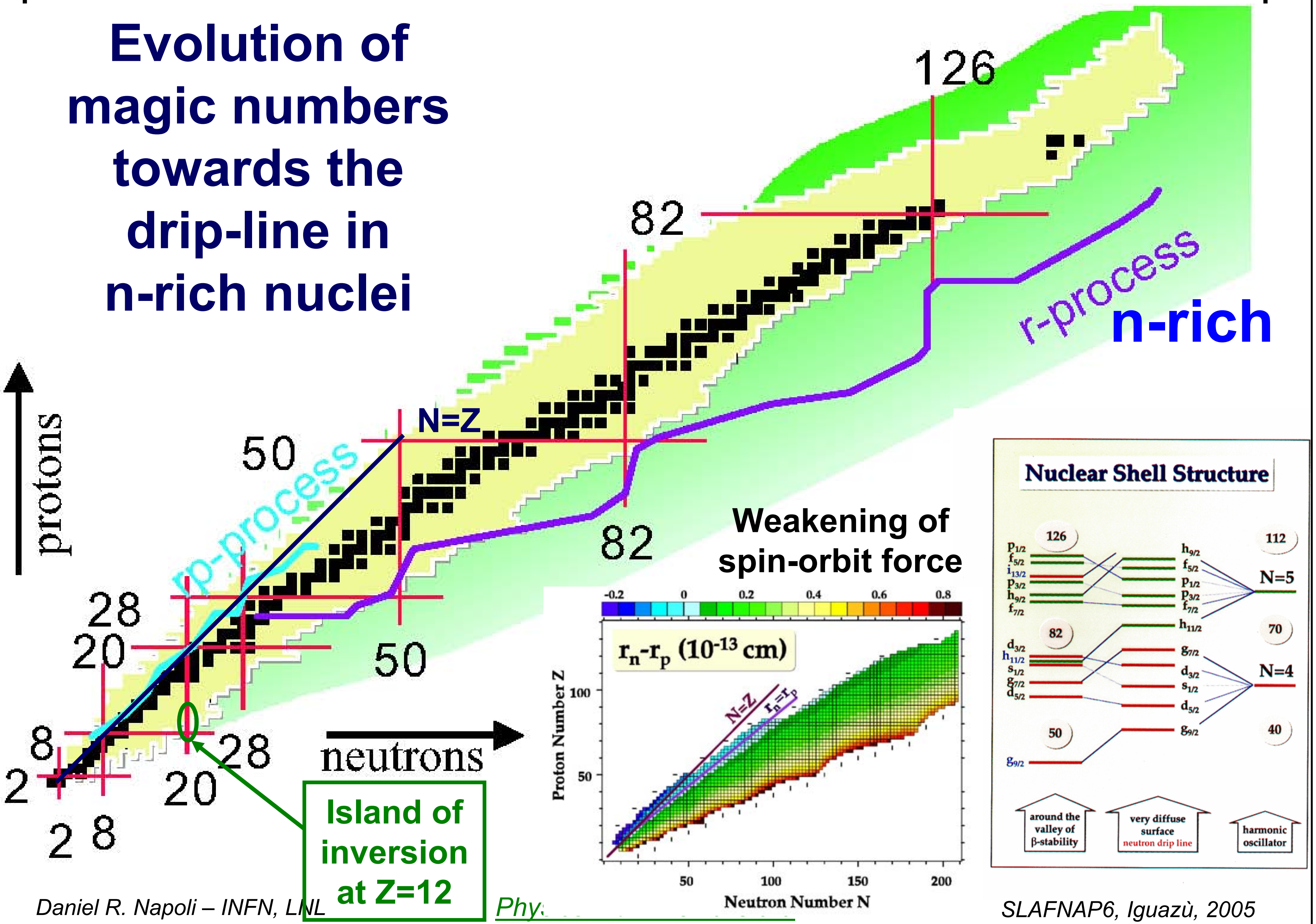
Evolution of magic numbers towards the drip-line in n-rich nuclei



Research activities of Prisma-Clara

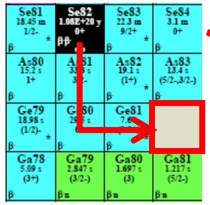
43% of the Tandem-ALPI beam time in 2004

$^{54}Fe+^{50}Cr$

Spectroscopy of ^{54}Co
Isospin non conserving part of the effective interaction

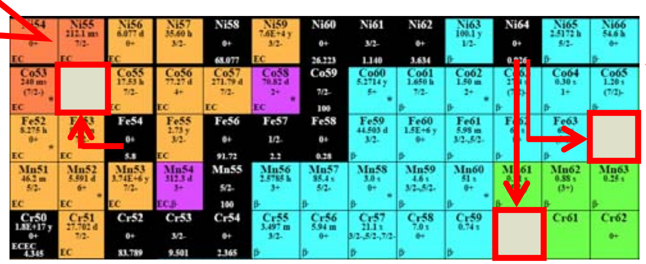
Multi-nucleon transfer

$^{90}Zr+^{208}Pb$



$^{82}Se+^{238}U$

Shell closure evolution at the magic number N=50

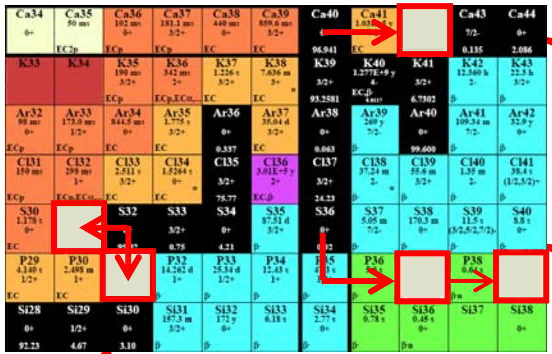


$^{64}Ni+^{238}U$

Shell model A~60

$^{58}Ni+^{60}Ni$

Large-angle scattering



$^{40}Ca+^{208}Pb$

Pairing-vibration states in ^{42}Ca

$^{36}S+^{208}Pb$

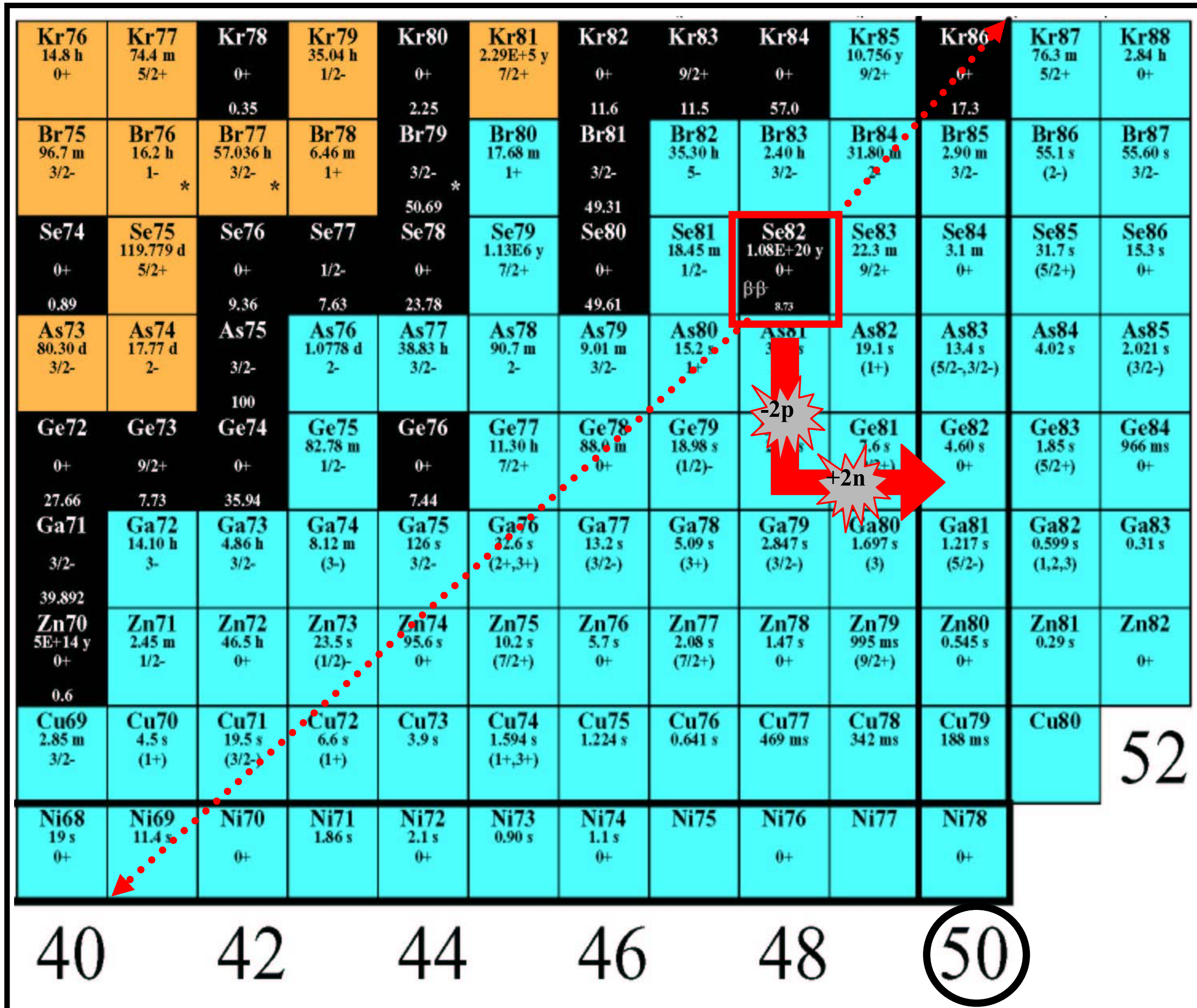
Shell model in ^{37}P and ^{39}P
Breaking of a semi-magic shell closure far from stability

$^{32}S+^{58}Ni$

Mirror pair ^{31}S and ^{31}P

Resonances in $^{24}Mg+^{24}Mg$ and molecular states in ^{48}Cr

$^{24}Mg+^{24}Mg$



$^{82}Se + ^{238}U$

G.Duchene Strasbourg

G.de Angelis Legnaro

Analysis:

N.Marginean Legnaro

4 days,

PRISMA at

θ_G=64°

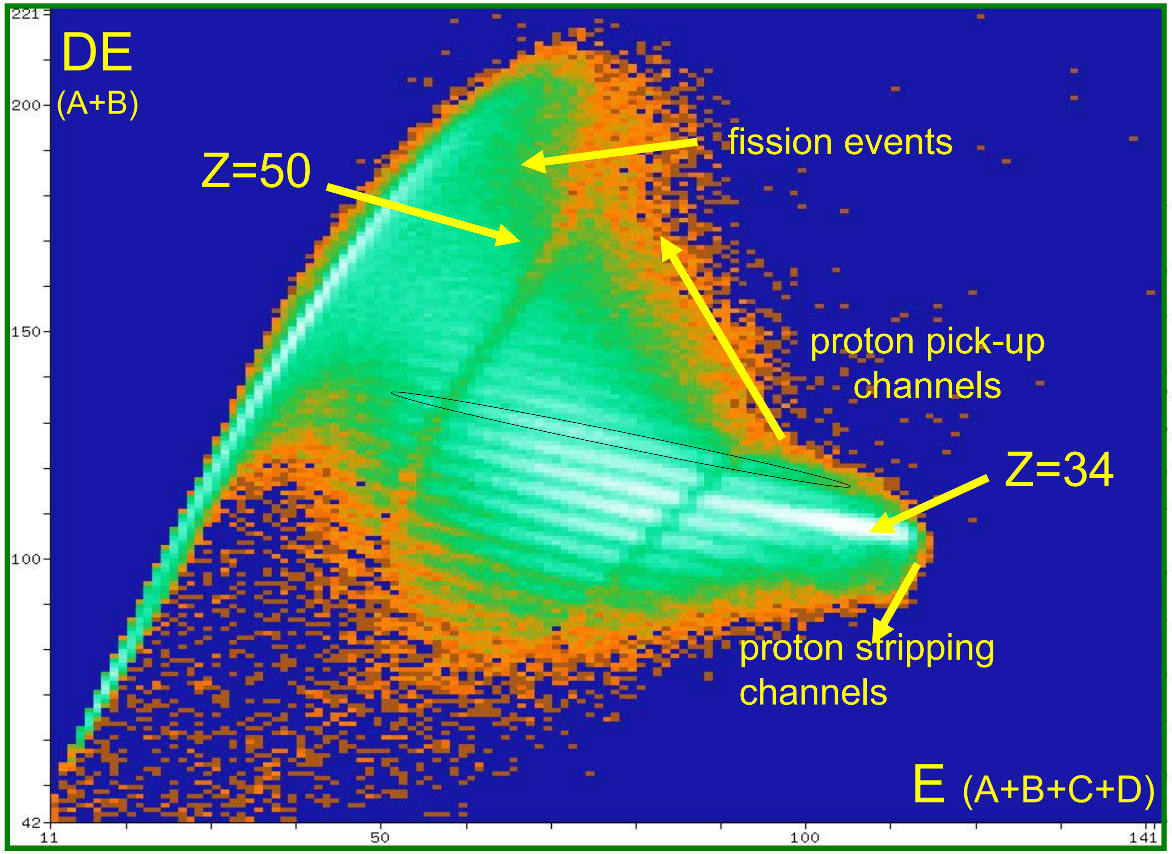
ALPI - Tandem

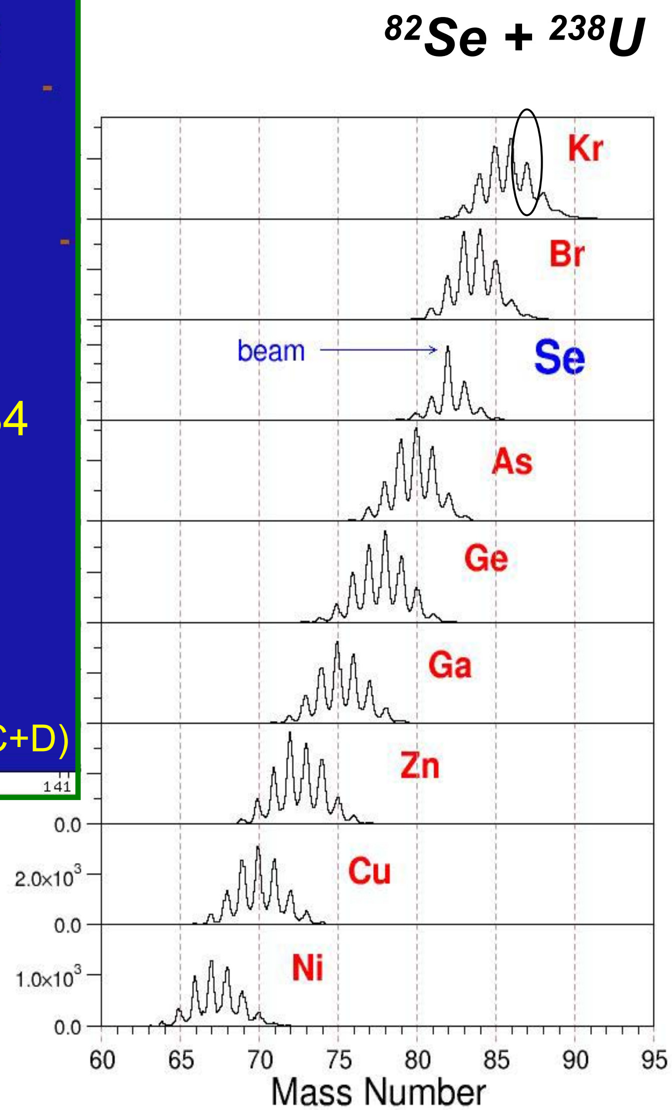
Evolution of the N=50 shell: Searching for the shell gap quenching (onset of deformation as in N=20, Z~12)

Z=32: INM, R.C.Nayak et al. PRC 60 (1999) 064305

Z=24-26: RMF, L.S.Geng et al. nucl-th/0402083

IC ΔE-E Matrix





^{82}Se + ^{238}U, E=505 MeV, θ_G=64°

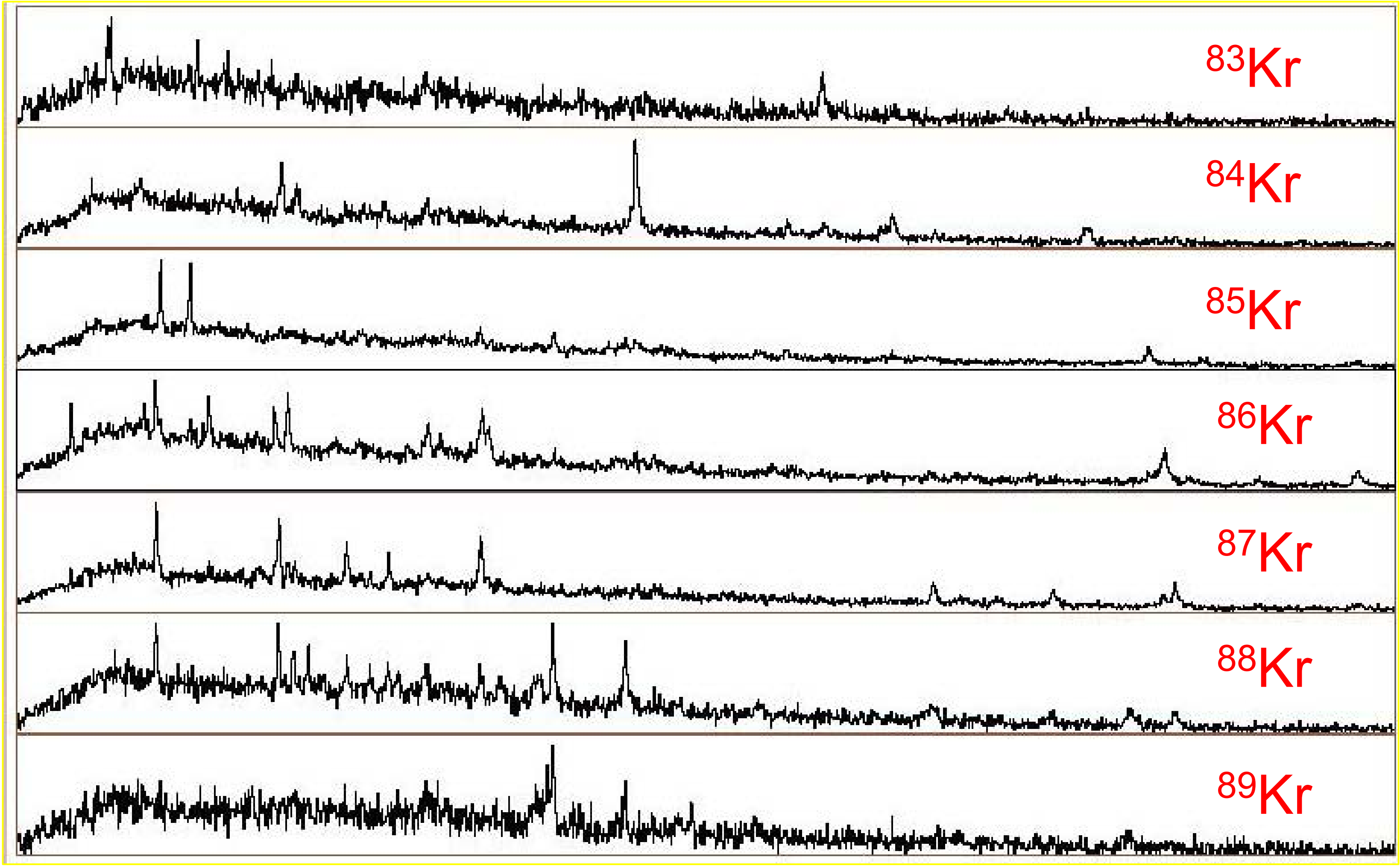
4 days beam time

G.Duchene Strasbourg, G.de Angelis Legnaro

Analysis: N.Marginean Legnaro

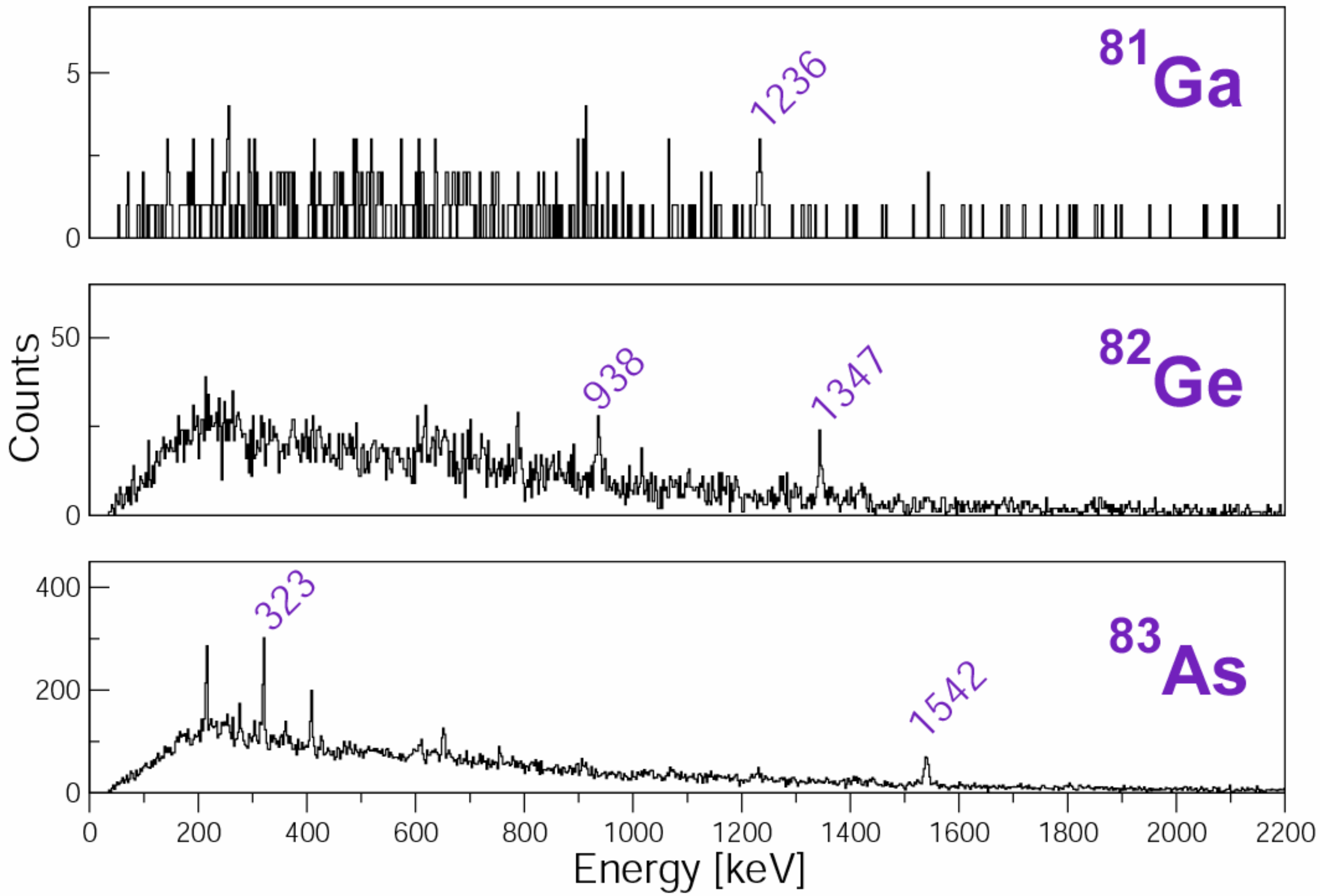
γ-spectroscopy of neutron rich nuclei

Kr isotopes populated in the 505 MeV ^{82}Se + ^{238}U reaction



Spectroscopy of the lightest N=50 isotones

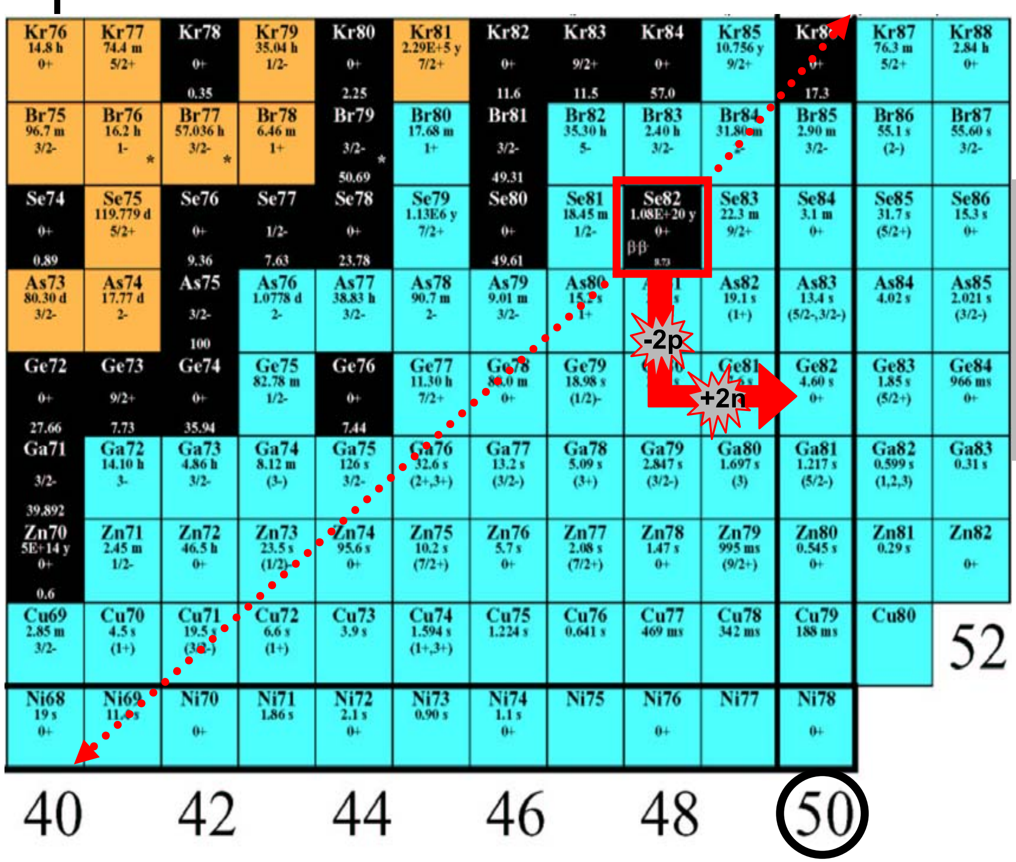
- First observation of γ rays from the decay of ^{81}Ga
- The exitation energy of the 4^+ state in ^{82}Ge firmly established
- First observation of the yrast levels of ^{83}As

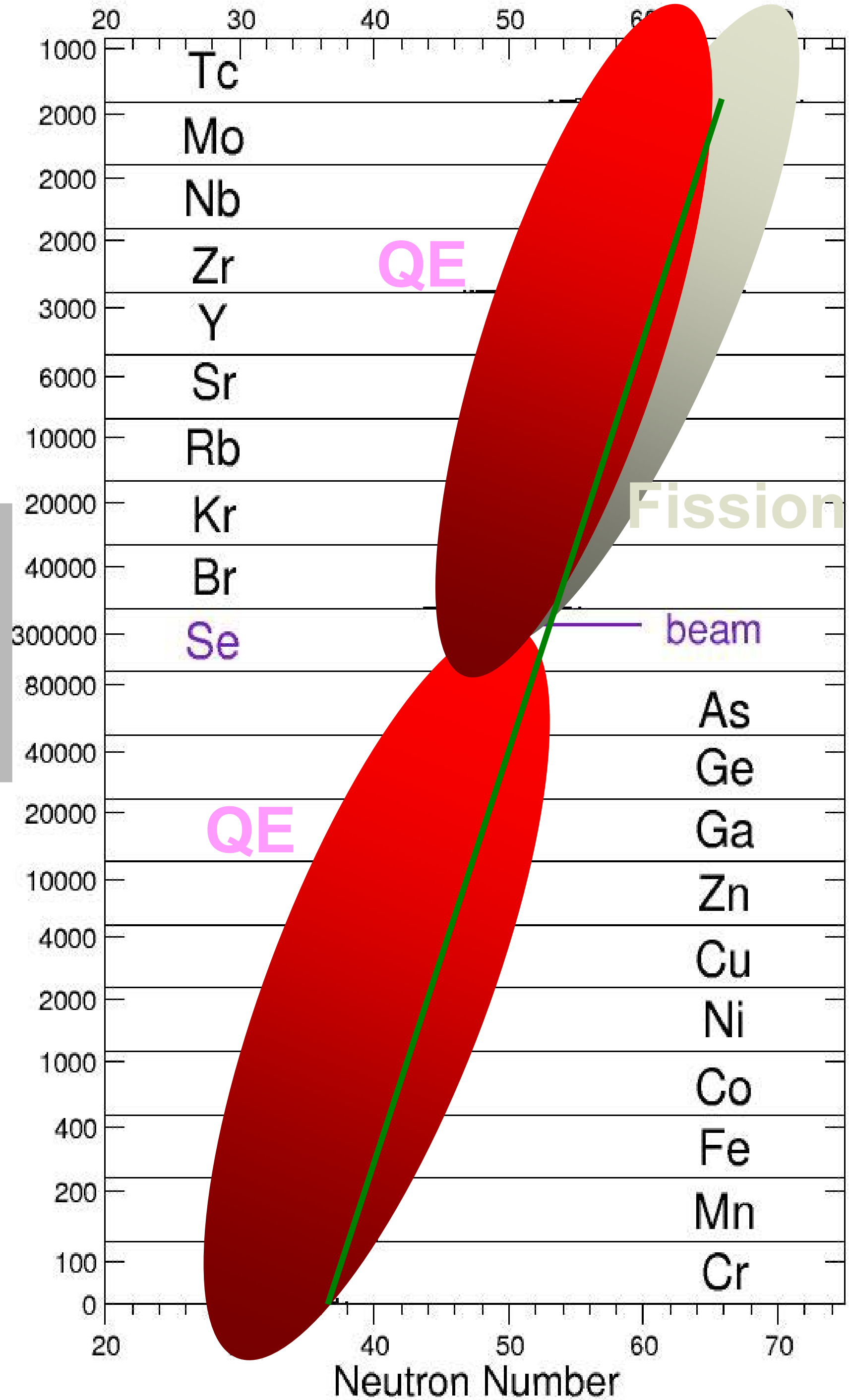


Nuclear spectroscopy of neutron rich nuclei in the N=50 region

^{82}Se + ^{238}U, E=505 MeV, θ_G=64°

4 days beam time

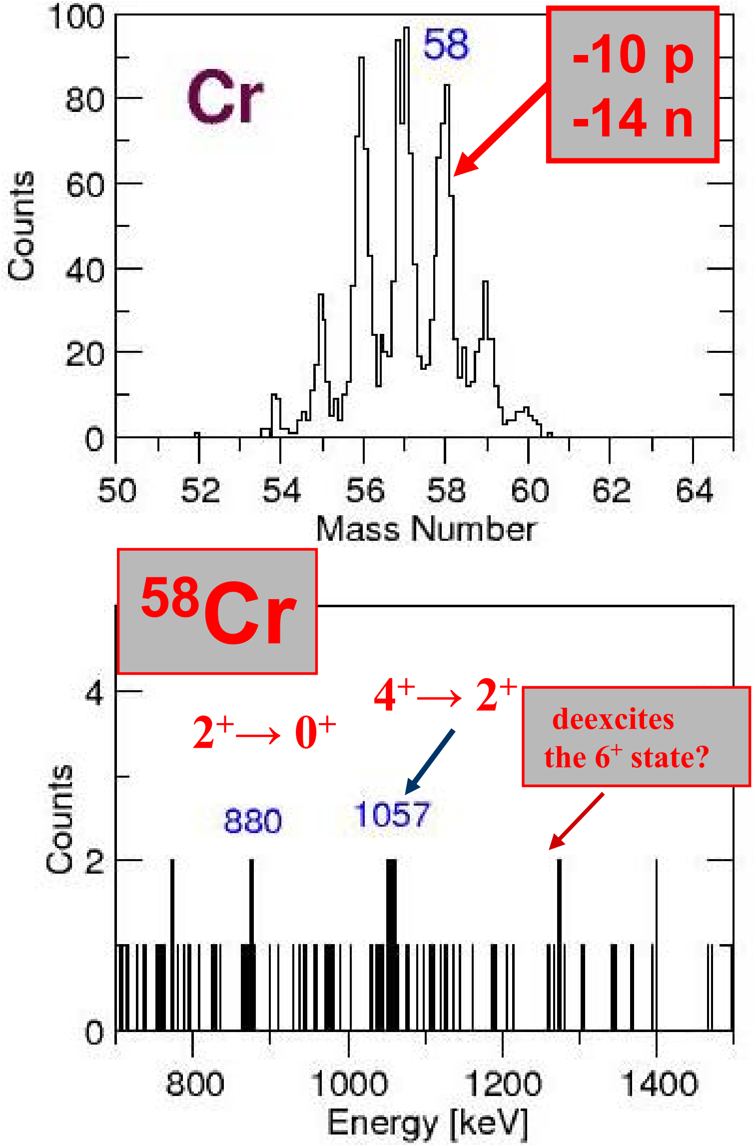




Analysis: N.Marginean Legnaro

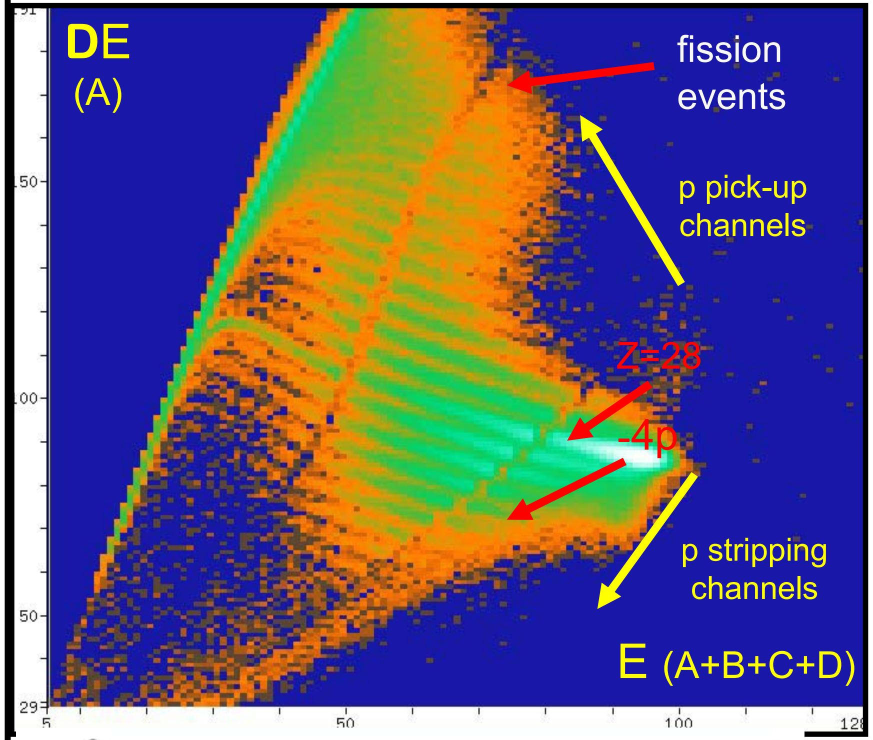
$^{82}Se + ^{238}U$ E=505 MeV

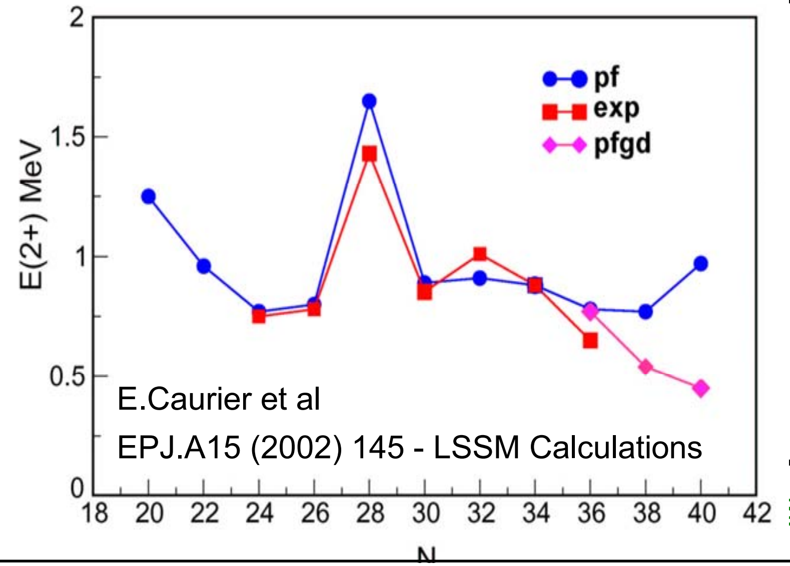
θ_G=64°



24 nucleons removed from projectile

Spectroscopy of deformed neutron rich A ~ 60 nuclei

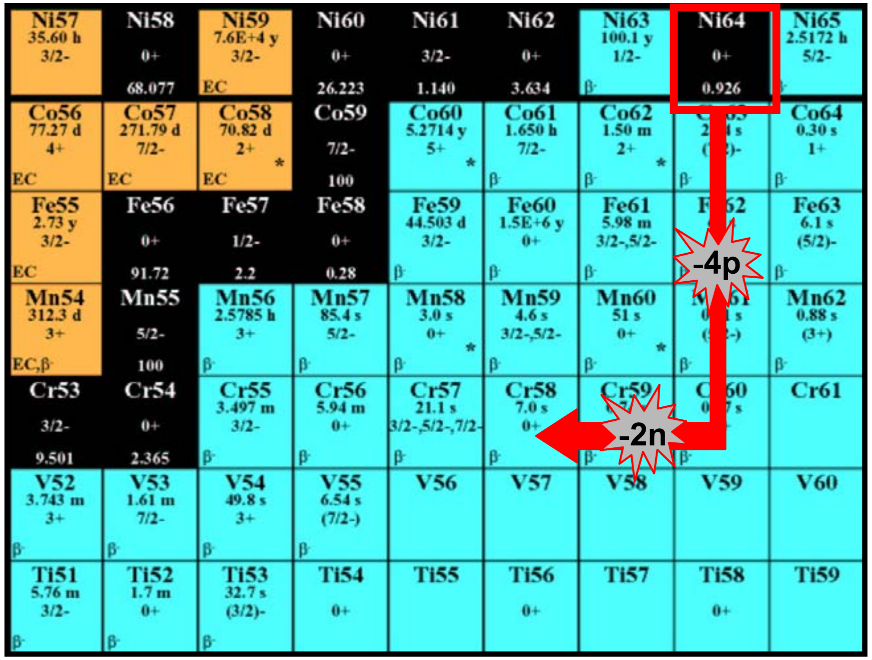


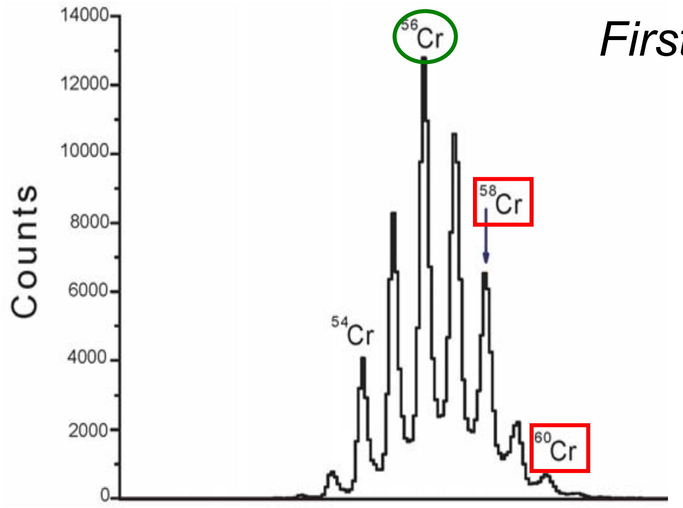


^{64}Ni (404MeV) + ^{238}U

S.M.Lenzi Padova, S.J.Freeman Manchester

To study n-rich A~60 (Cr,Fe &Ti) nuclei, to investigate a new deformation region in the middle of the $\pi f_{7/2}$ νpf-shell, and to test recent SM predictions



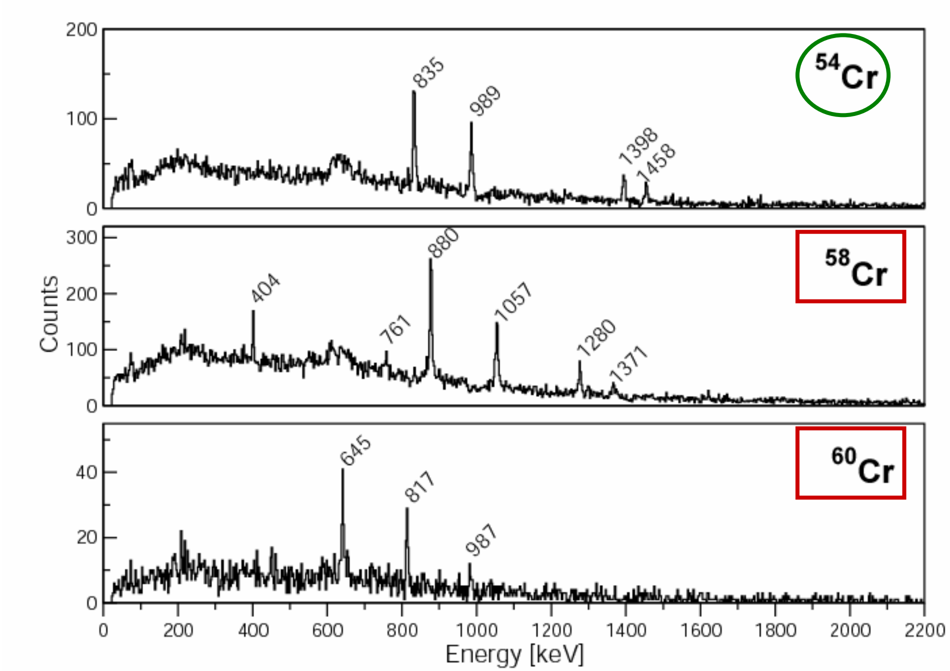


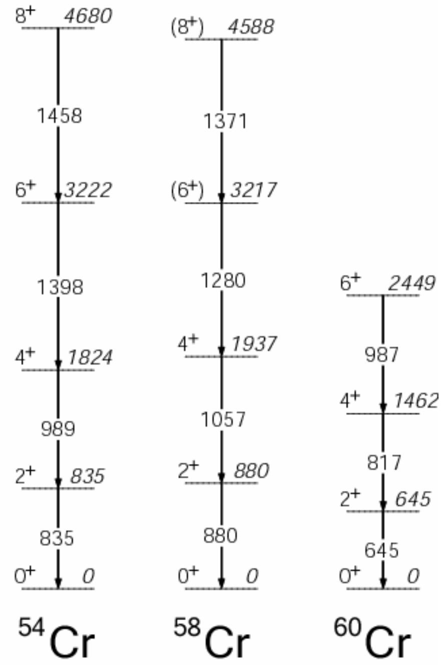
First observation of γ rays from the yrast levels of ^{58}**Cr**

^{64}Ni (400MeV) + *^{238}U*

S.M.Lenzi Padova, S.J.Freeman Manchester

From our data, the 1057 keV transition in ^{58}Cr is the 4+ → 2+ member of the yrast cascade.





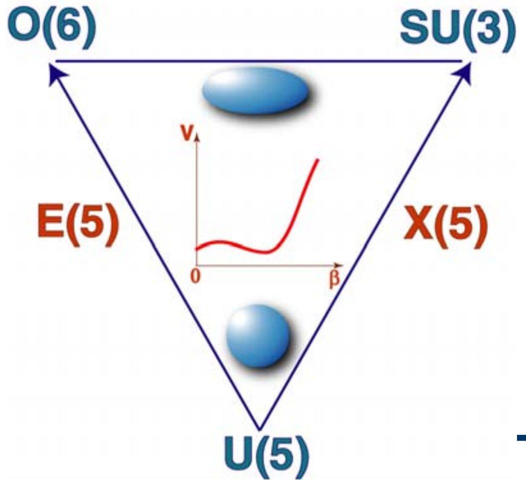
Analysis N.Marginean, LNL

Pure fp shell LSSM calculations reproduce the experimental levels in this slightly deformed nucleus

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

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

^{58}Cr



E(5) critical point symmetry

vibrator to γ-soft rotor

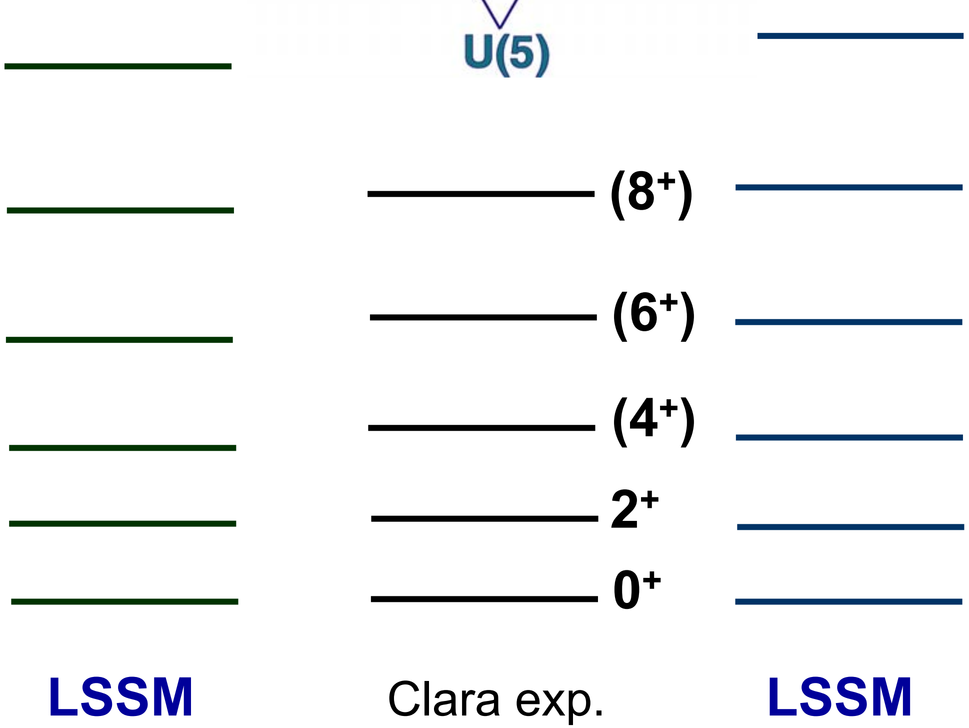
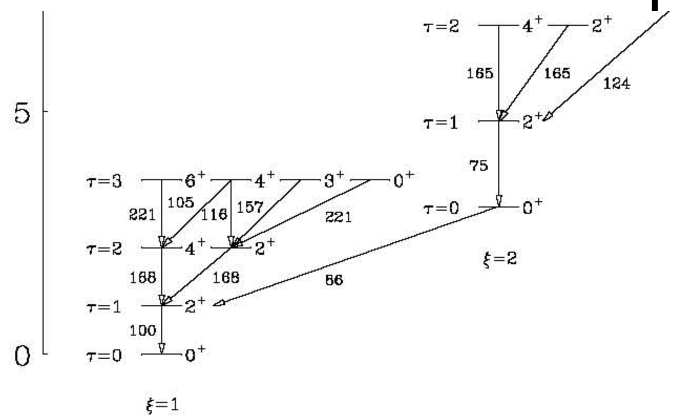


TABLE 1. Excitation energies of the E(5) symmetry.

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



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Dynamic Symmetries at the Critical Point

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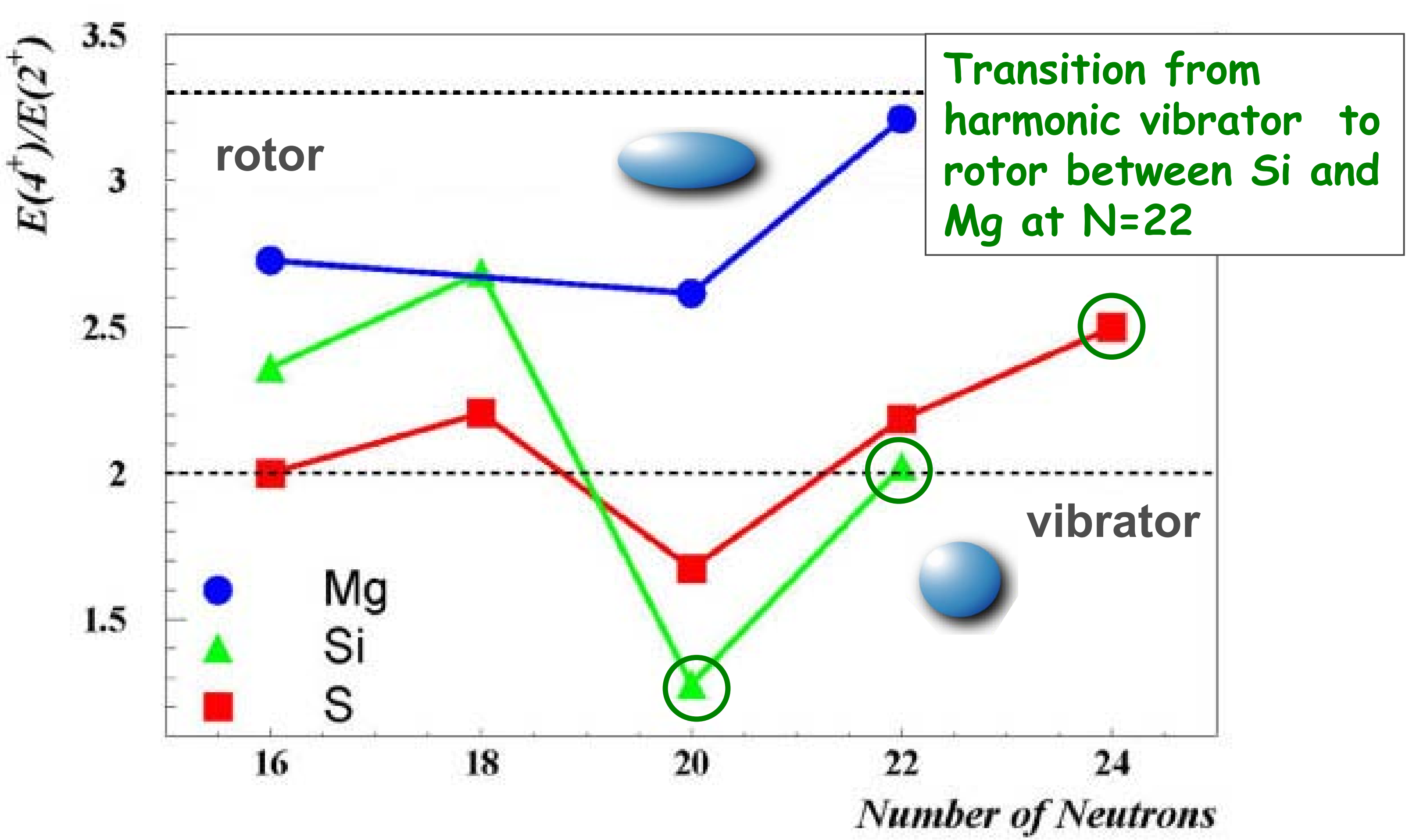
Shell evolution @ N=20

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

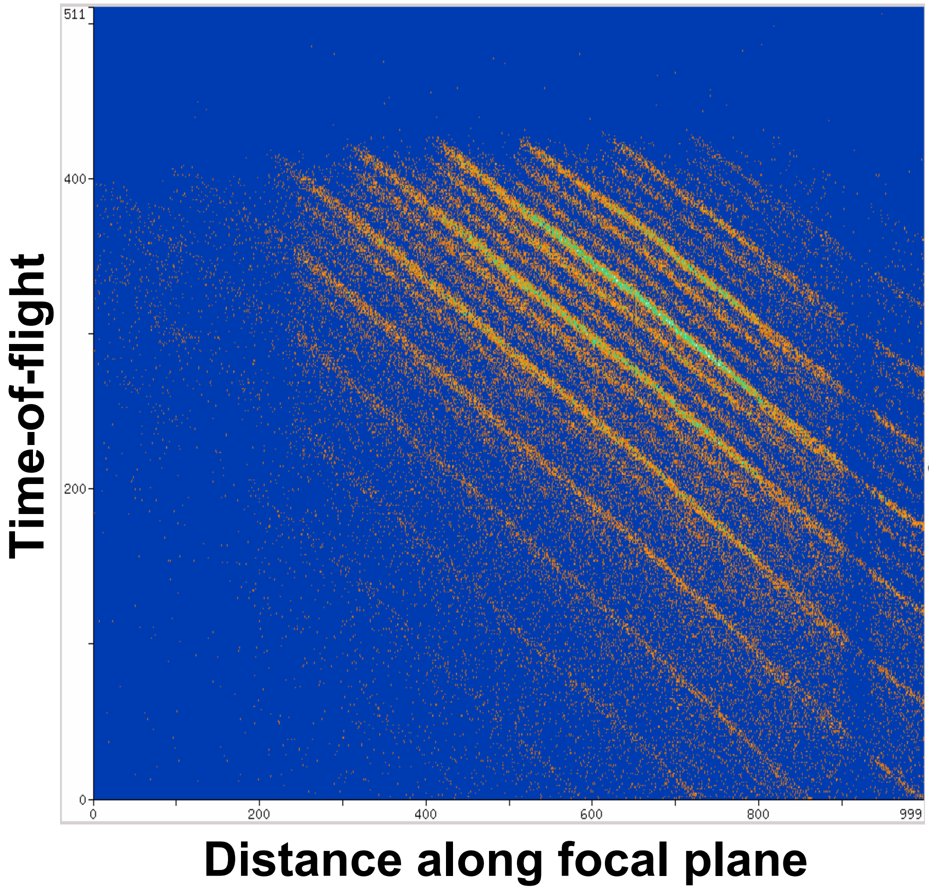


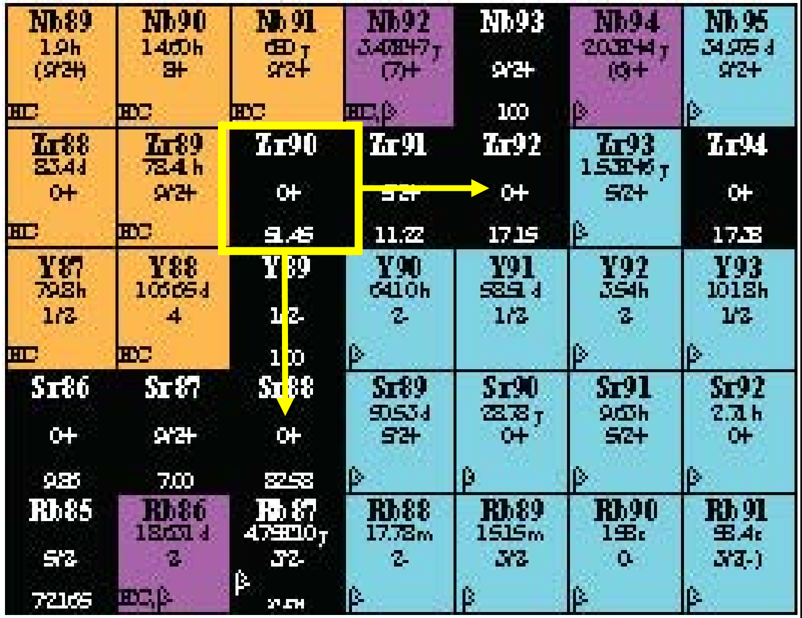
The spacing between the 2^+ and 4^+ can suggest, to good extent the shapes of the N~20 nuclei

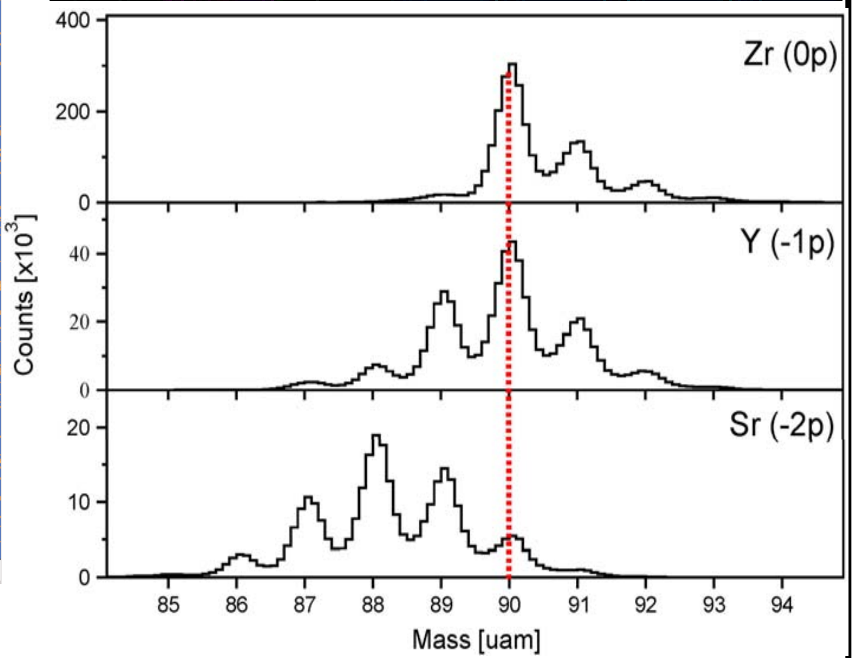
^{90}Zr 560MeV + ^{208}Pb

L.Corradi Legnaro, C.Ur Padova

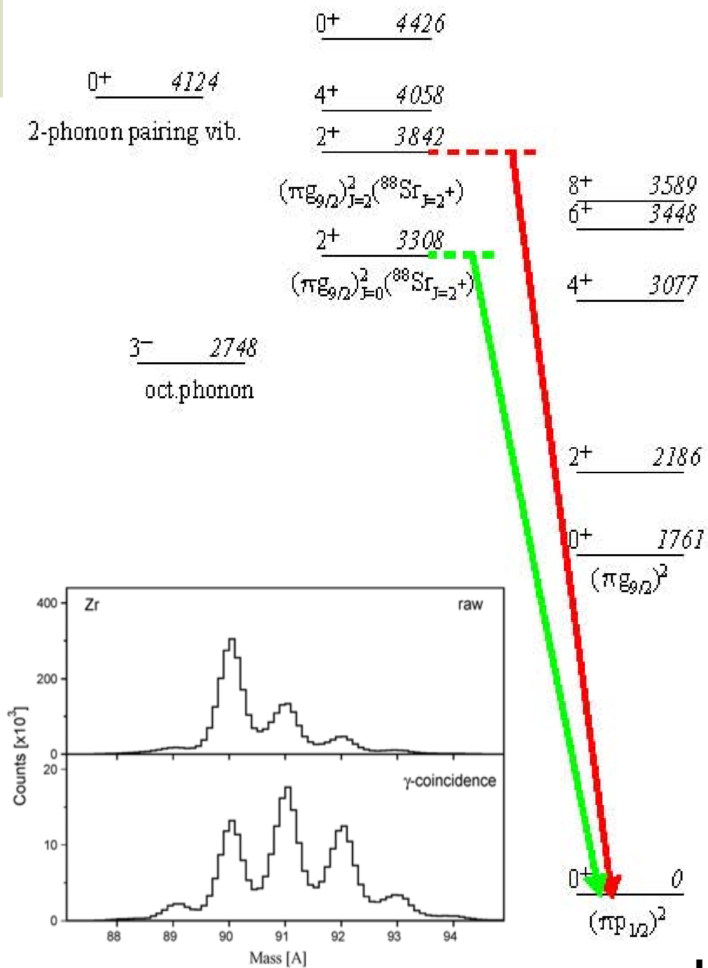
1 day beam run



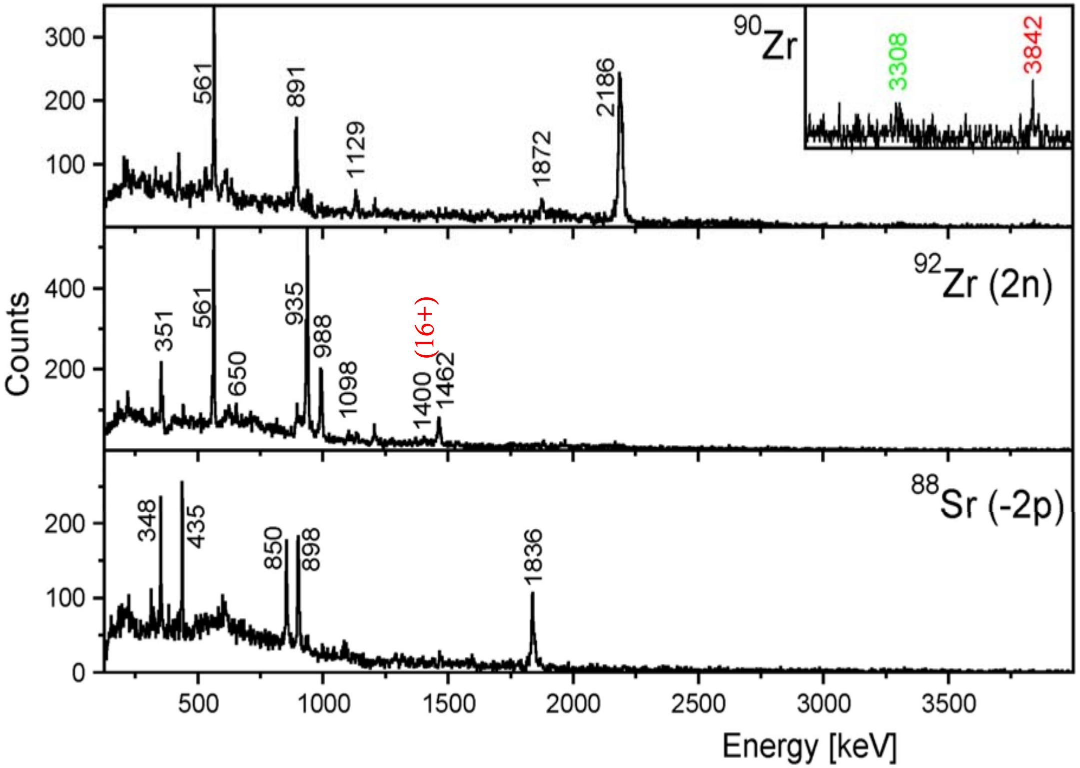




^{90}Zr 560MeV + ^{208}Pb: ^{90}Zr, ^{92}Zr(+2n), ^{88}Sr(-2p)



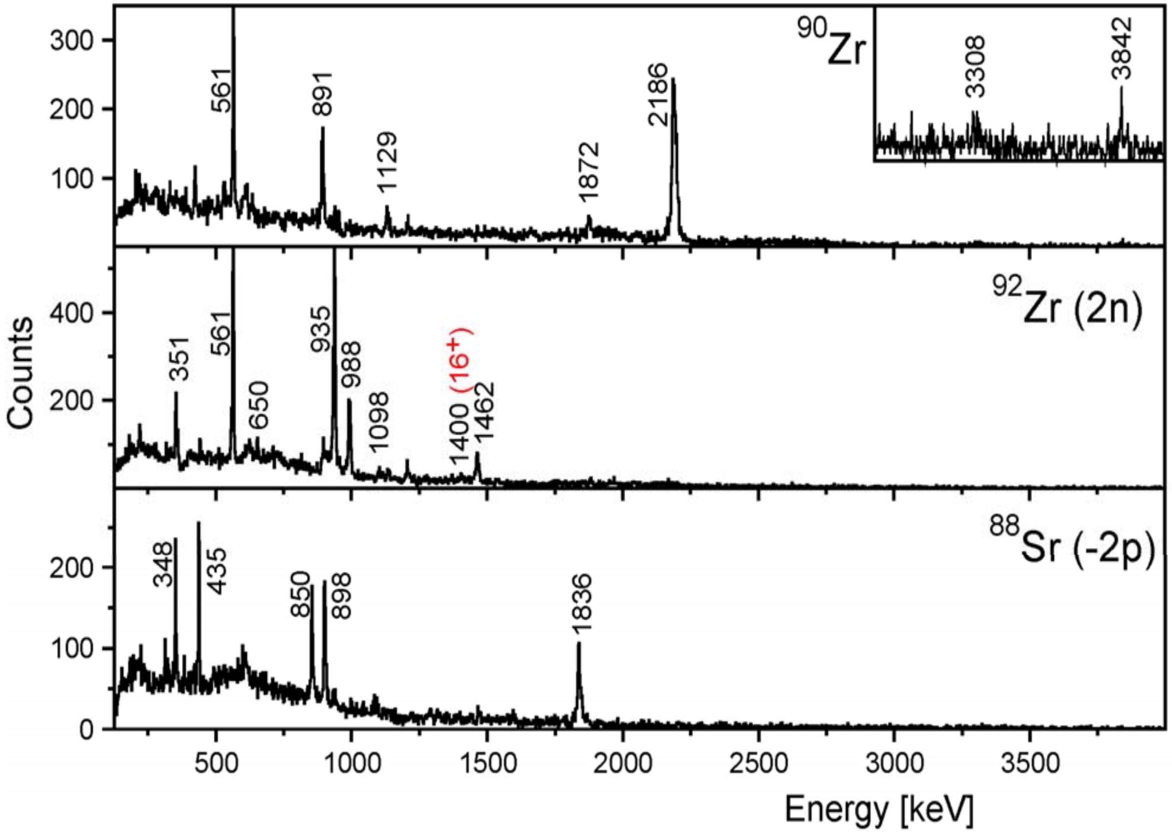
L.Corradi, C.A.Ur et al.



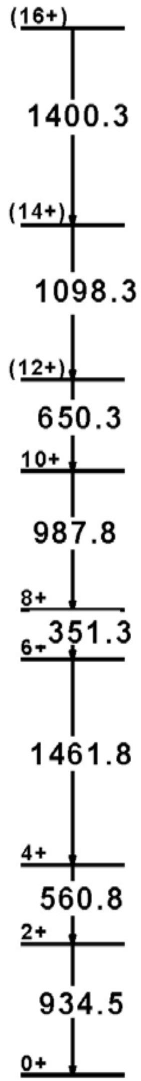
Level Scheme from:
$^{90}Zr(n,n`g)$
P.E.Garrett et al.
PRC68 (2003)024312

^{90}Zr 560MeV + ^{208}Pb : ^{92}Zr

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



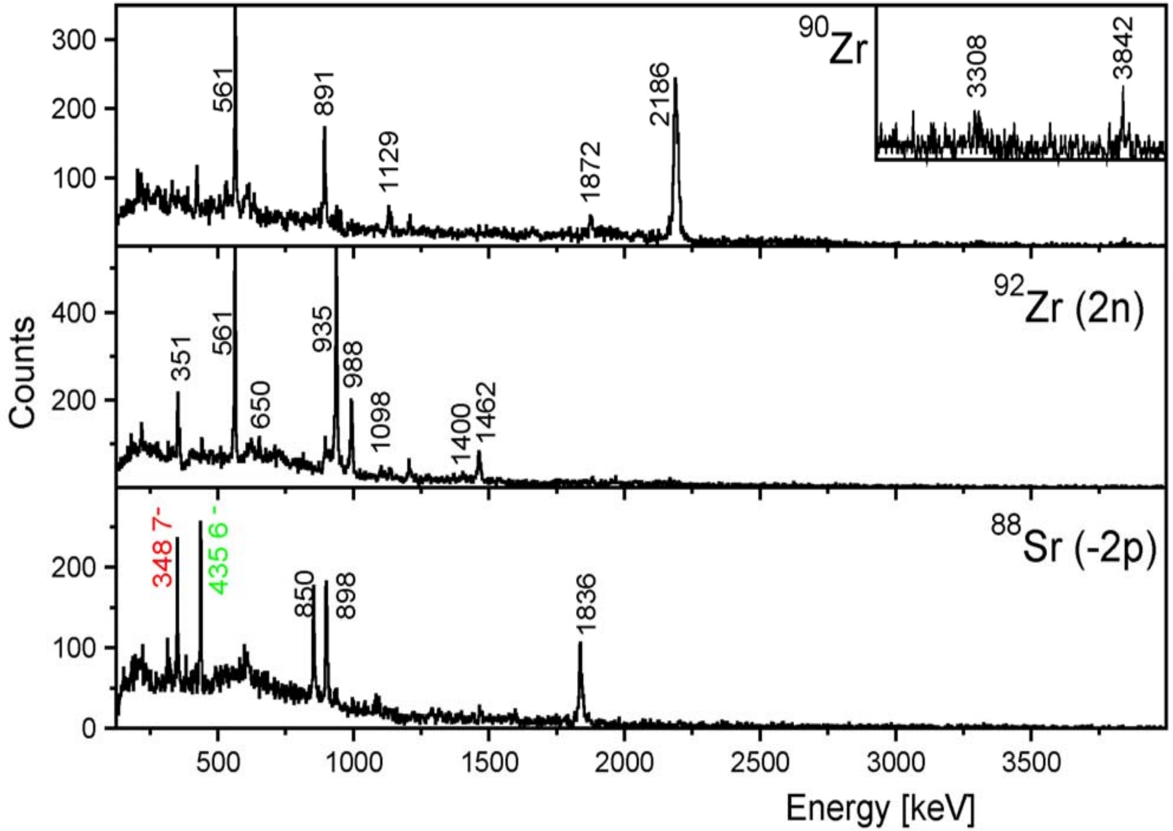
Adopted NNDC Level Scheme
^{92}Zr

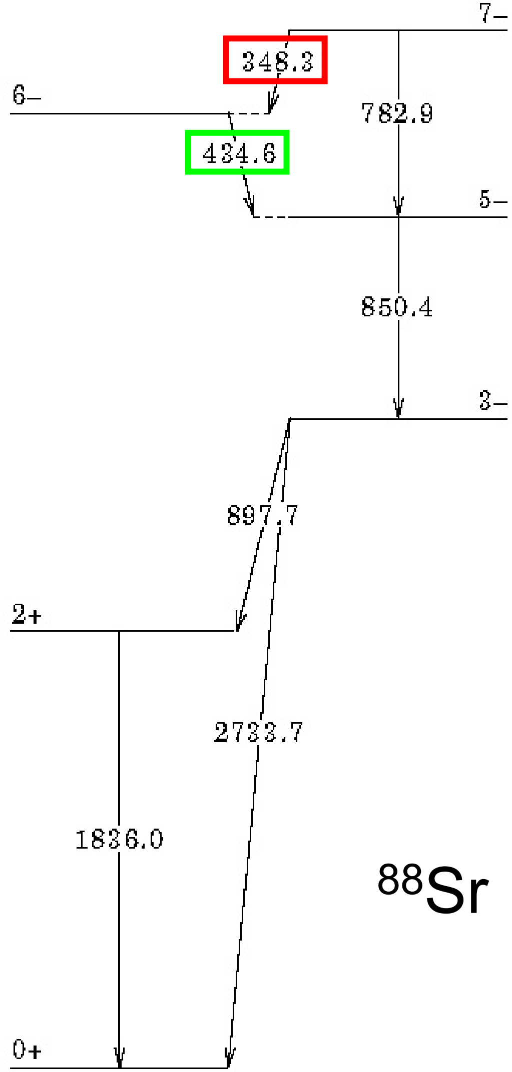


^{90}Zr 560MeV + ^{208}Pb : ^{88}Sr

Adopted NNDC Level Scheme

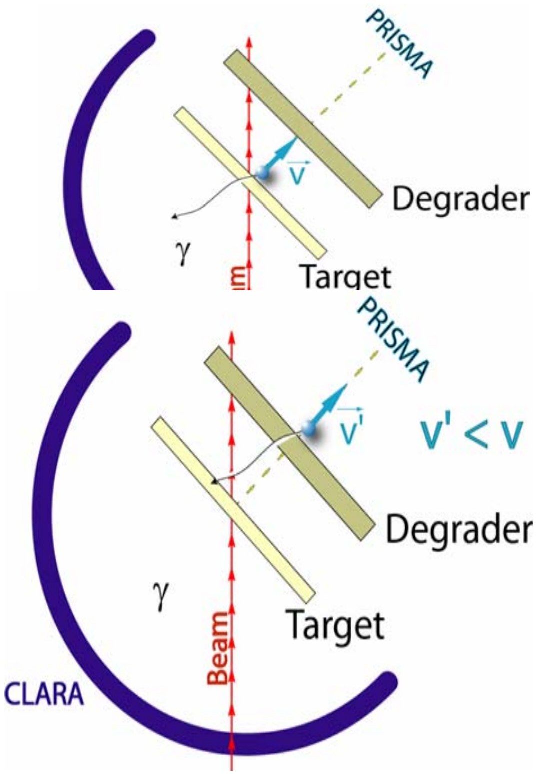
L.Corradi, C.A.Ur et al.



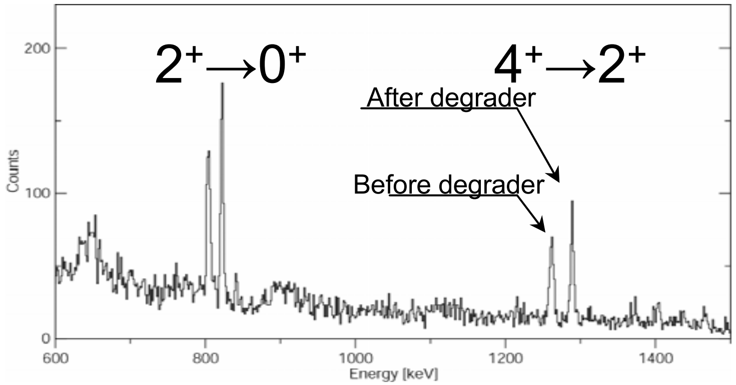


Differential plunger with PRISMA/CLARA

- Consists in having an energy degrader at fixed distance after the target
- The gamma rays emitted before or after the recoil passes the degrader will have different Doppler shifts
- The lifetimes will be obtained from the intensity ratio before/after degrader



^{60}Fe – simulation based on existing experimental data



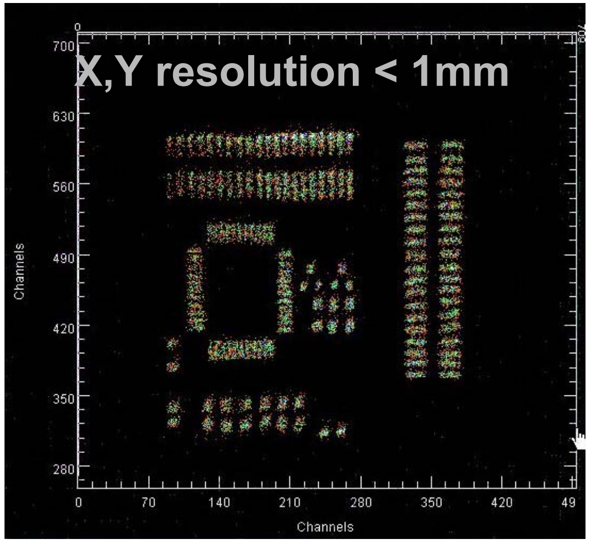
DANTE

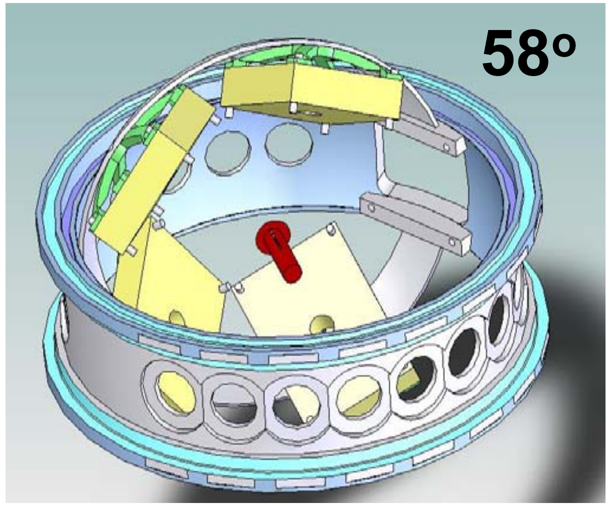
MCP Detector array

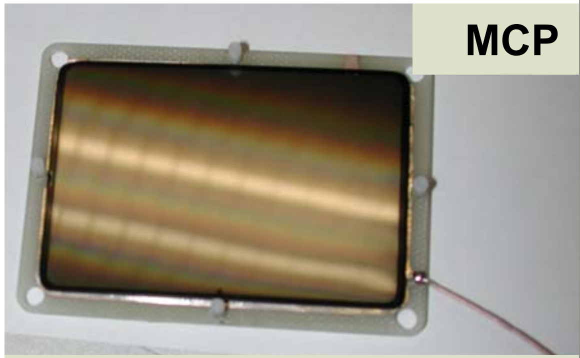
γ–PRISMA

γ–γ–DANTE

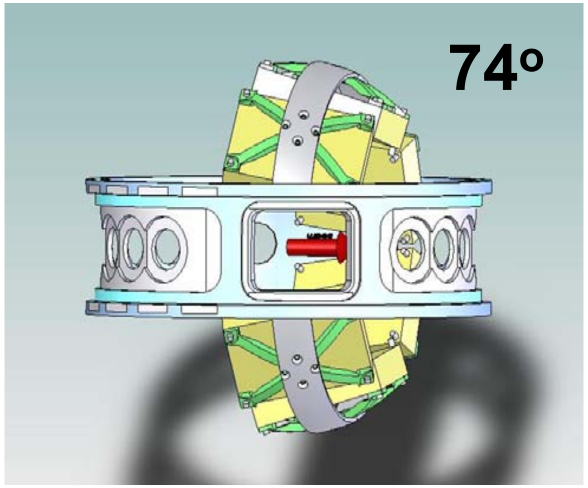
3% → 20% of 4π







first prototype of DANTE



J.J. Valiente-Dobon, et al. in collaboration with FLNR Dubna

Summary

- ***The CLARA-PRISMA setup consisting on an array of 25 EUROBALL Clover detectors coupled with the large acceptance magnetic spectrometer PRISMA is starting its second year of operation at LNL.***
- ***The first preliminary results show the capabilities of such installation in combination with the stable beam delivered by the LNL Tandem-ALPI complex and gives good perspectives for the future, with PIAVE-ALPI.***
- ***In a single experiment ~ 50 nuclei can be studied.***
- ***At the present stage of the instrument and for most cases, additional experimental information is required to build up 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***
- ***Near future improvements: ECR-Piave beams, Dante (γ–γ), Lifetimes…***

CLARA-PRISMA collaboration

- *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*
- *Romania*
  - *NIPNE Bucharest*
- *France*
  - *IReS Strasbourg*
  - *GANIL Caen*
- *UK*
  - *University of Manchester*
  - *Daresbury Laboratory*
  - *University of Surrey*
  - *University of Paisley*
- *Germany*
  - *HMI Berlin*
  - *GSI Darmstadt*
- *Spain*
  - University of Salamanca

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