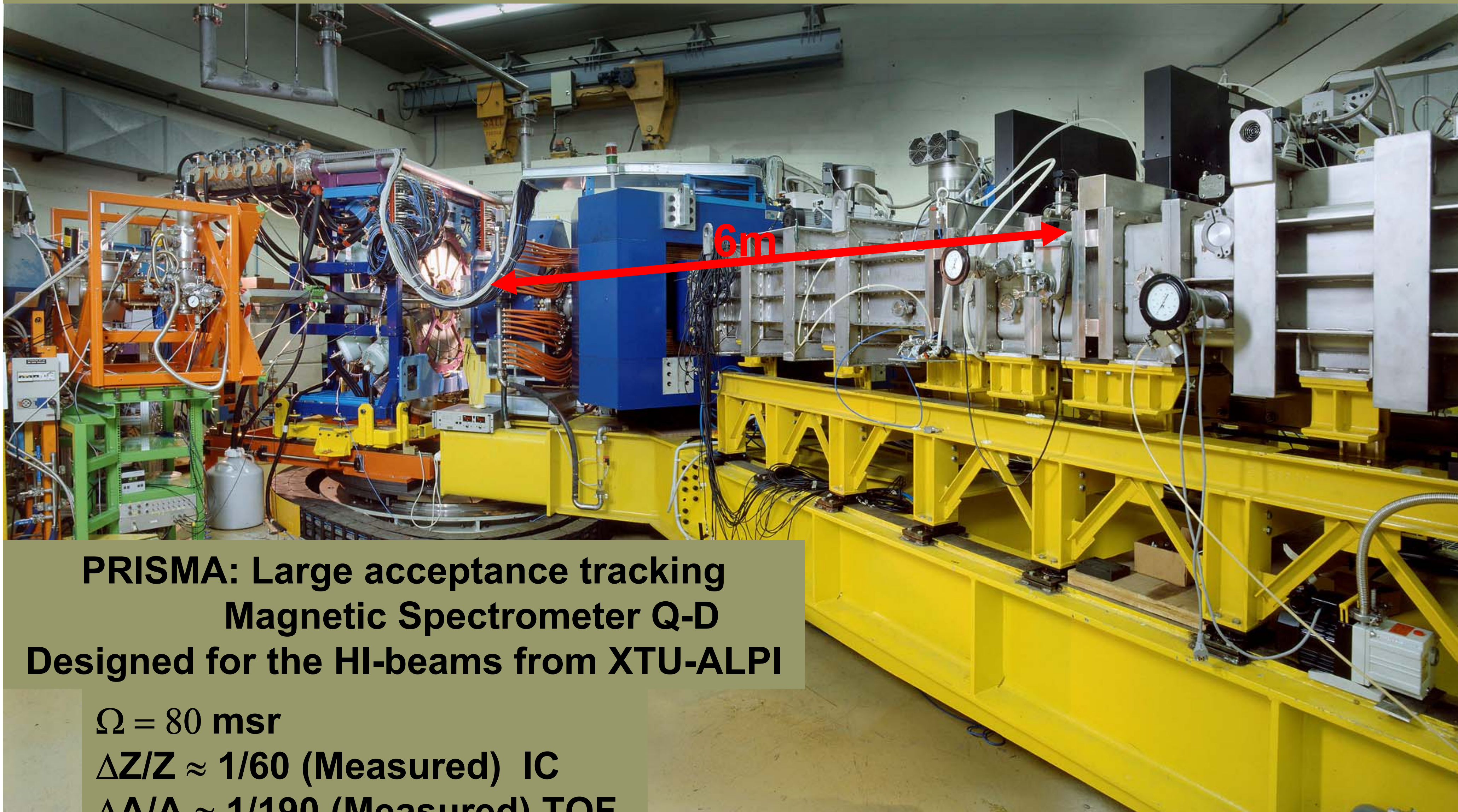
Spectroscopy of n-rich nuclei with CLARA-PRISMA

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

- Description of the setup
- Grazing reactions as mechanism to study the structure of moderately neutron-rich nuclei
- Results on n-rich medium mass (A~80 and A~60) nuclei
- Perspectives with CLARA-PRISMA and the AGATA Demonstrator-PRISMA setup



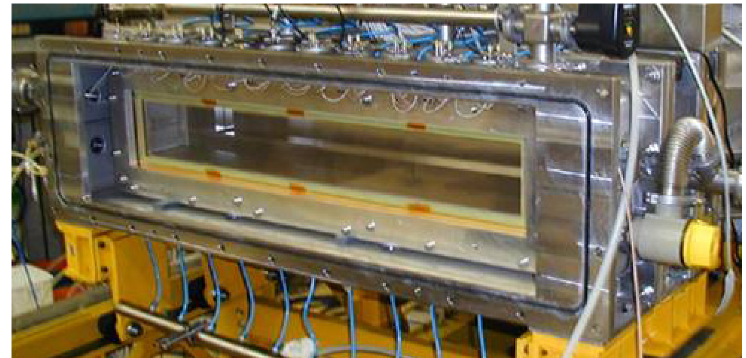
PRISMA: Large acceptance tracking Magnetic Spectrometer Q-D
Designed for the HI-beams from XTU-ALPI

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

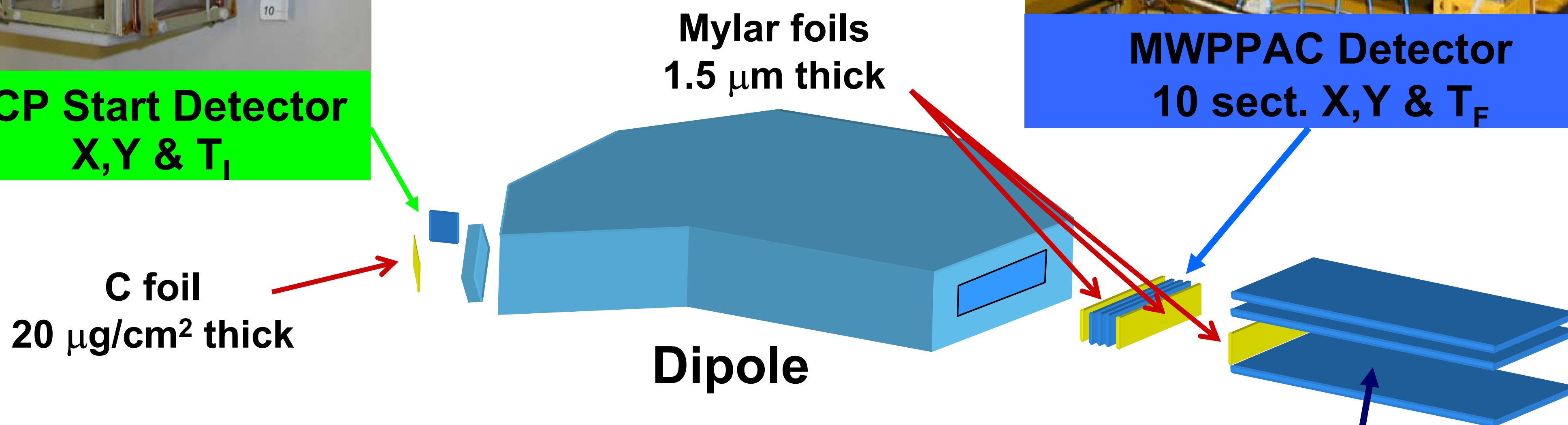
Note: Dispersion 4cm / 1%, focal plane 1m

THE PRISMA DETECTORS

MCP Start Detector
X,Y & T_I



MWPPAC Detector
10 sect. X,Y & T_F

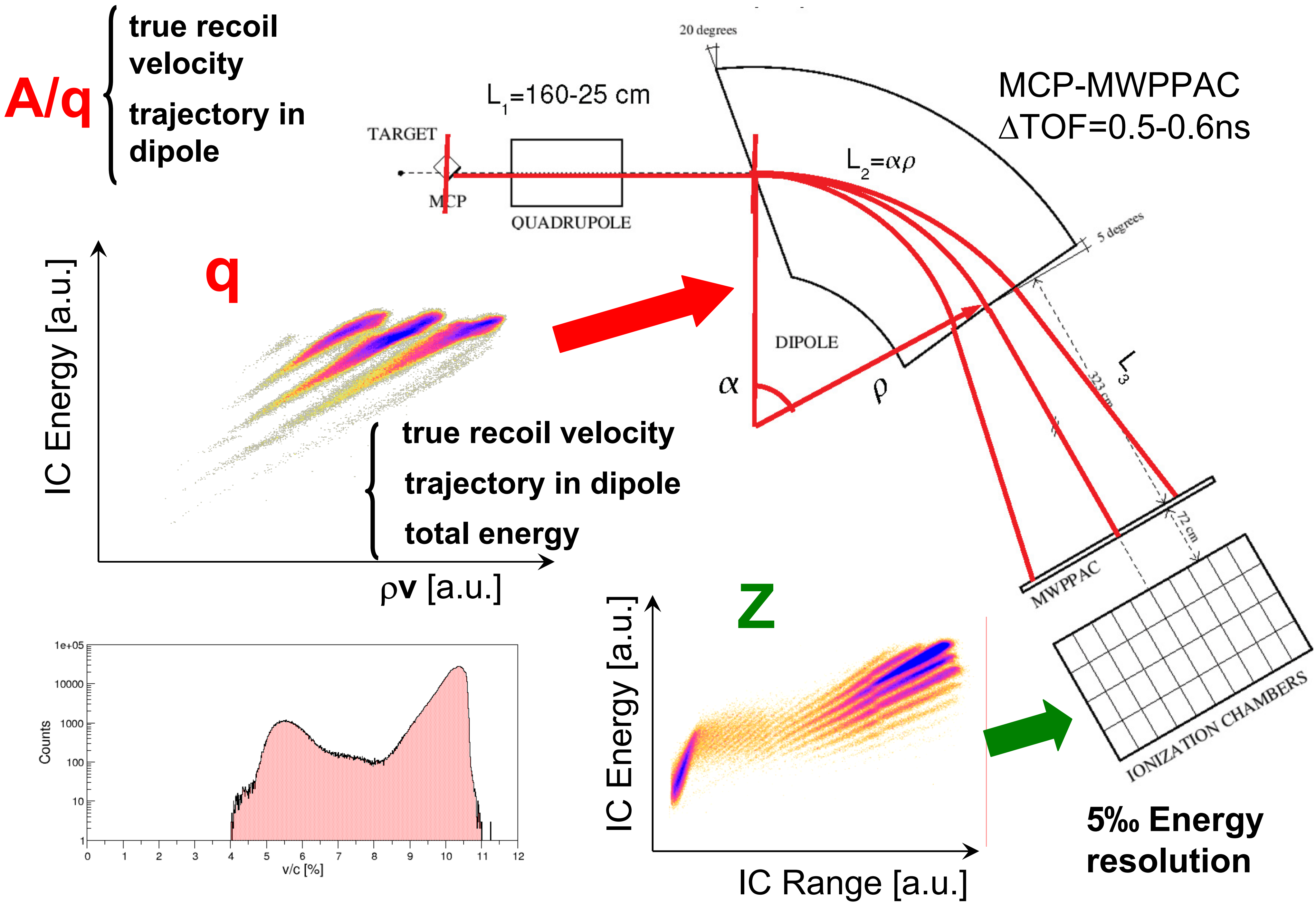


Ionisation Chamber
10x4 sect. DE - E

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

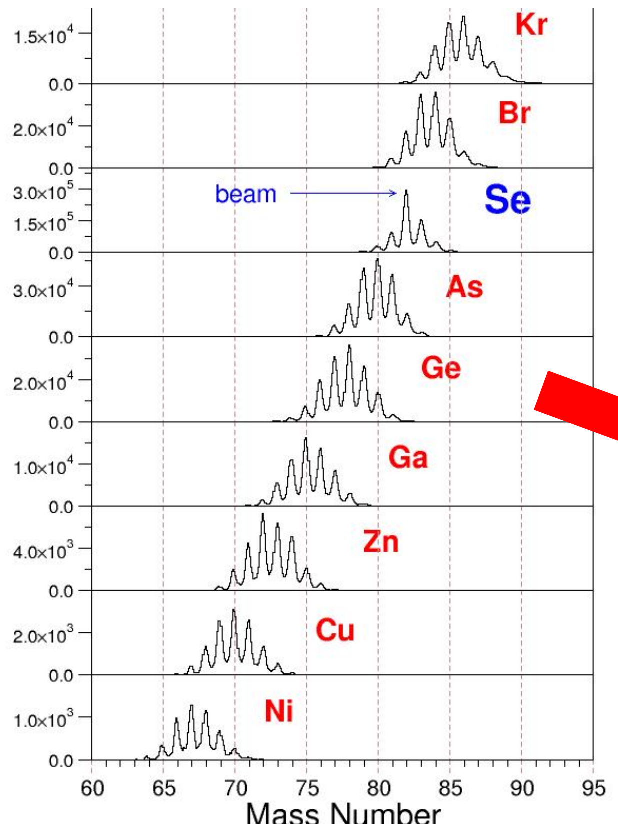
S.Beghini et al. Nucl. Instr. Methods Phys. Res. A551, 364 (2005)

G.Montagnoli et al. Nucl. Instr. Methods Phys. Res. A547, 455 (2005)

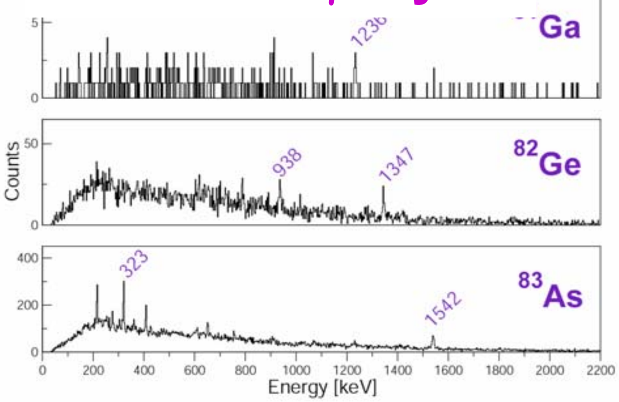

A/q
true recoil velocity
trajectory in dipole
L1=160-25 cm
TARGET
MCP
QUADRUPOLE
20 degrees
MCP-MWPPAC
ΔTOF=0.5-0.6ns
L2=αρ
5 degrees
DIPOLE
α
ρ
L3
323 cm
72 cm
MWPPAC
IONIZATION CHAMBERS
q
IC Energy [a.u.]
ρv [a.u.]
true recoil velocity
trajectory in dipole
total energy
Counts
v/c [%]
Z
IC Energy [a.u.]
IC Range [a.u.]
5‰ Energy resolution

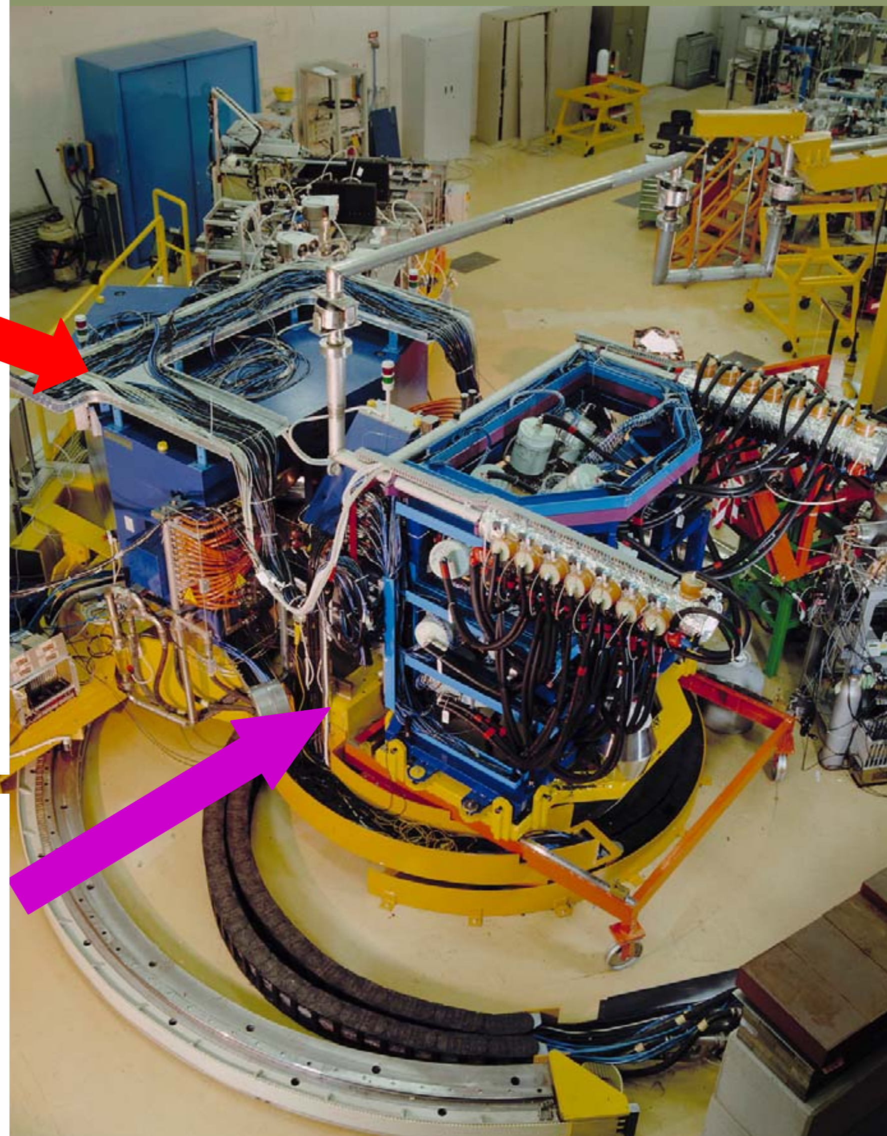
CLARA: Clover Detector array

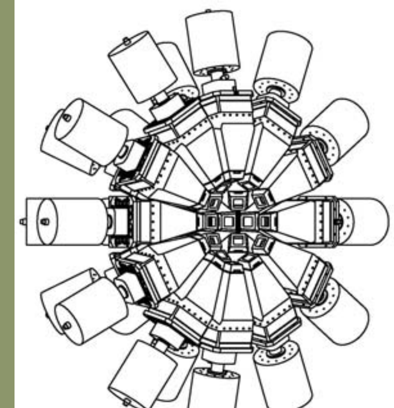
A & Z identification

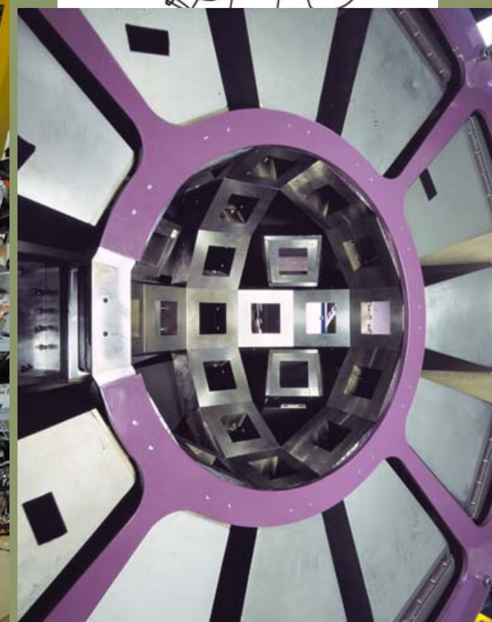


"in-beam" γ-ray









25 Euroball Clover detectors (EB GammaPool)

Performance at Eγ= 1.3MeV

Efficiency ~ 3 %

Peak/Total ~ 45 %

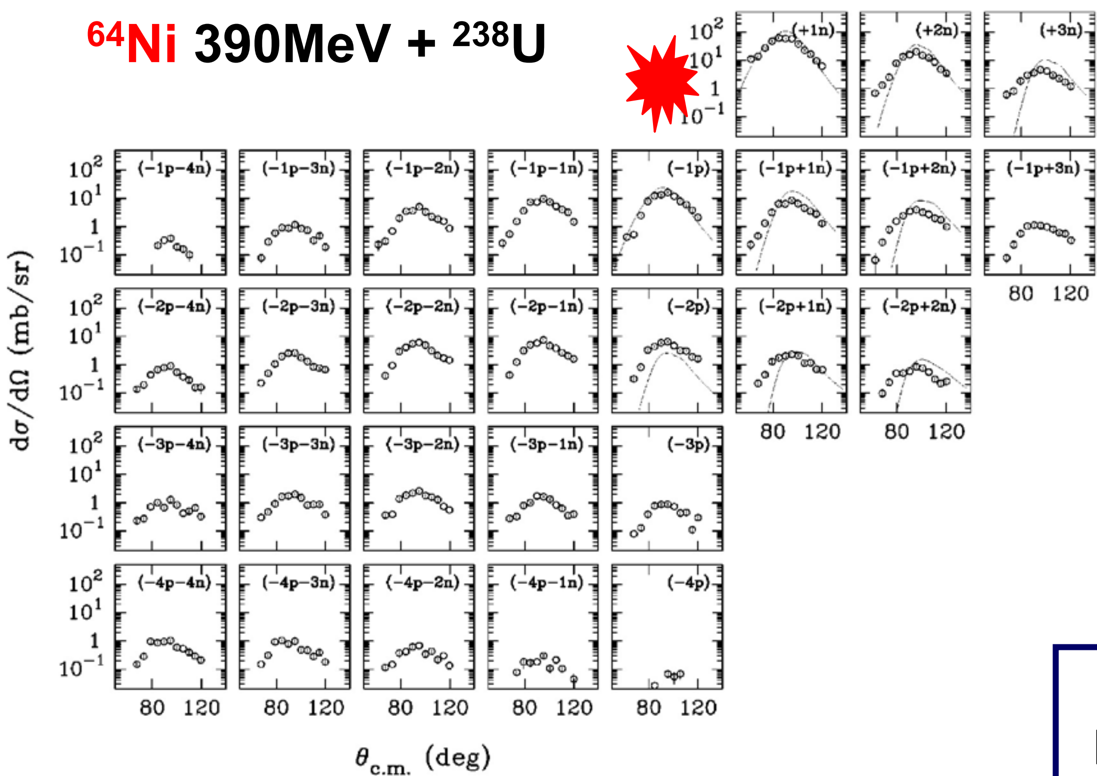
FWHM < 10 keV

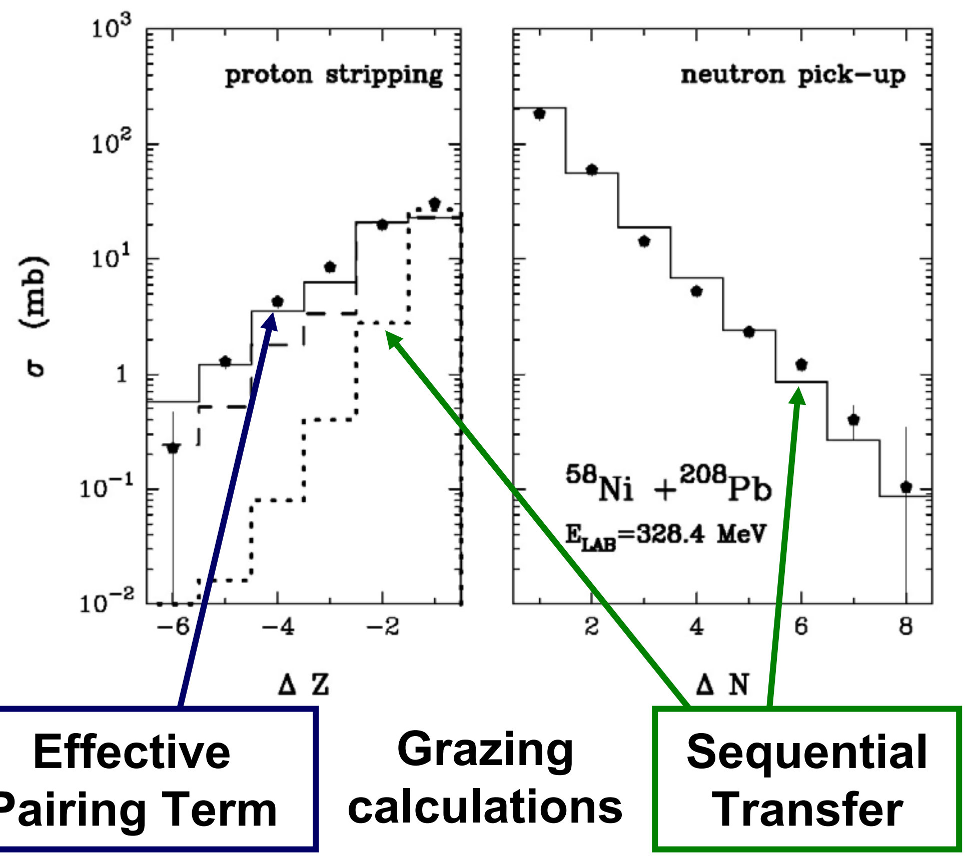
(at v/c = 10 %)

Grazing reactions transferring several nucleons as a tool to study n-rich nuclei

Deep-inelastic reactions used since thick target pioneering work of R.Broda et al. (Phys. Lett. B 251 (1990) 245)

Use of Multinucleon-transfer triggered by the work of L. Corradi et al. at LNL

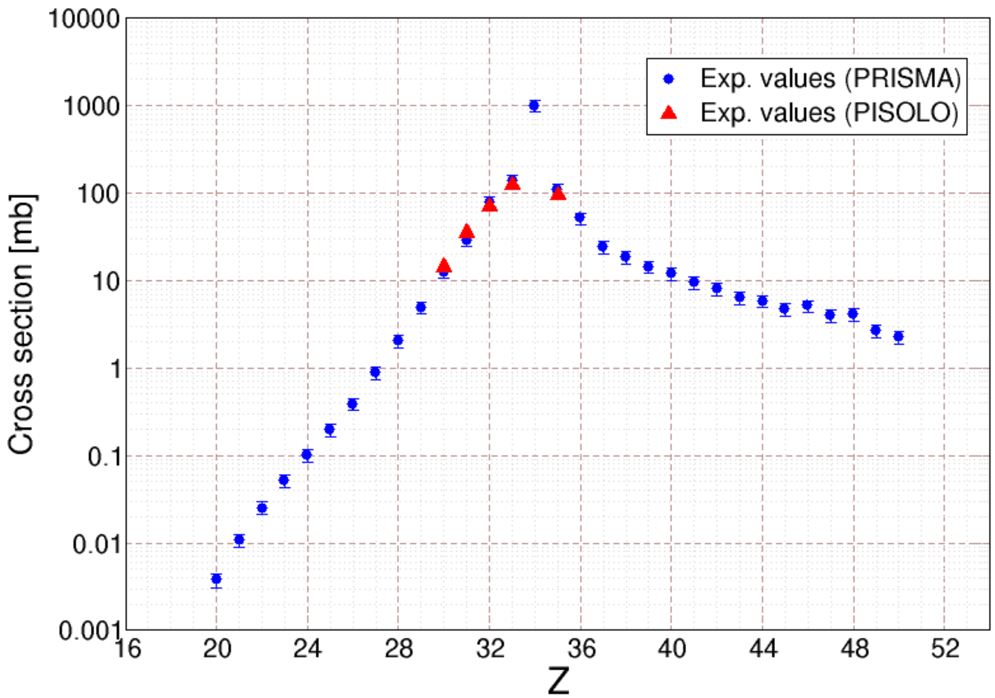


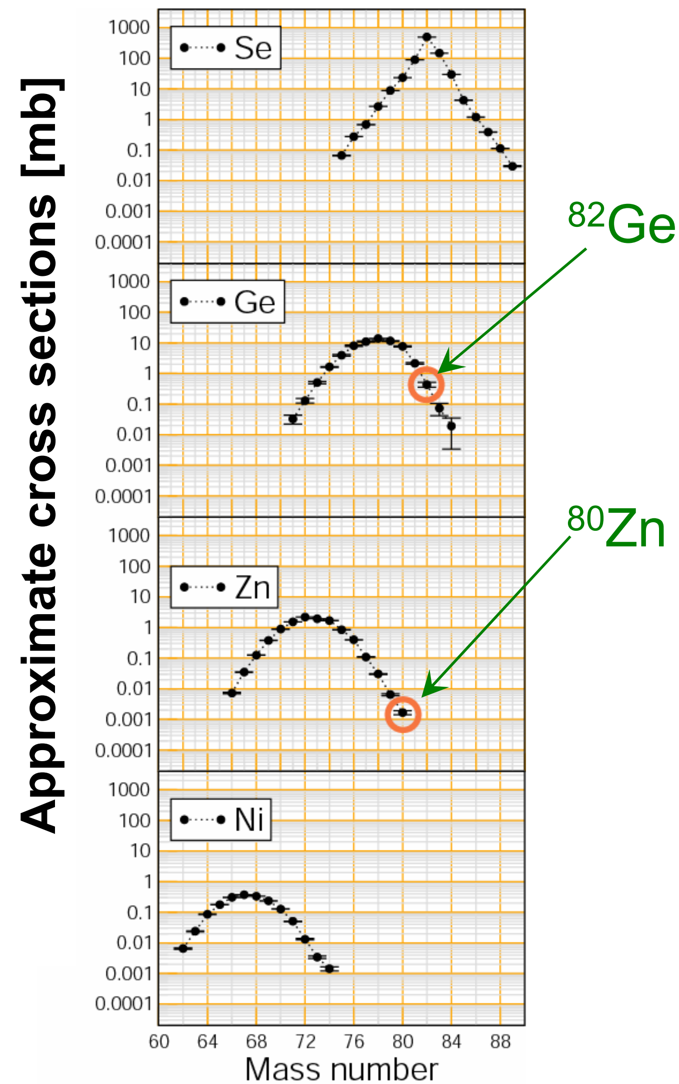


L.Corradi et al., Phys.Rev.C59 (99)261, Theory: G.Pollarolo

Estimated cross sections for N=50 n-rich nuclei

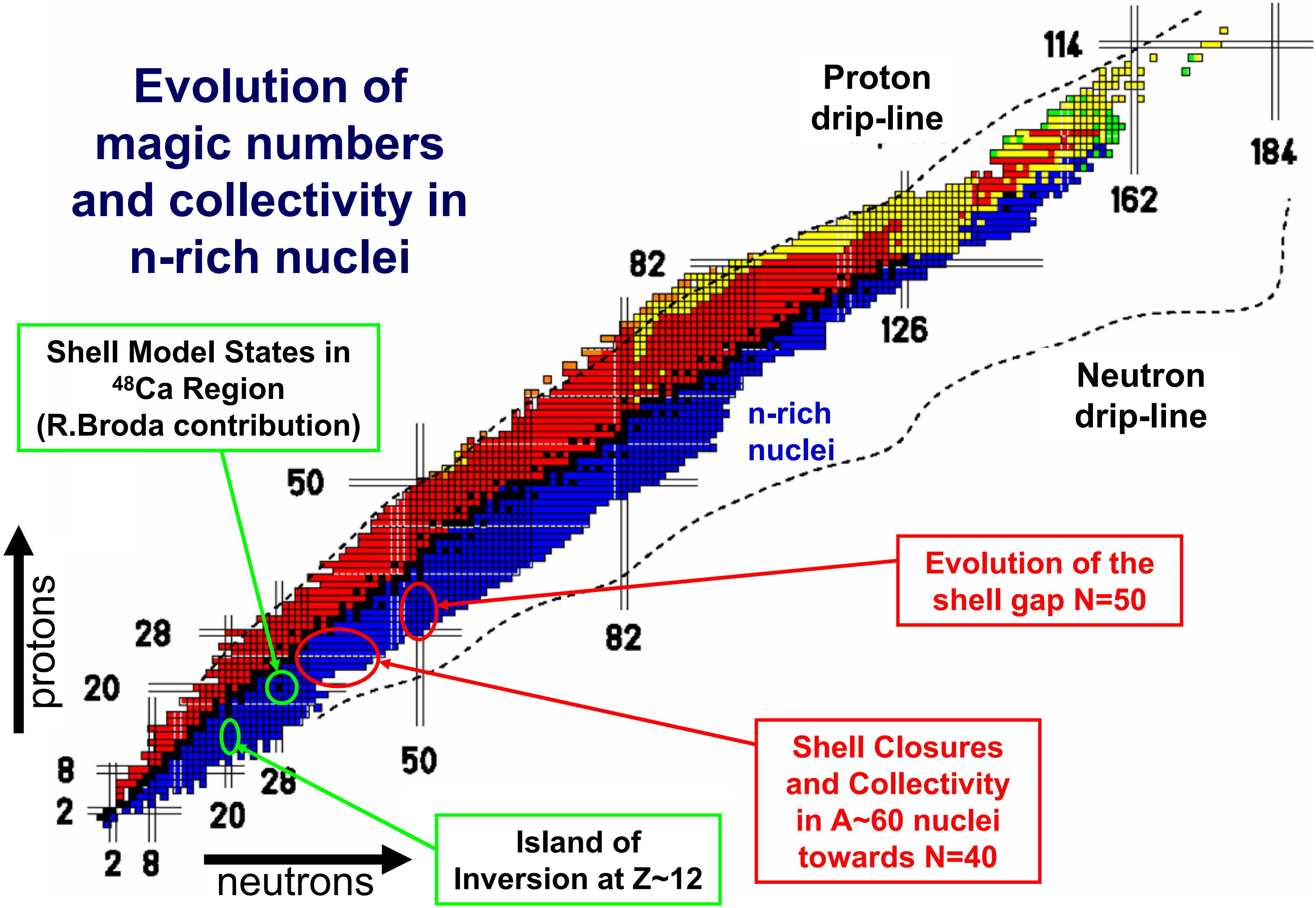
$^{82}Se(500\ MeV) + ^{238}U$





PISOLO: LNL electrostatic spectrometer used for binary reaction cross section measurements

Evolution of magic numbers and collectivity in n-rich nuclei

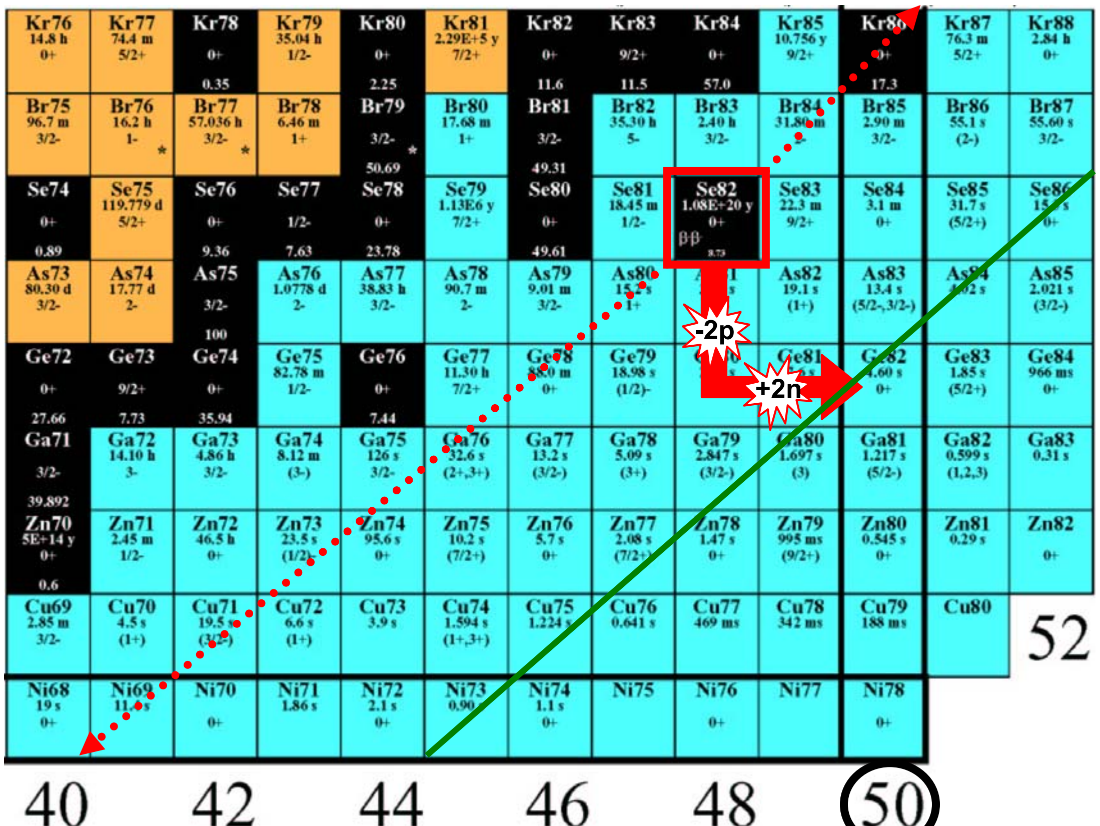


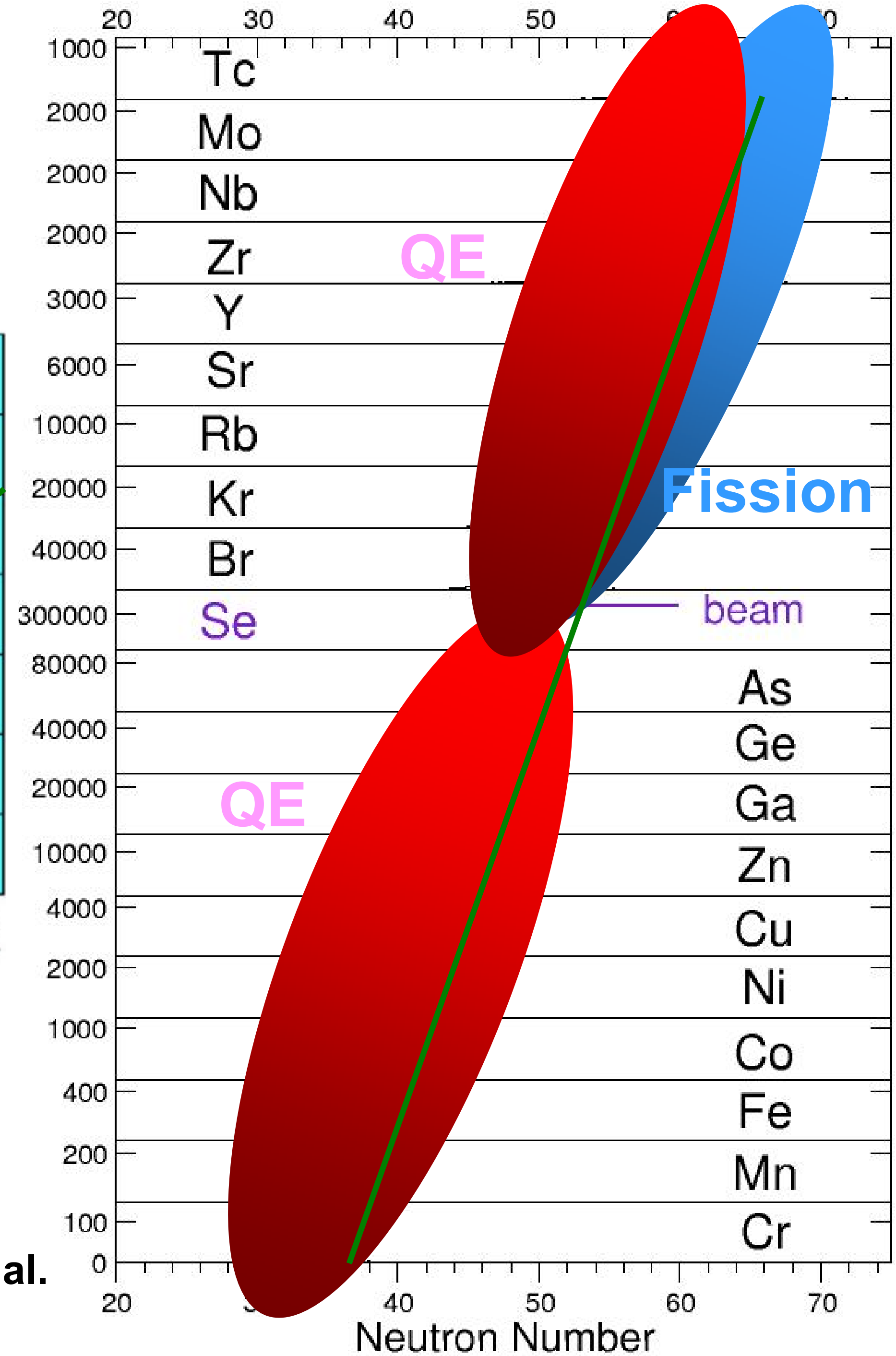
^{82}Se + ^{238}U E=505 MeV (ALPI)

PRISMA at θ_G=64°

G.deAngelis, G.Duchêne

Analysis: N.Marginean

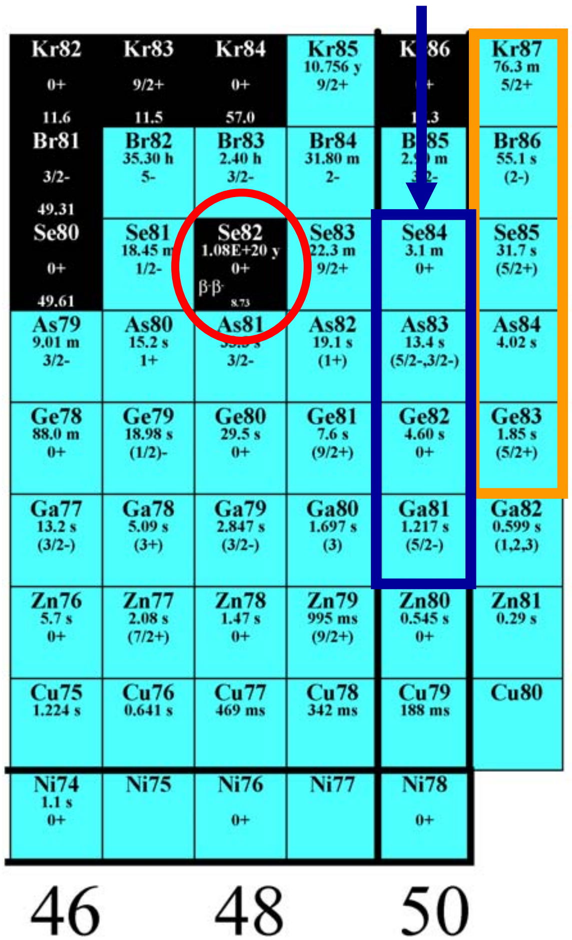


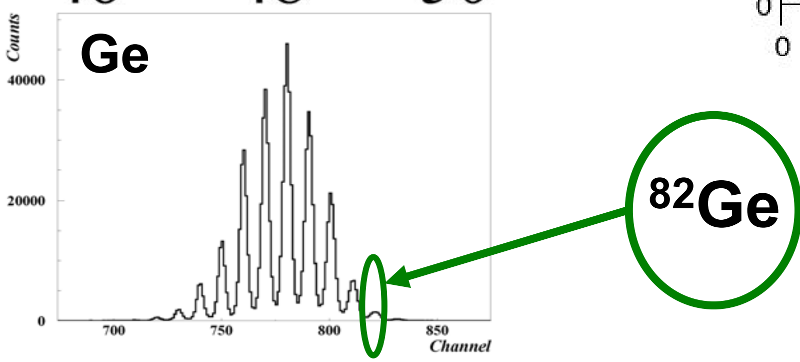


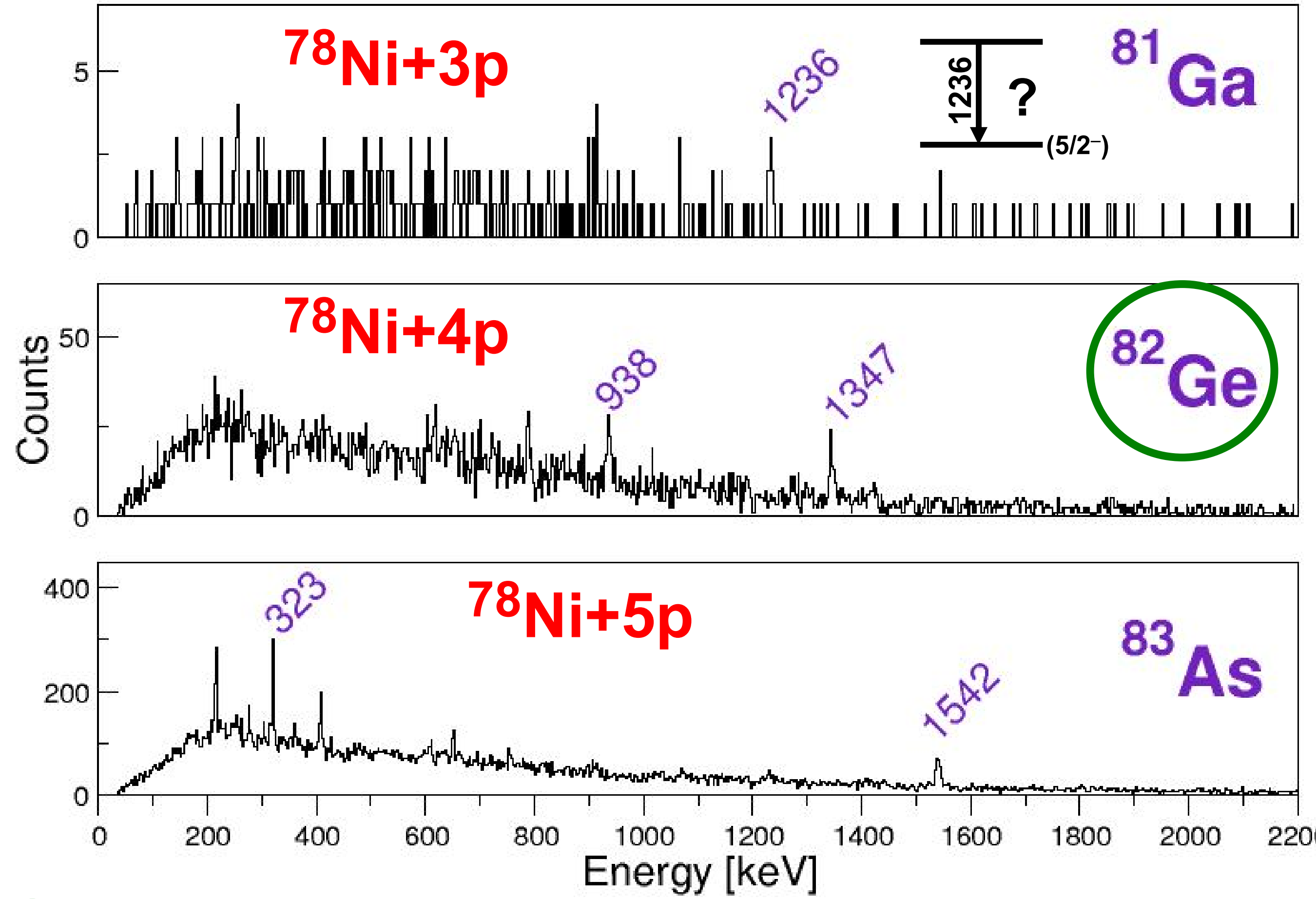
Evolution of the N=50 shell: Searching for the shell gap quenching

- **Z=32**: INM, R.C.Nayak et al. PRC 60 (1999) 064305
- **Z=24-26**: RMF, L.S.Geng et al. J. Phys. G 30 (2004) 1915

Spectroscopy of the N=50 Isotones

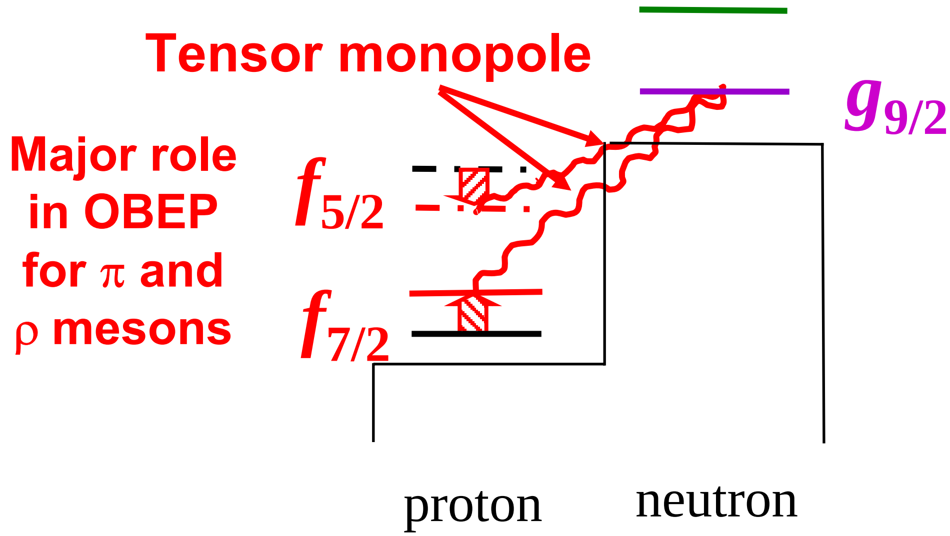


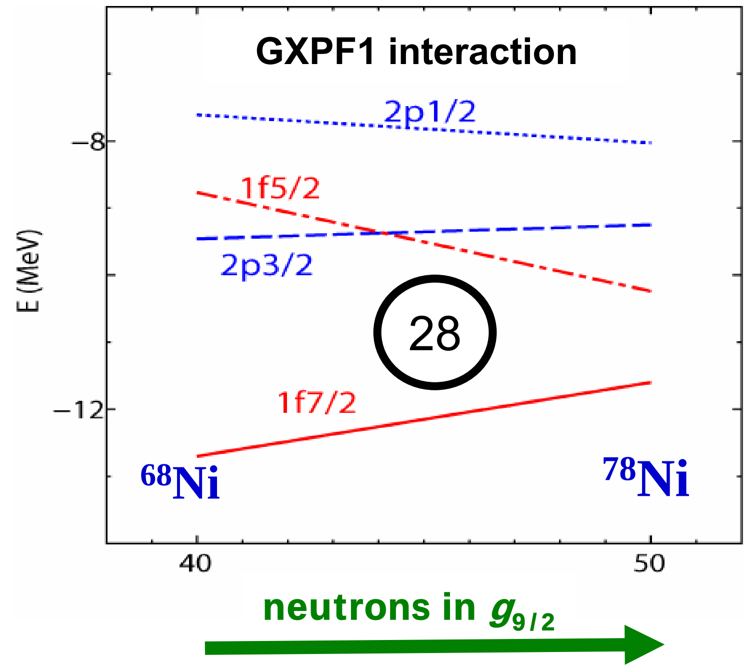




S.M. for the N=50 isotones

Systematic variation of proton effective single-particle energies from N=40 to N=50 due to the evolution of the monopole interaction.





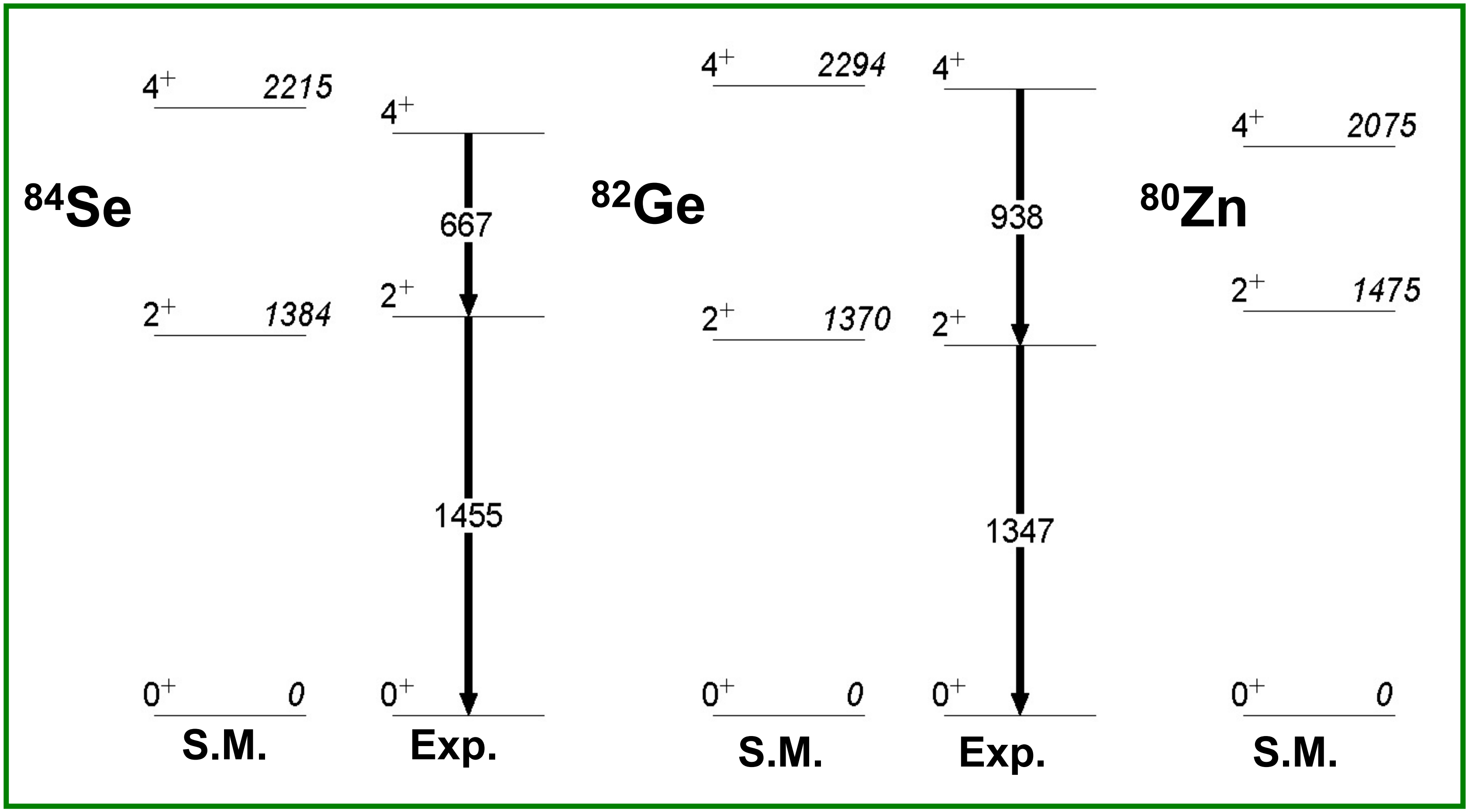
Basic trend reproduced using realistic interactions (Shell model with renormalized SPE: monopole migration)

Inversion of the effective single particle orbitals $f_{5/2}$ and $p_{3/2}$.

A.F. Lisetskiy et al., PRC 70, (2004) 044314
X. Ji and B.H. Wildenthal PRC 37 (1988) 1256
Y.H. Zhang et al., PRC 70 (2004)24301

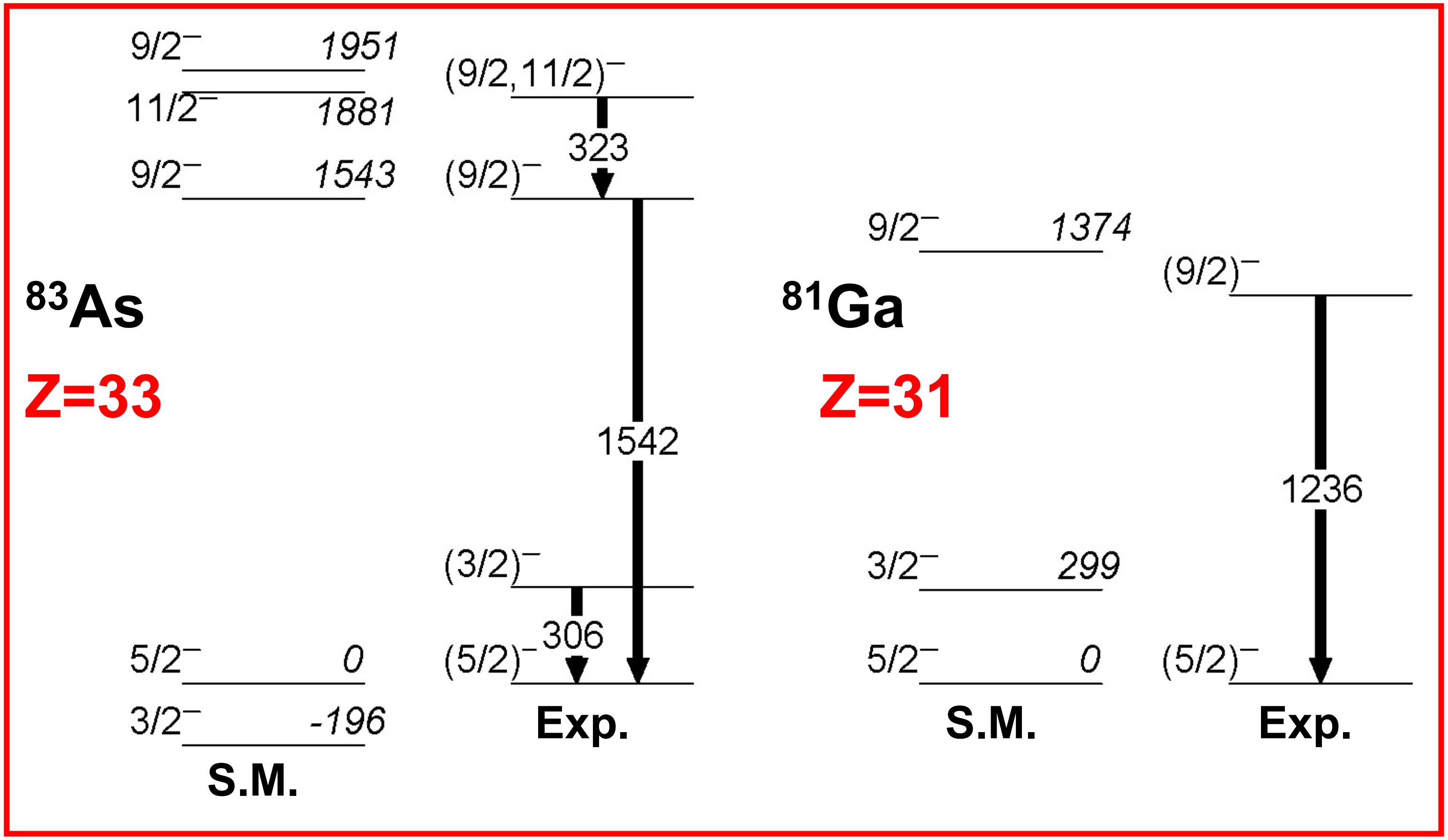
T. Otsuka et al. PRL95, 232502 (2005)

Even-even N=50 isotones



Interaction from A.F. Lisetskiy, B.A.Brown, M. Horoy, H. Grawe PRC 70 (2004) 44314, EPJA 25 s01 (2005) 95 (G-Matrix based on Bonn-C)

Odd-Z N=50 isotones



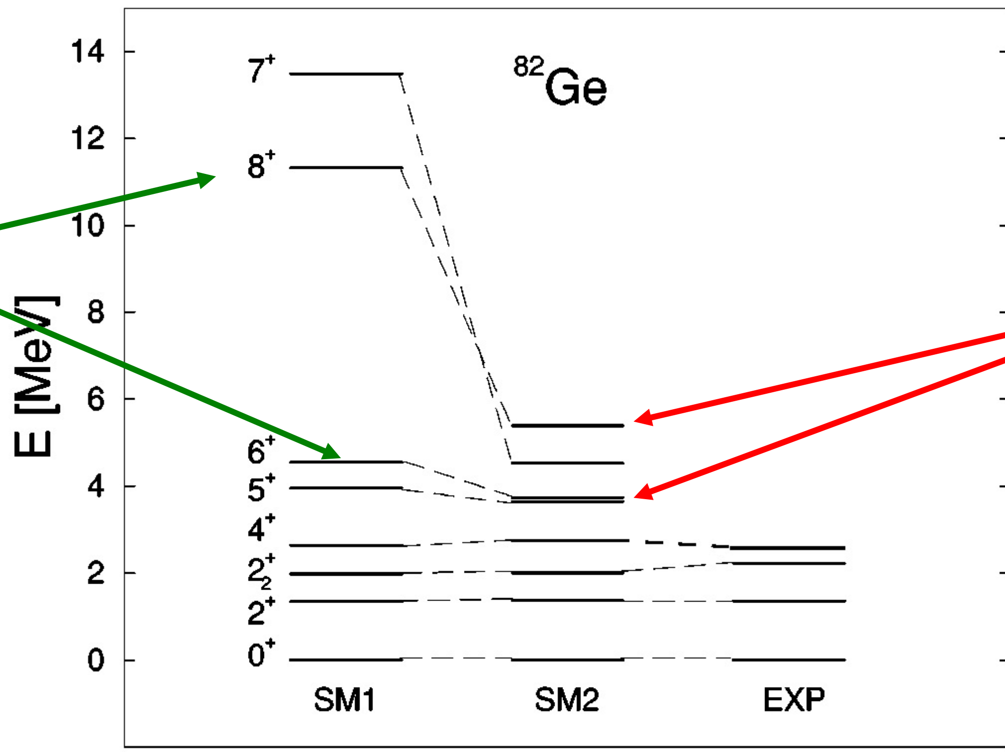
Interaction from A.F. Lisetskiy, B.A.Brown, M. Horoy, H. Grawe
PRC 70 (2004) 44314, EPJA 25 s01 (2005) 95
(G-Matrix based on Bonn-C)

Conclusions on N=50

No evidence of shell gap change down to 81Ga (Z=31)

Information can be derived from high spin states in ^{82}Ge and ^{81}Ga.

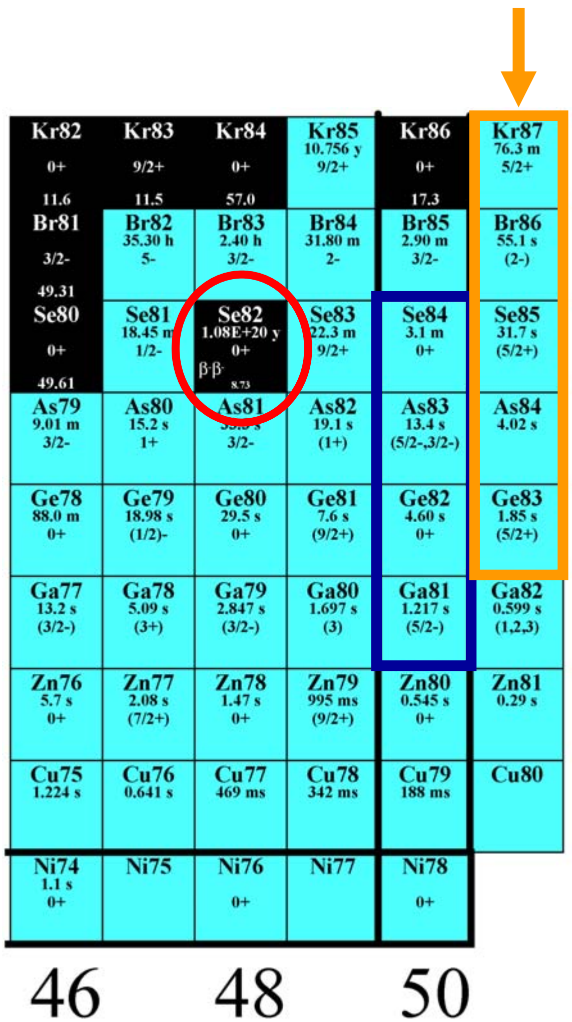
No excitation across N=50

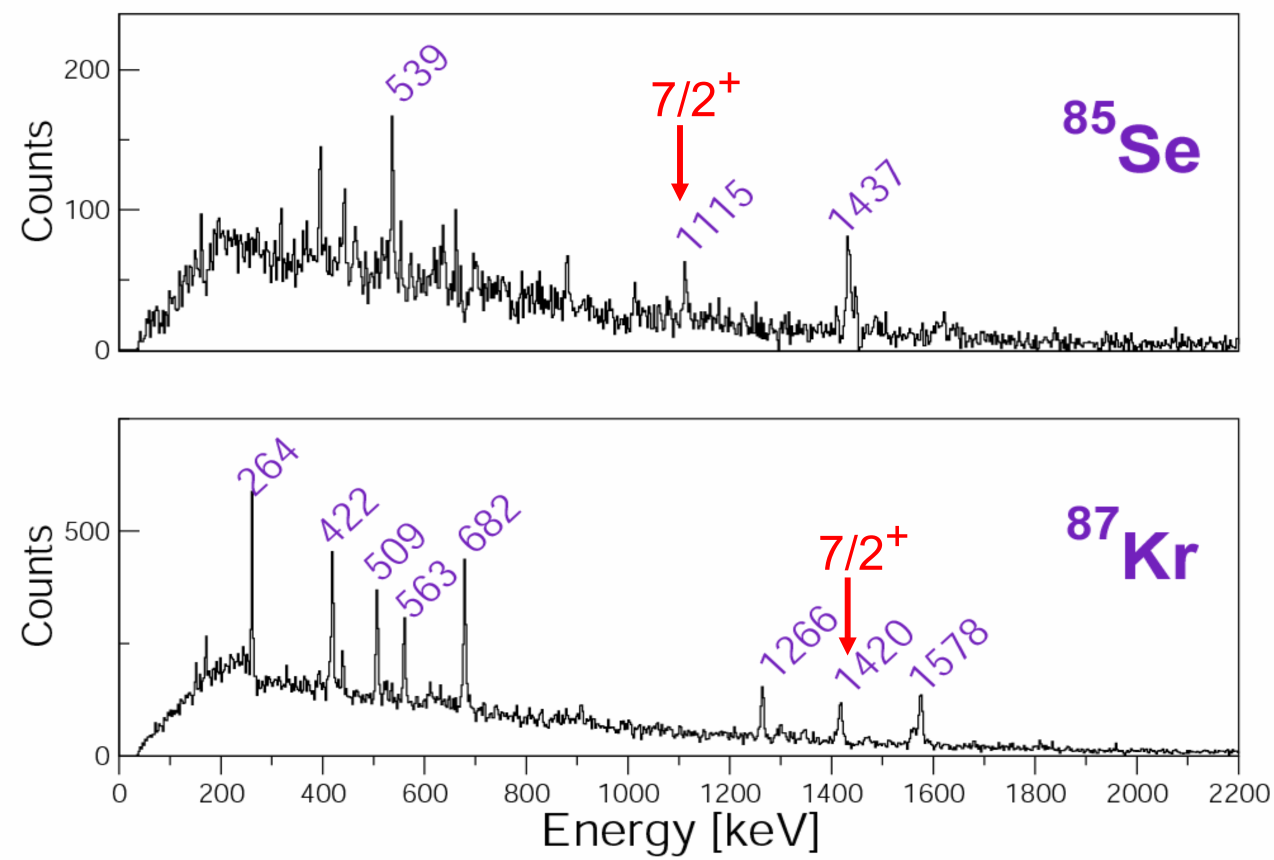


Excitation across N=50

X. Ji and B.H. Wildenthal PRC 37 (1988) 1256
Y.H. Zhang et al., PRC 70 (2004)24301

Spectroscopy of the N=51 Isotones

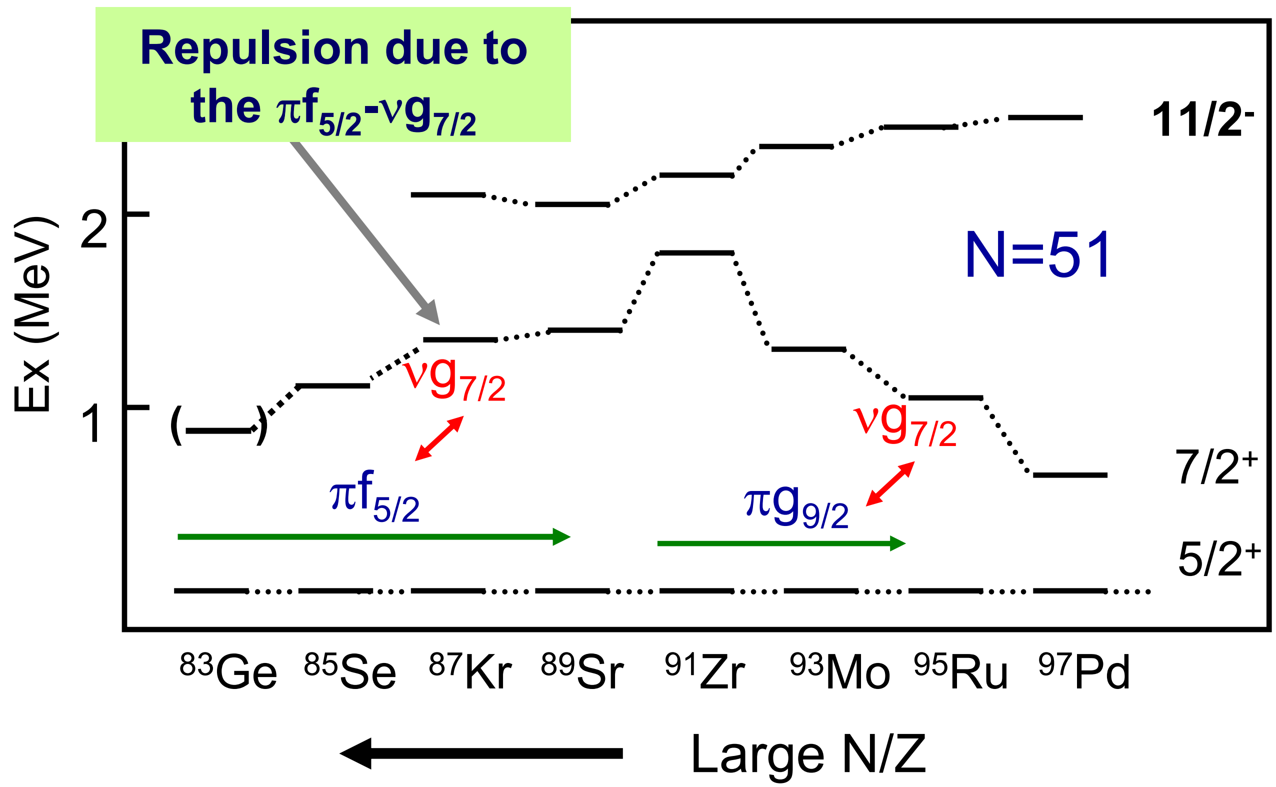


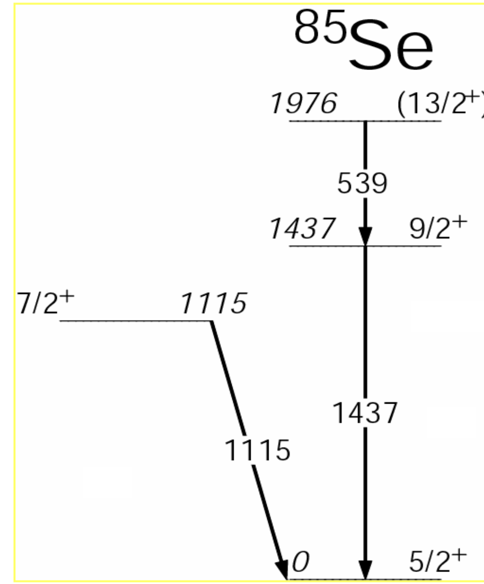


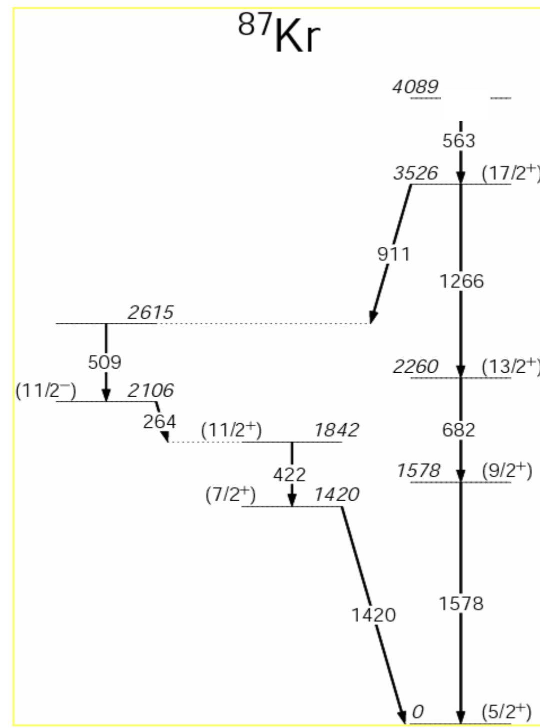
N=51 is the ideal region to study the evolution of the neutron g7/2 monopole due to the πf5/2↔νg7/2 tensor interaction

The N=51 isotones

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







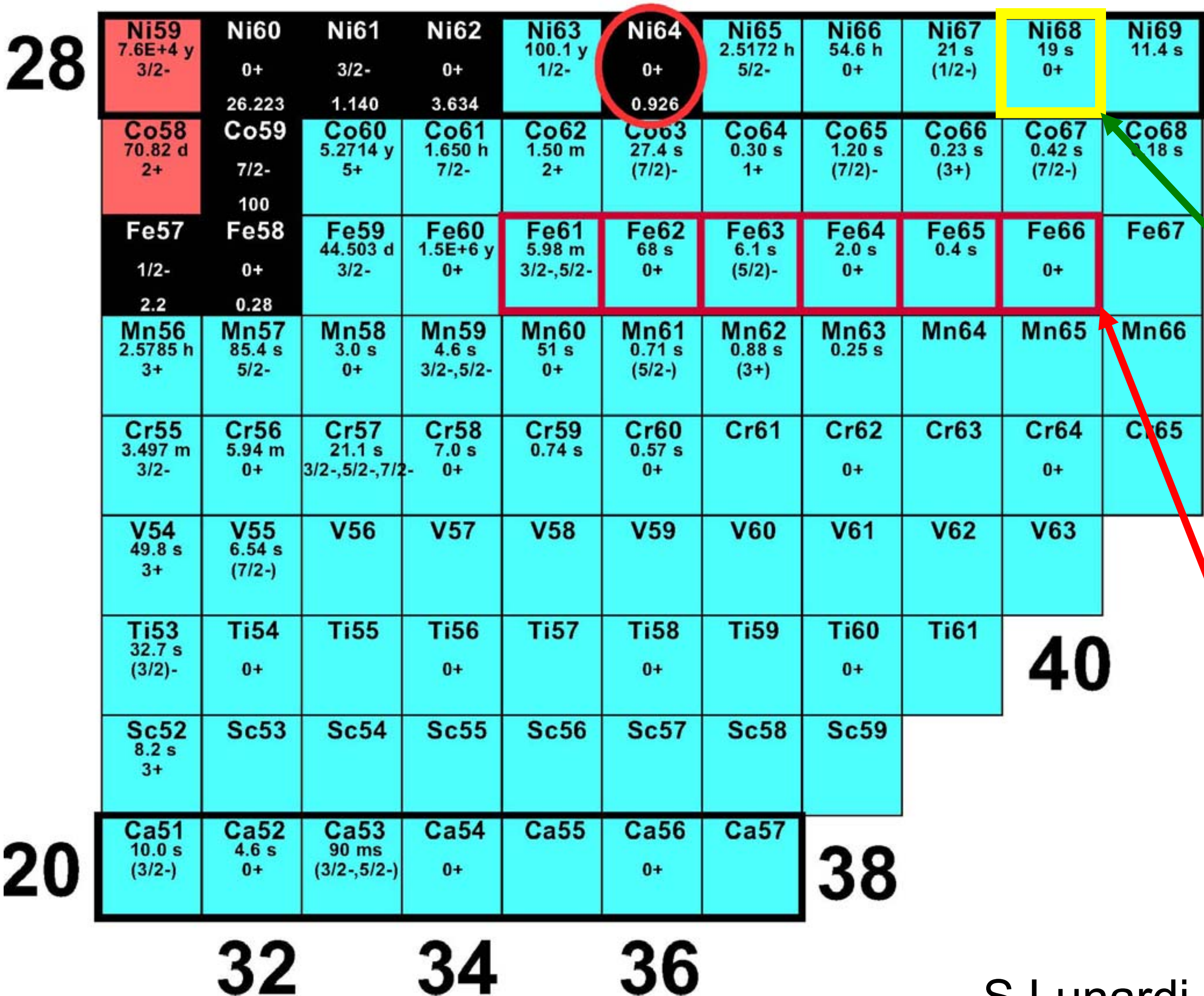
Calculations in progress by T.Otsuka.

A~60: Neutron-rich Fe isotopes

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

CLARA-PRISMA

$\theta_G = 64^o$



Doubly magic character suggested

R.Broda et al., PRL 74 (1995) 868

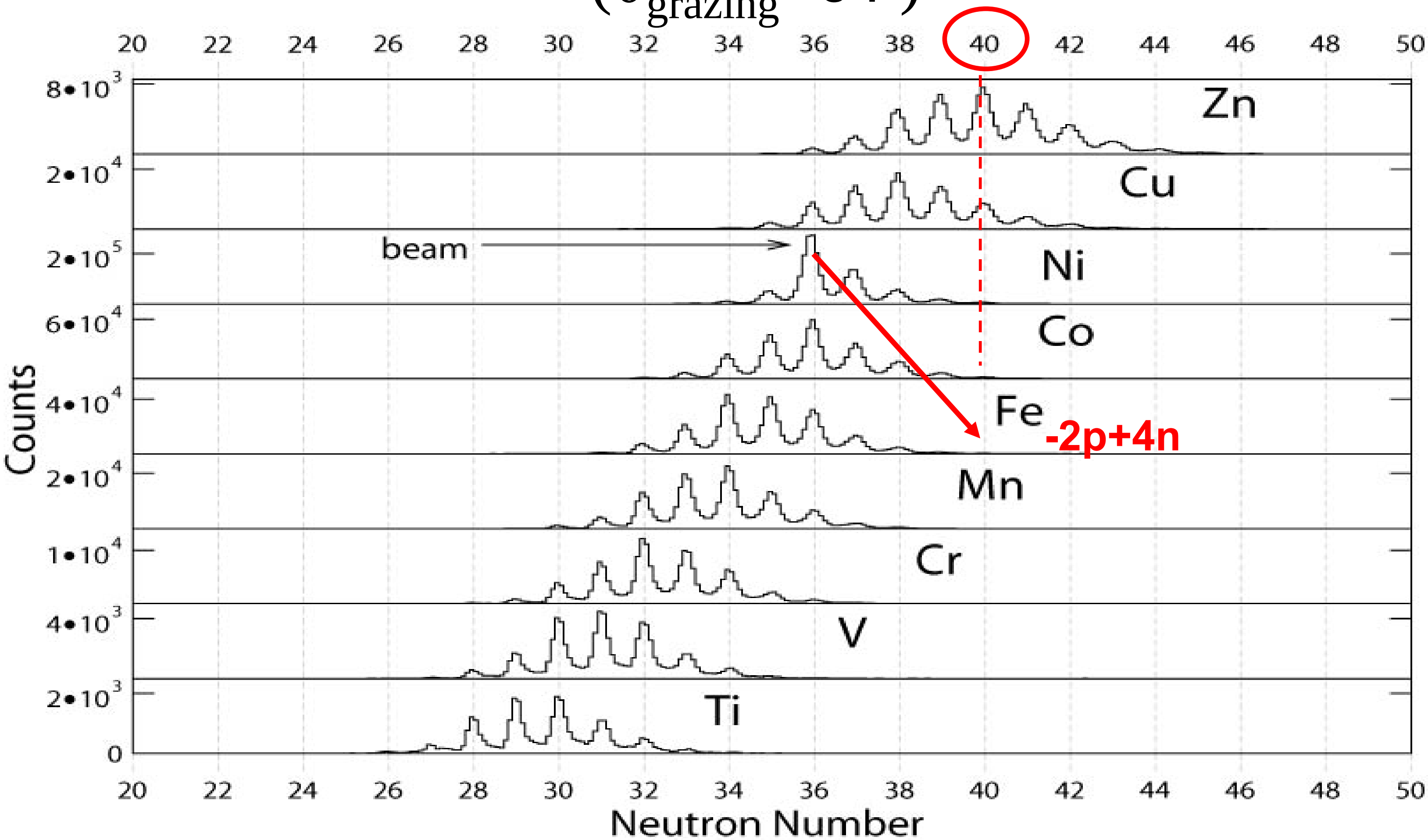
Yrast states: evolution of the collectivity towards N=40 in the Fe (Z=26) isotopes

S.Lunardi, S.M.Lenzi, S.Freeman

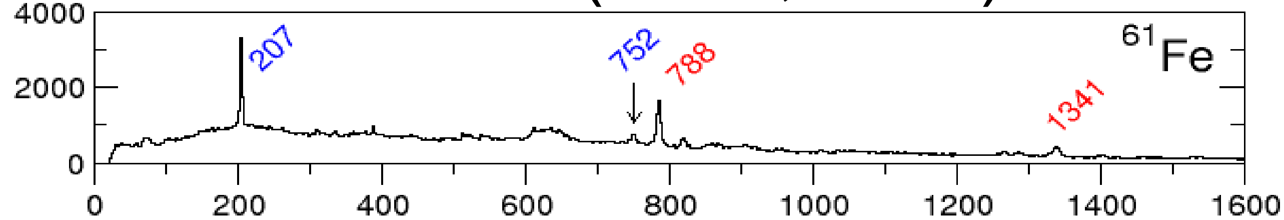
Mass distribution

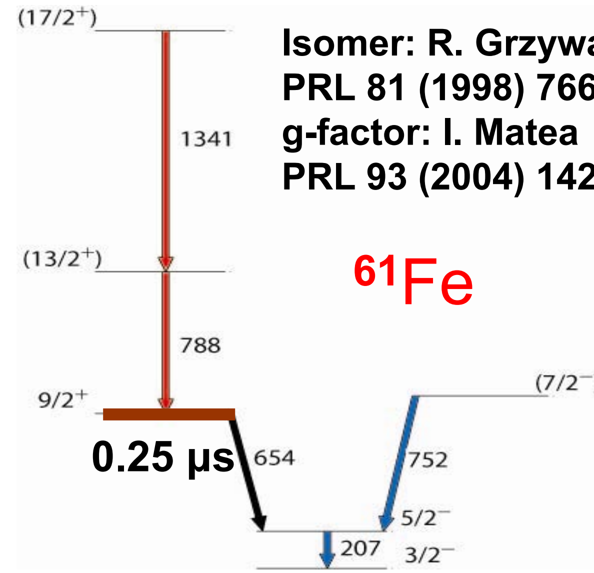
^{64}Ni (400 MeV)+ ^{238}U

($\theta_{grazing}$=64°)



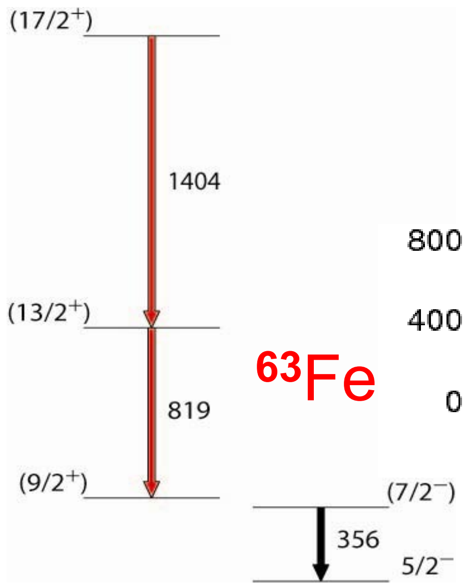
^{61}Fe (Z=26,N=35)

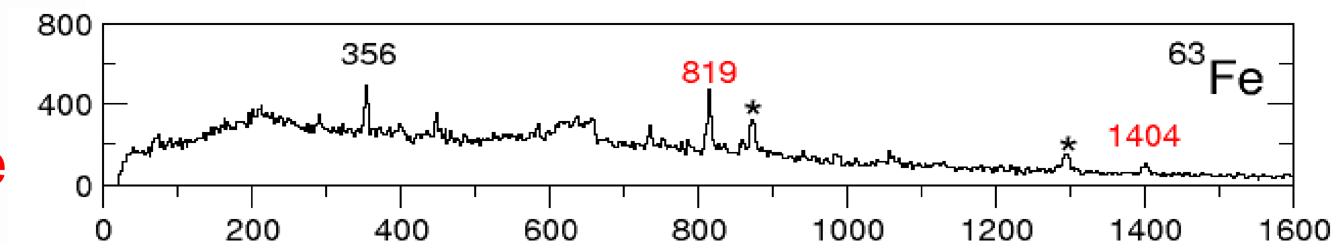




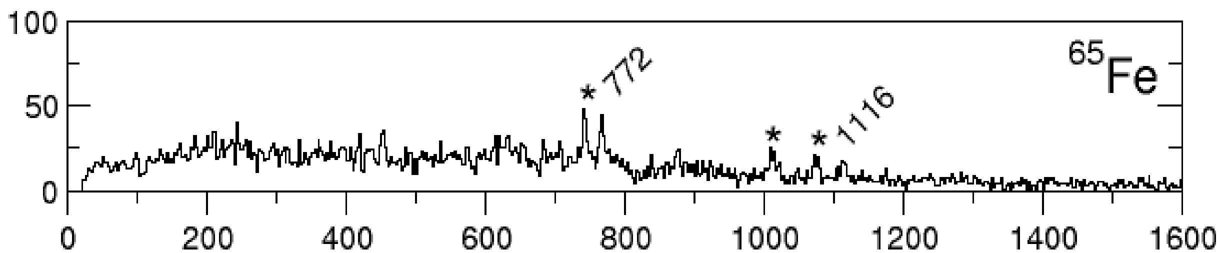
Isomer: R. Grzywacz
PRL 81 (1998) 766
g-factor: I. Matea
PRL 93 (2004) 142503

^{63}Fe (Z=26,N=37)

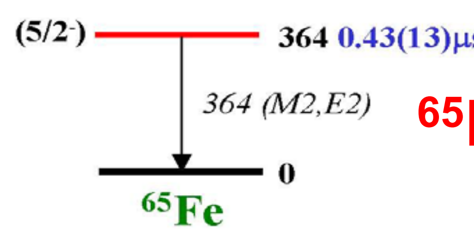


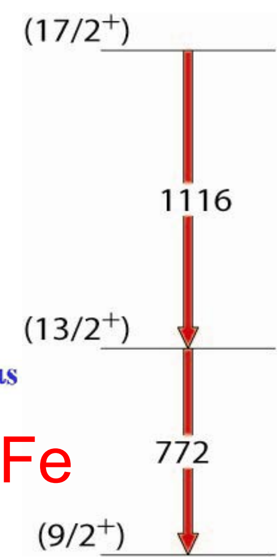


^{65}Fe (Z=26,N=39)



Isomer: R. Grzywacz
PRL 81 (1998) 766

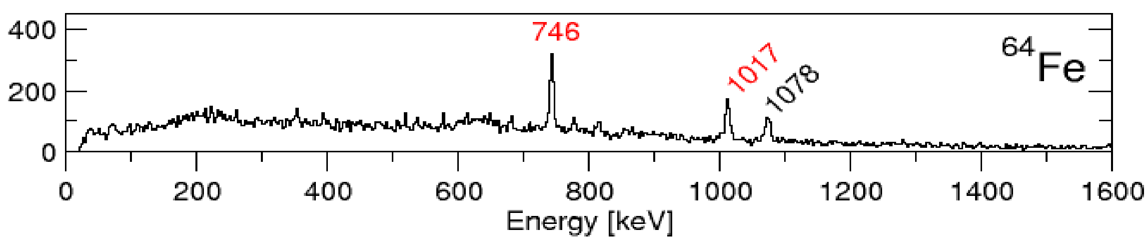


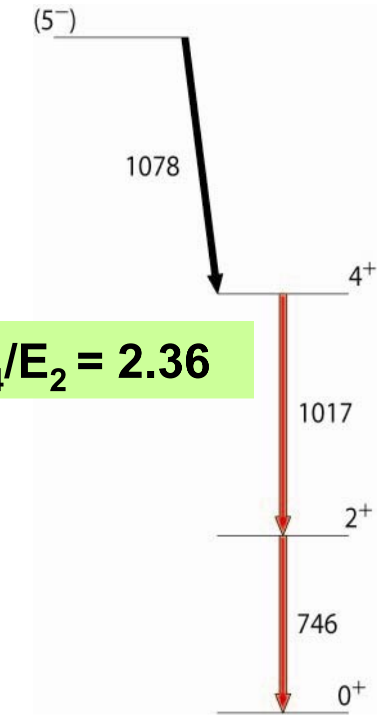


Neutron-rich even Fe nuclei

2^+ in ^{64}Fe and ^{66}Fe known from Mn β-decay measurements at ISOLDE (M.Hannawald et al., PRL 82 (1999) 1391)

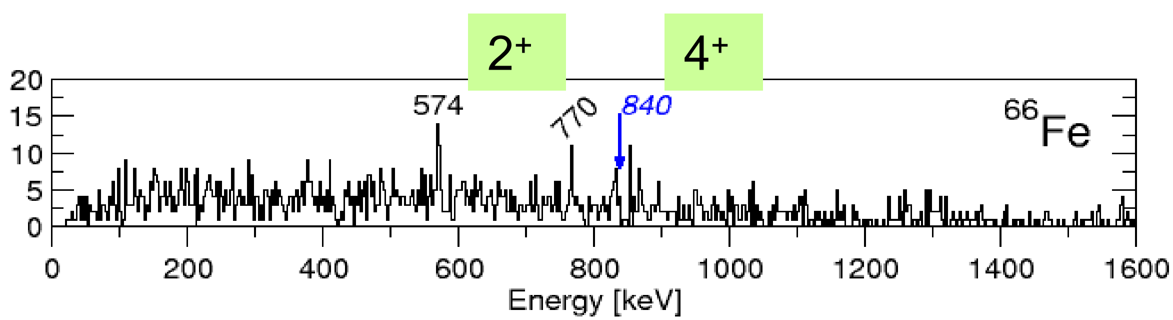
^{64}Fe (Z=26,N=38)





E_4/E_2 = 2.36

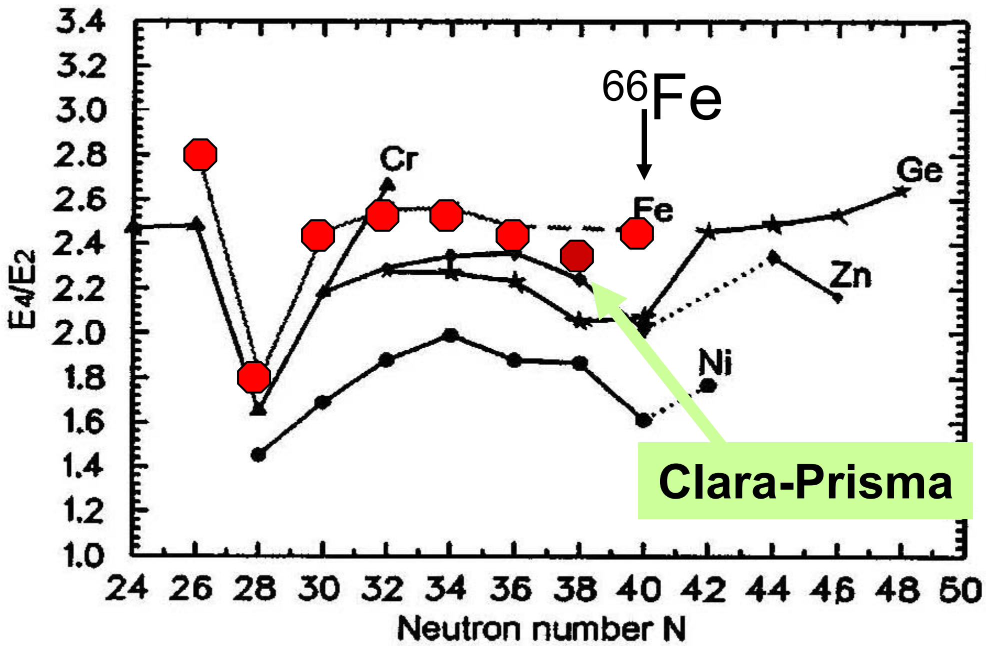
^{66}Fe (Z=26,N=40)

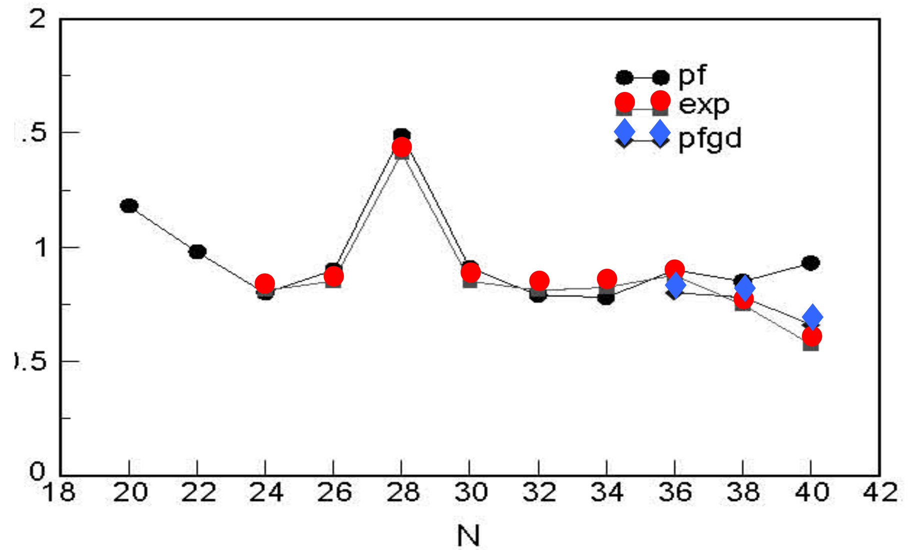


Observed the known 2^+

Two candidates for 4^+

New region of deformation





7. Excitation energy of the 2^+ states in MeV: Fe isotopes.

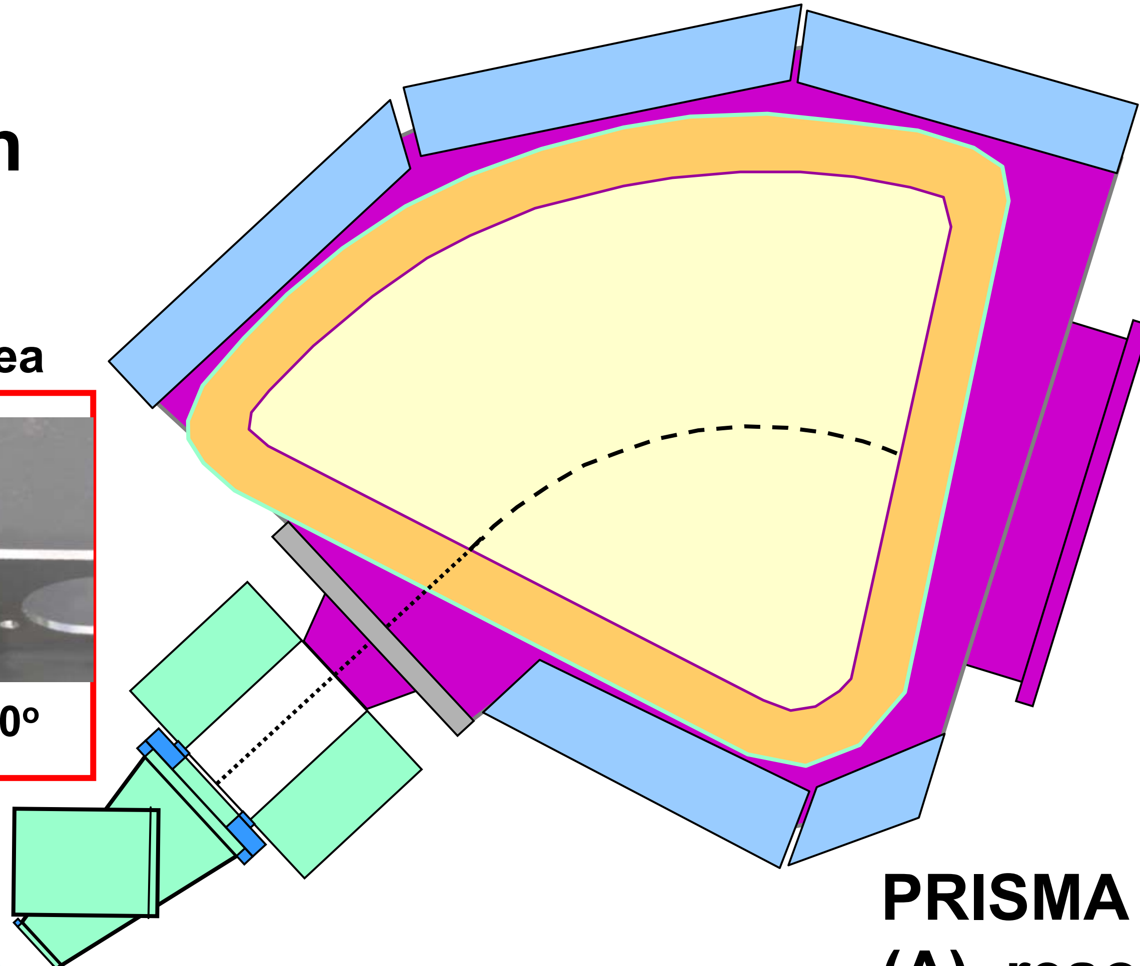
In nuclei where the $1f_{7/2}$ proton shell is not filled, the neutrons excited to the sdg-shell couple to the pf-proton and deformation appears. The removal of 2 protons from ^{68}Ni drives ^{66}Fe into prolate shapes generating a new region of deformation.

M. Hannawald et al., PRL82, 1391 (1999)
E. Caurier et al., Eur. Phys. J A 15, 145 (2002)

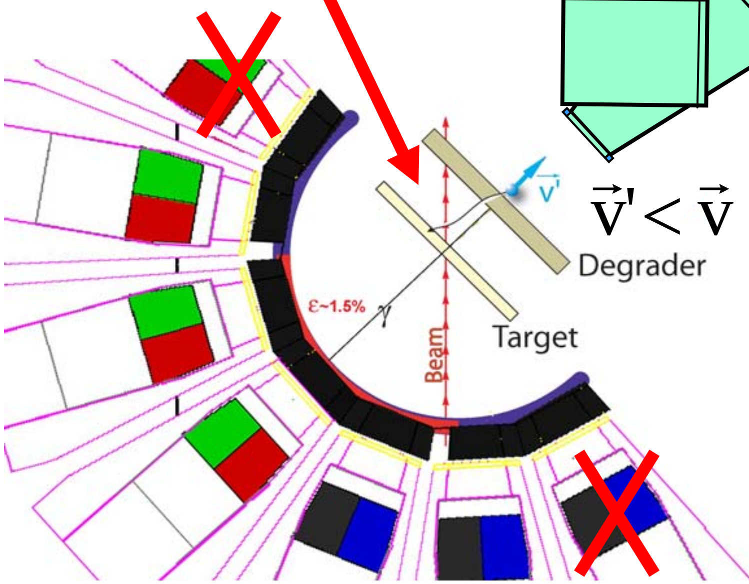
Differential RDDS Measurements with CLARA-PRISMA

A,Dewald, N.Marginean, A.Gadea

Differential Plunger for angles ≠ 0°



PRISMA mass (A) resolution after degrader

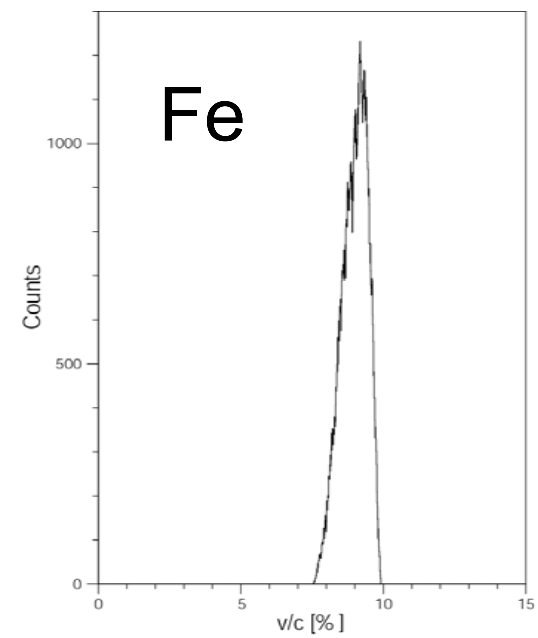


$\vec{v}' < \vec{v}$

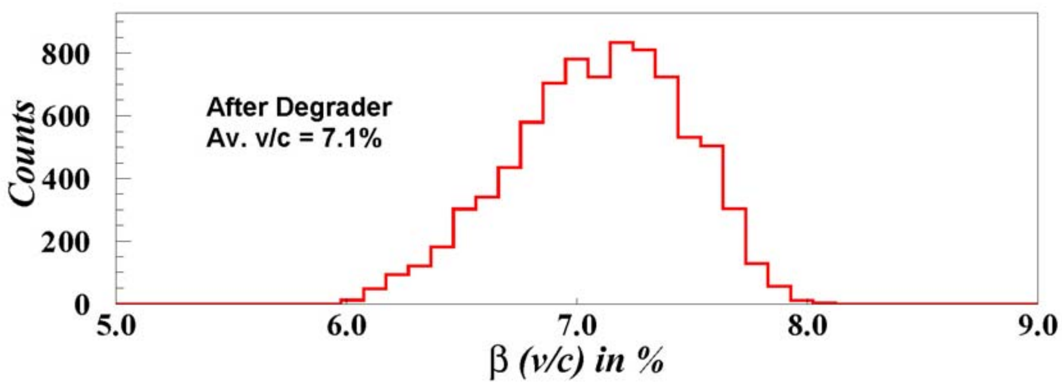
102° ring (1/2 efficiency) not usable for lifetime measurements

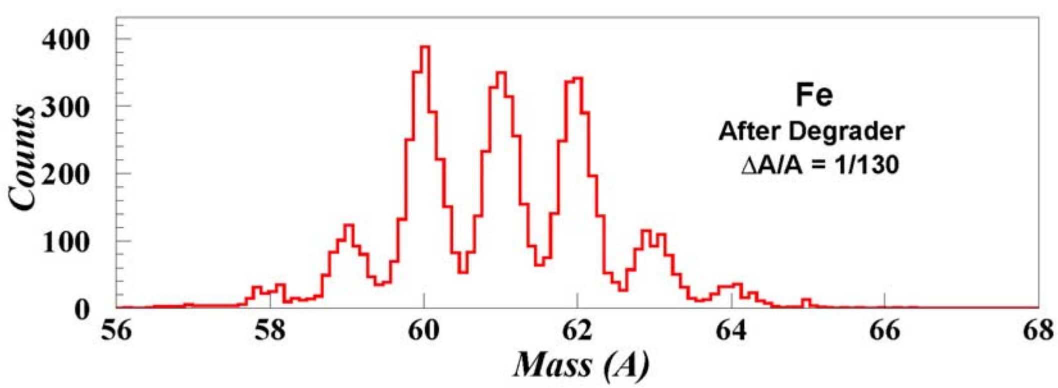
Test Experiment performed in June 2006

Beam: ^{64}Ni at 400MeV
Target: ^{93}Nb 1mg/cm^2 + ^{208}Pb 1mg/cm^2
Degrader: ^{24}Mg 2mg/cm^2
Debugging of the setup + 2 days of measurement at 150μm and 50μm performed with limited beam intensity



Average v/c after reaction 8.8% and after degrader 7.1%

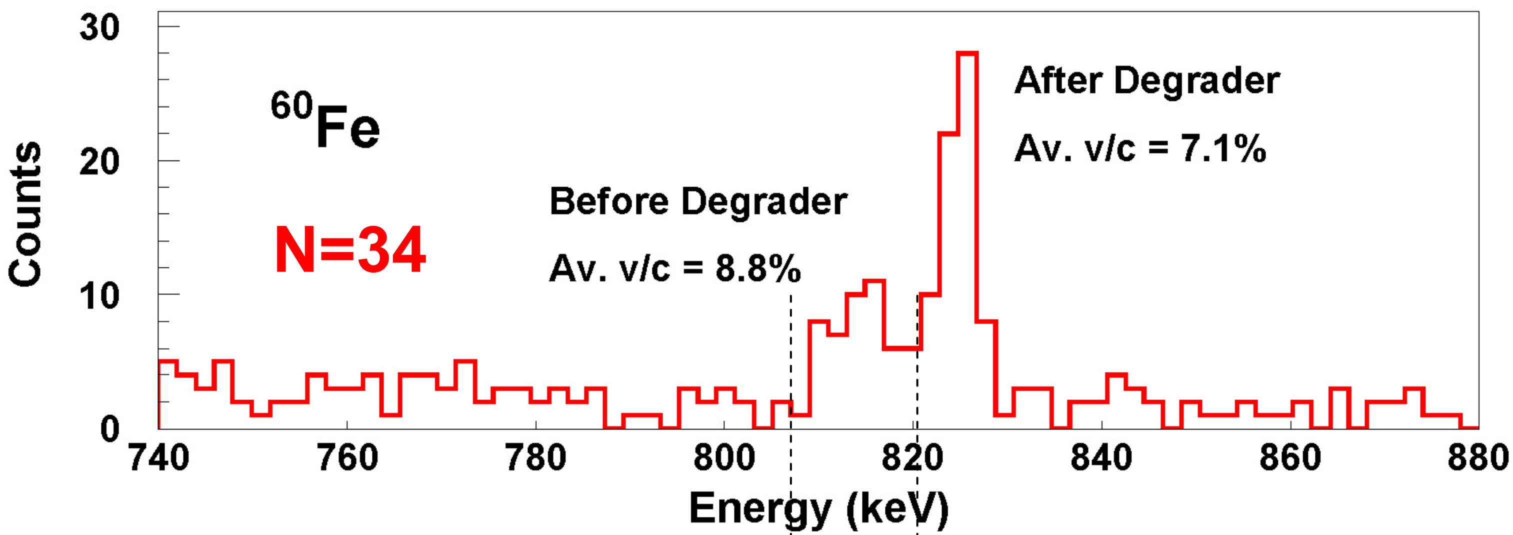


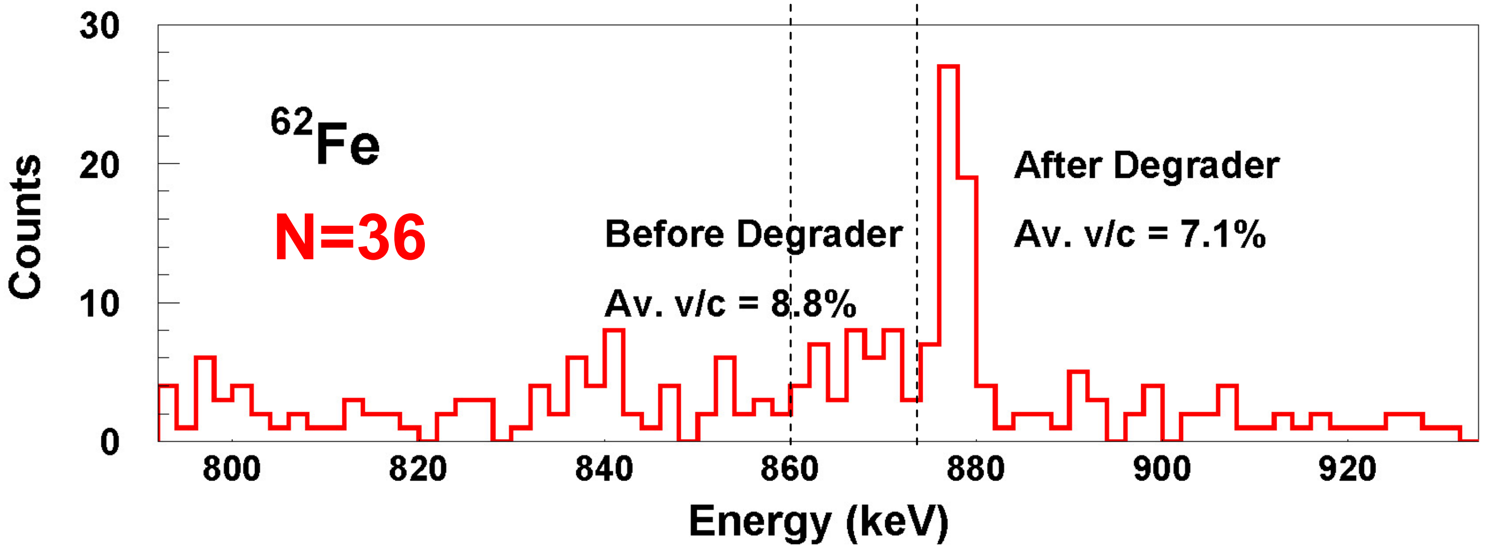


Product Energies ~4MeV.A

Mass and Z resolution preserved

Preliminary Results for 150μm Target-Degrader Distance





Test case ^{60}Fe

(2^+ at 824 keV)

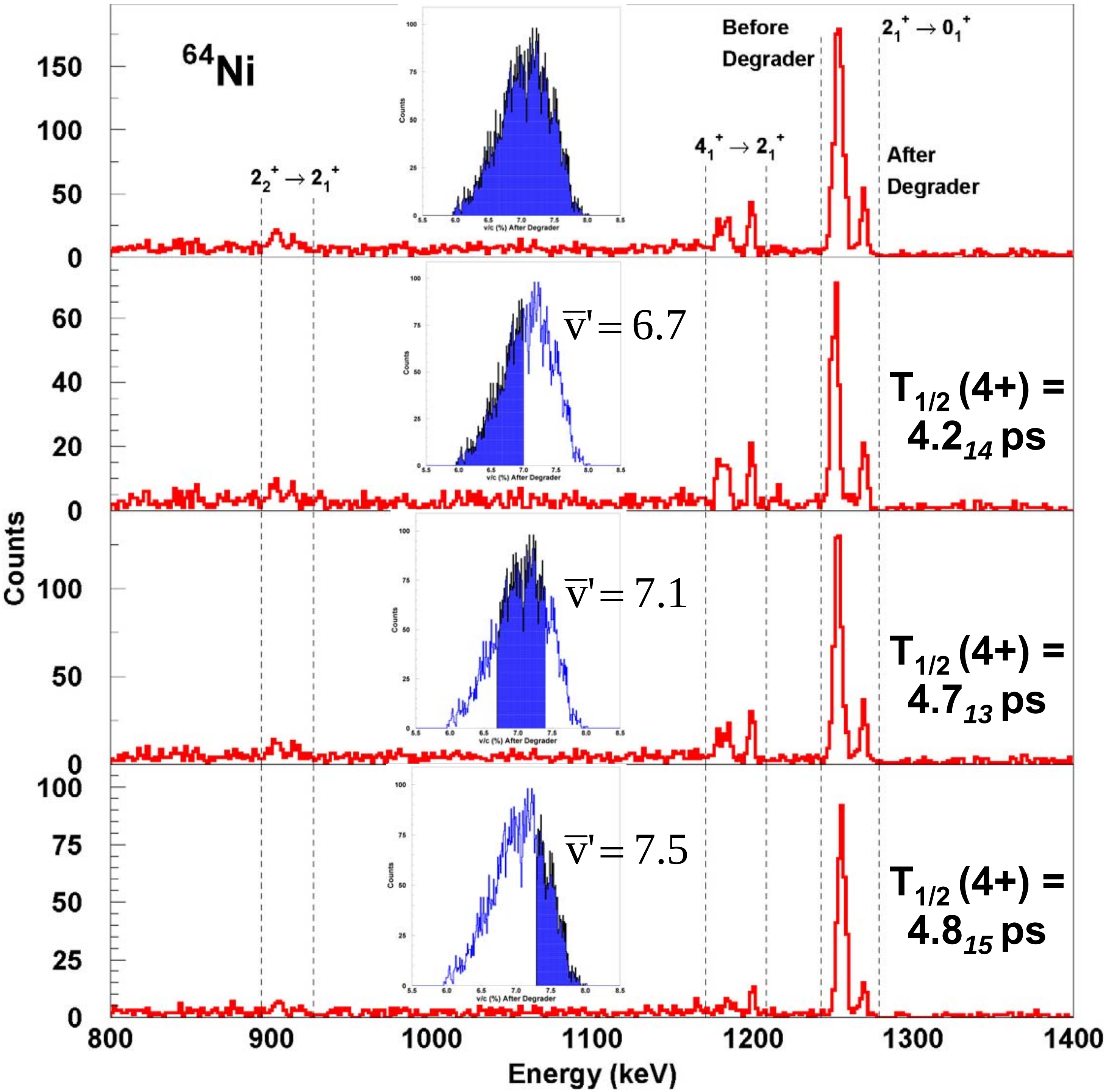
$T_{1/2}$= 8.2(15) ps (agreement with known 8.0(15) ps)
B(E2)=0.018 e^2b^2 (13 W.u.)

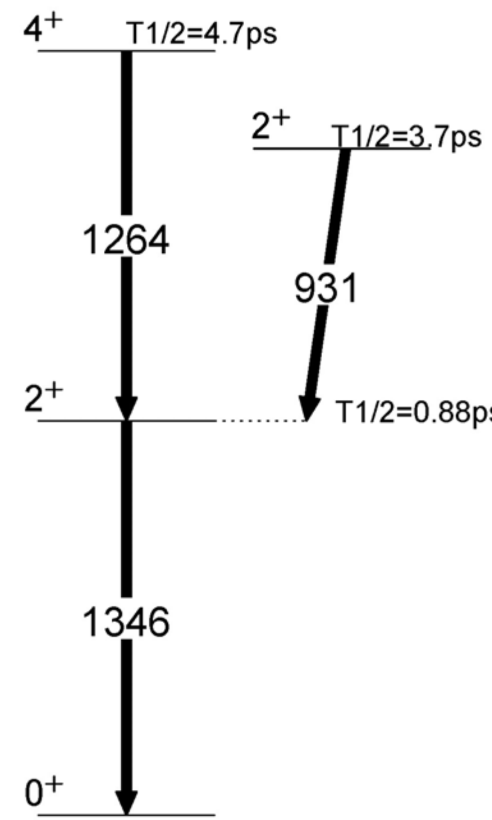
sign of "longer" lifetime in ^{62}Fe

(2^+ at 877 keV)

$T_{1/2}$~9.5(20) ps
B(E2)~0.012 e^2b^2 (8 W.u.)

^{64}Ni Inelastic Scattering





CLARA-PRISMA 2006-2007

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, developed in collaboration with FLNR Dubna, in phase of data evaluation of firsts runs.

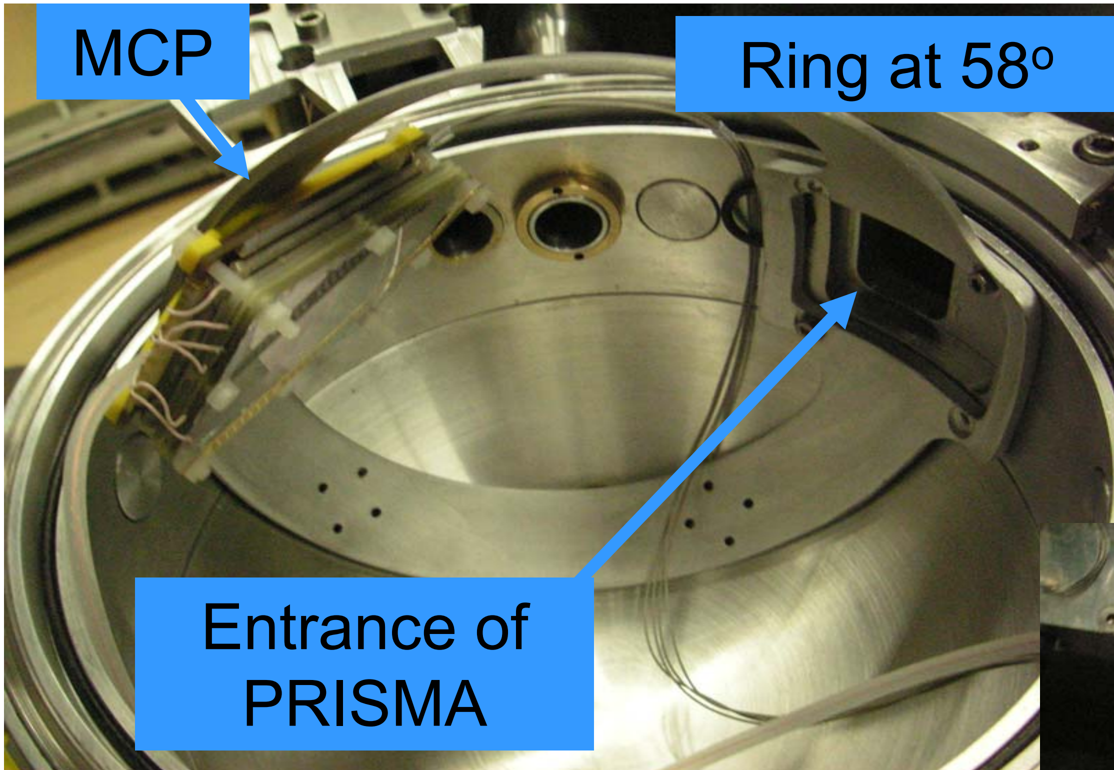
Development of the Differential Plunger RDDS technique for CLARA-PRISMA in collaboration with IKP-Koeln.

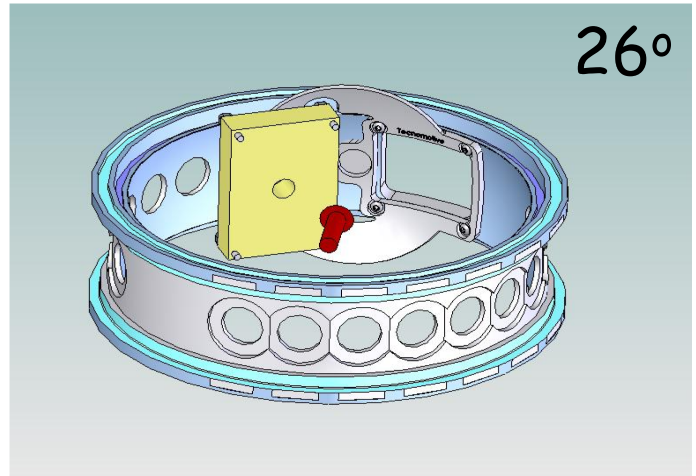
Development of a new focal-Plane detector for PRISMA based on SeD (collaboration U.K. - INFN)

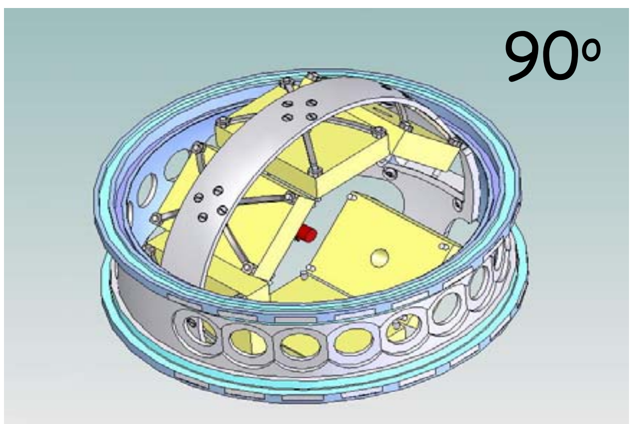
Heavier beams from ALPI linac with the new positive ion injector PIAVE.

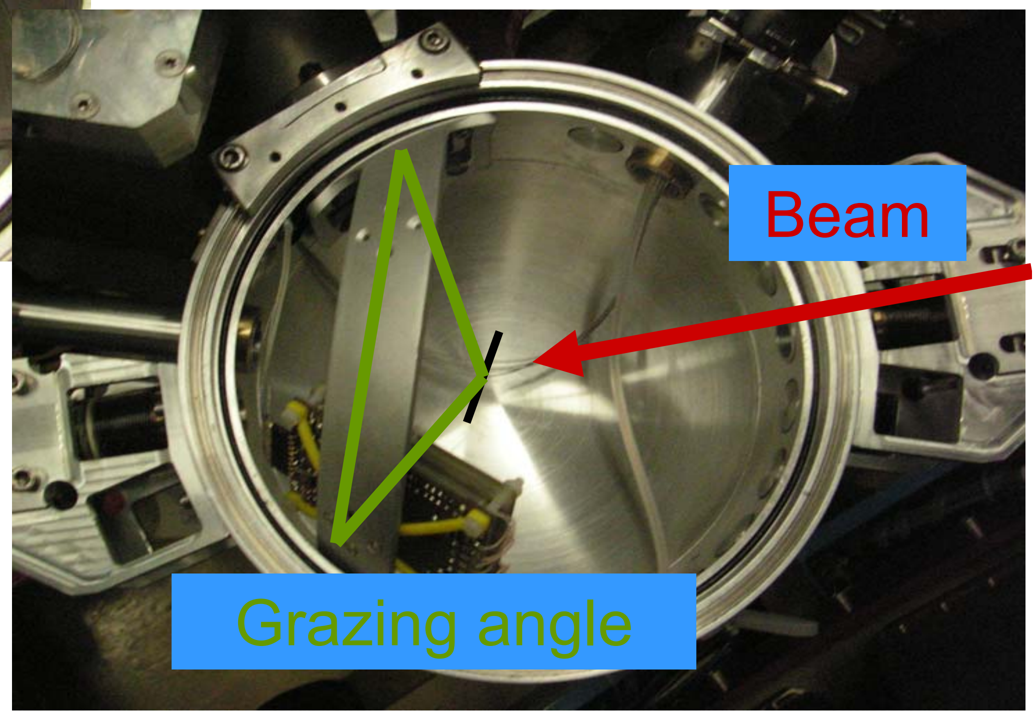
DANTE

INFN-LNL, INFN-Milano, FLNR-Dubna, INFN-Padova,

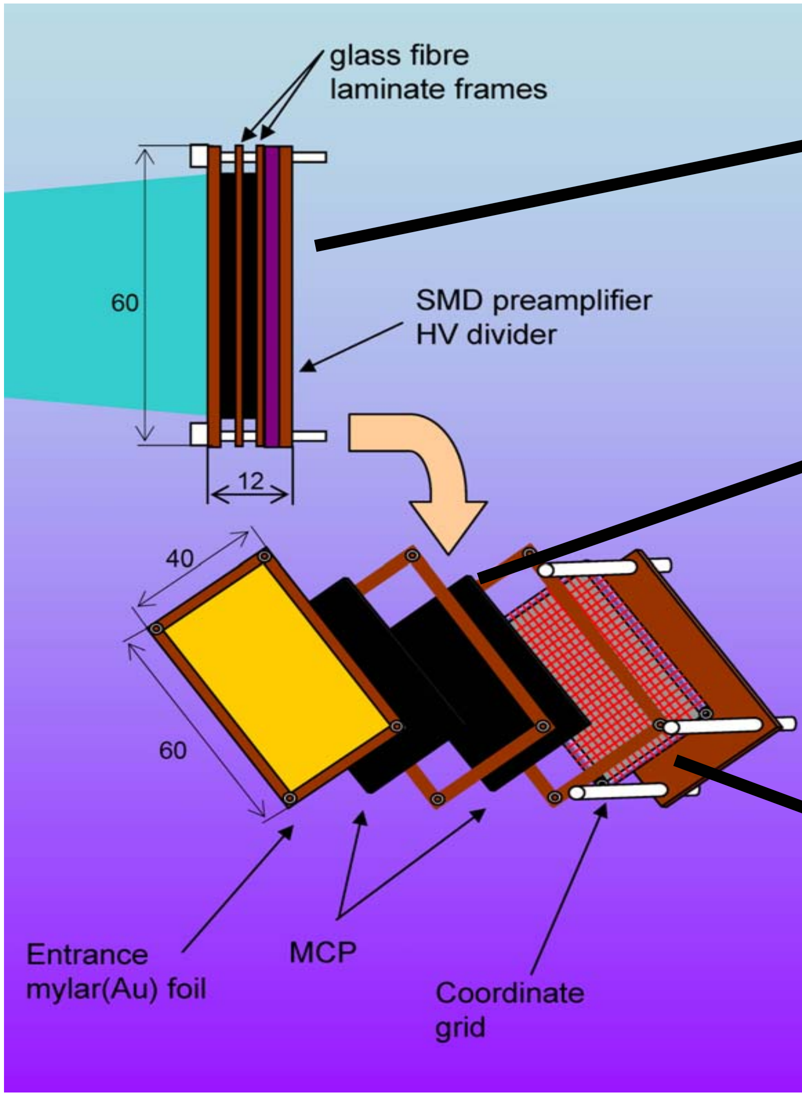




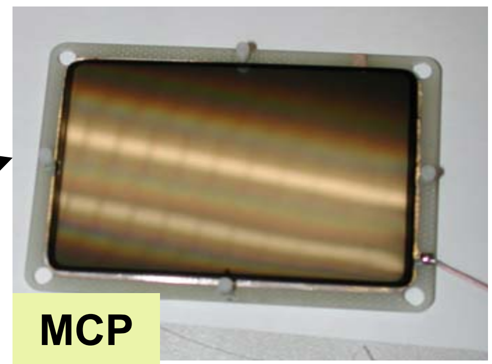




The DANTE detectors



Preamplifier in vacuum

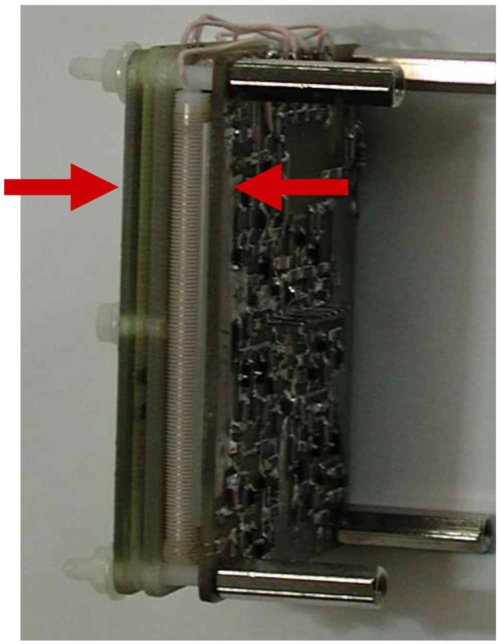


MCP

Delay line

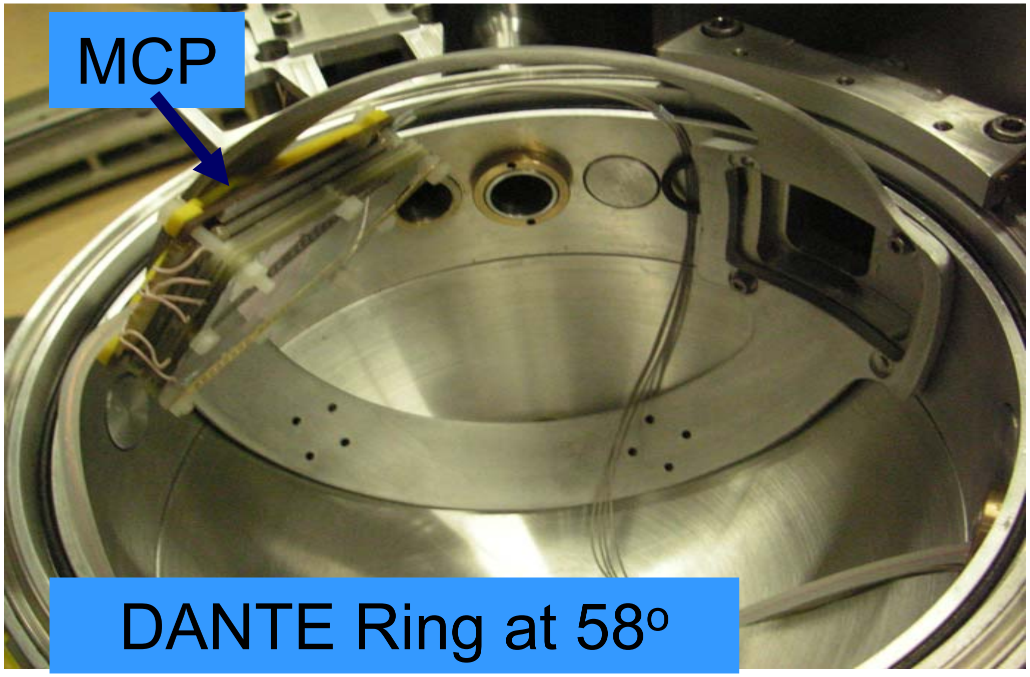
Based on FLNR–Dubna Corset design

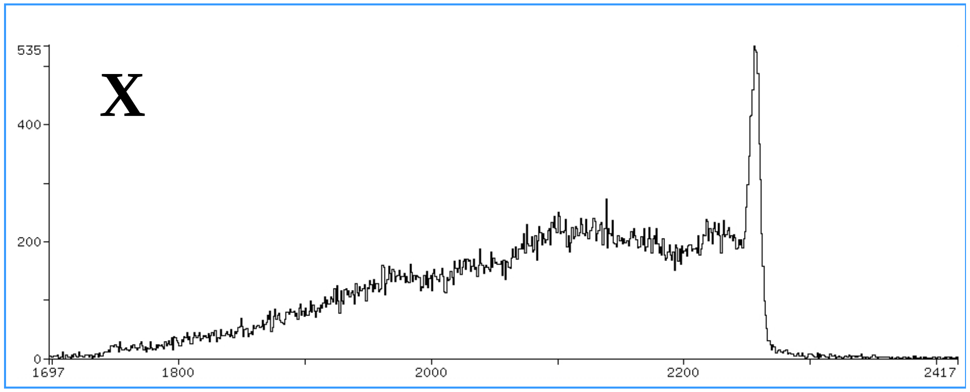
Thickness:13mm

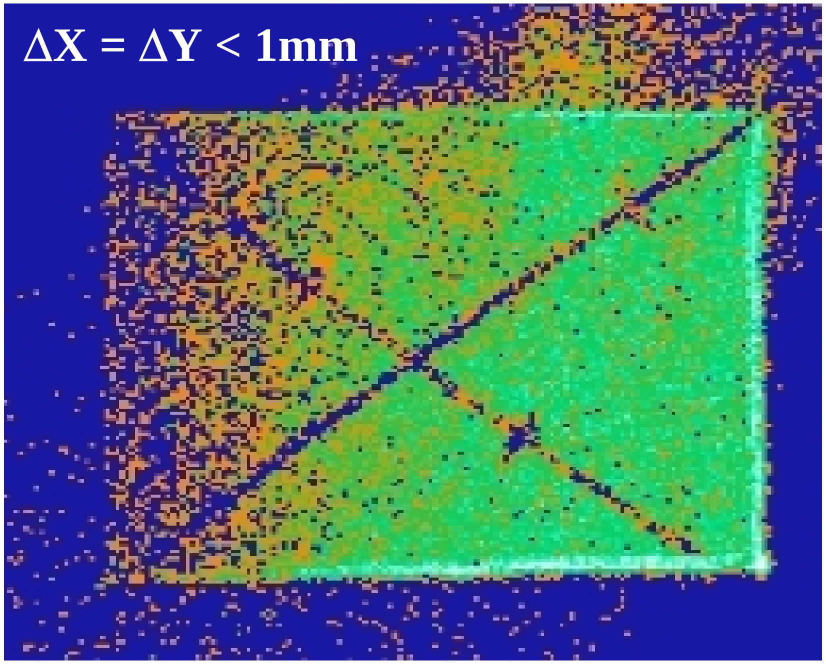


Lateral section of a DANTE detector

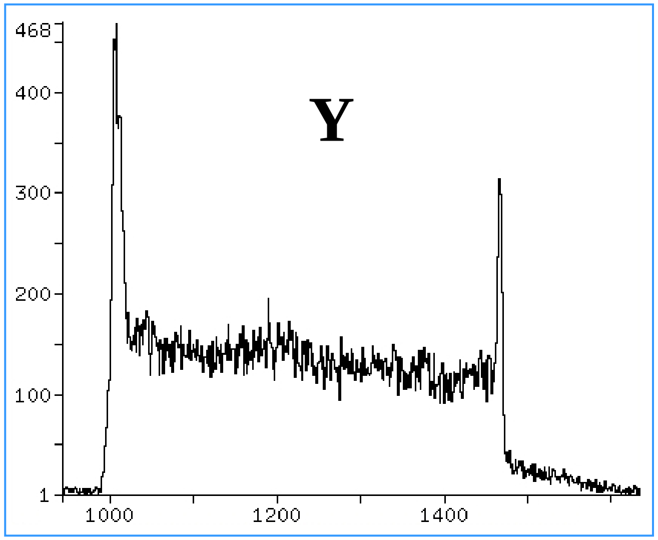
In-Beam Commissioning at LNL Legnaro





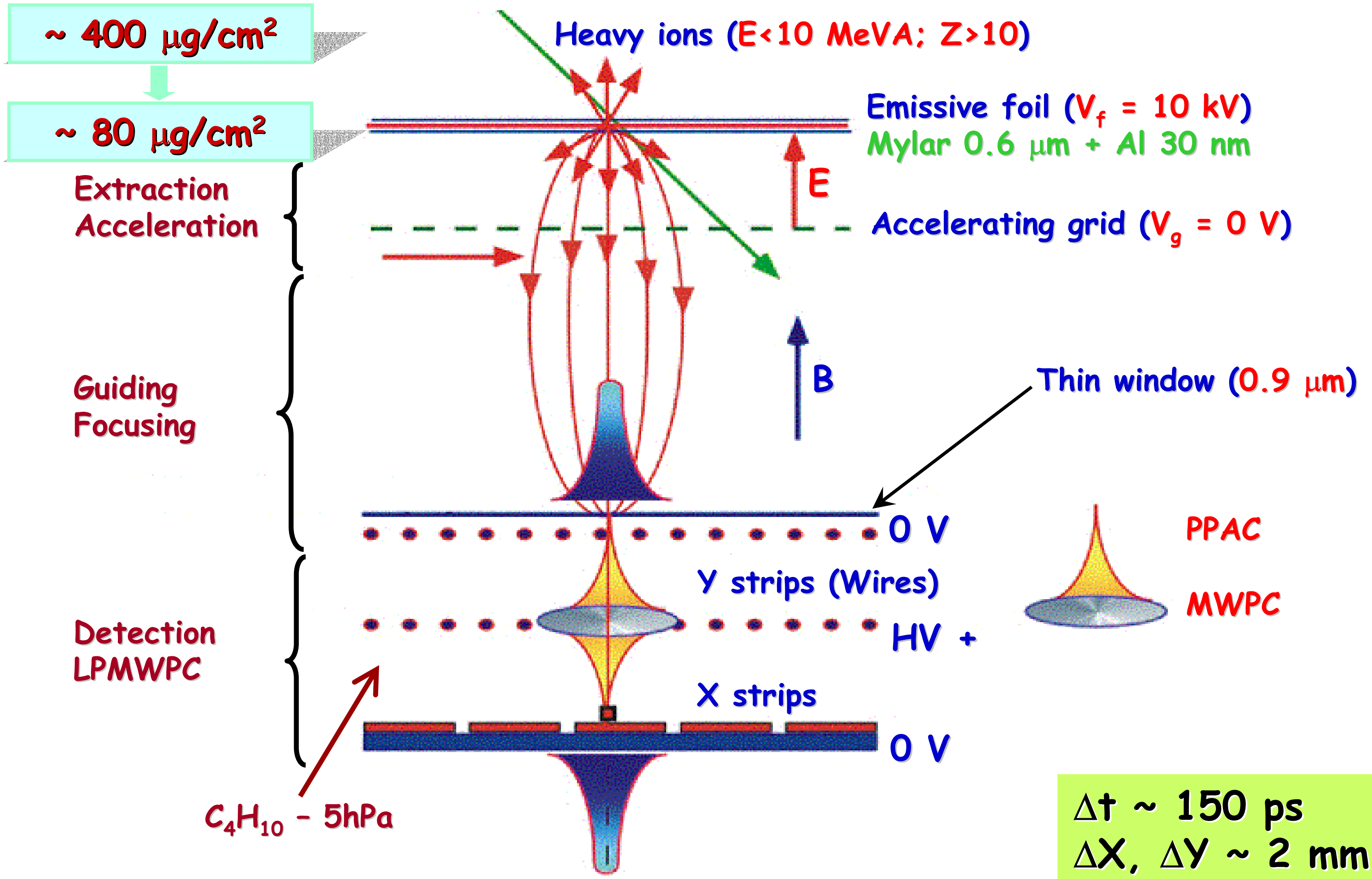


Time resolution 130ps
Position resolution <1mm
High counting rate
High noise rejection



Development of a new FPD for PRISMA

New FPD for low energy HI ➡ Se-D

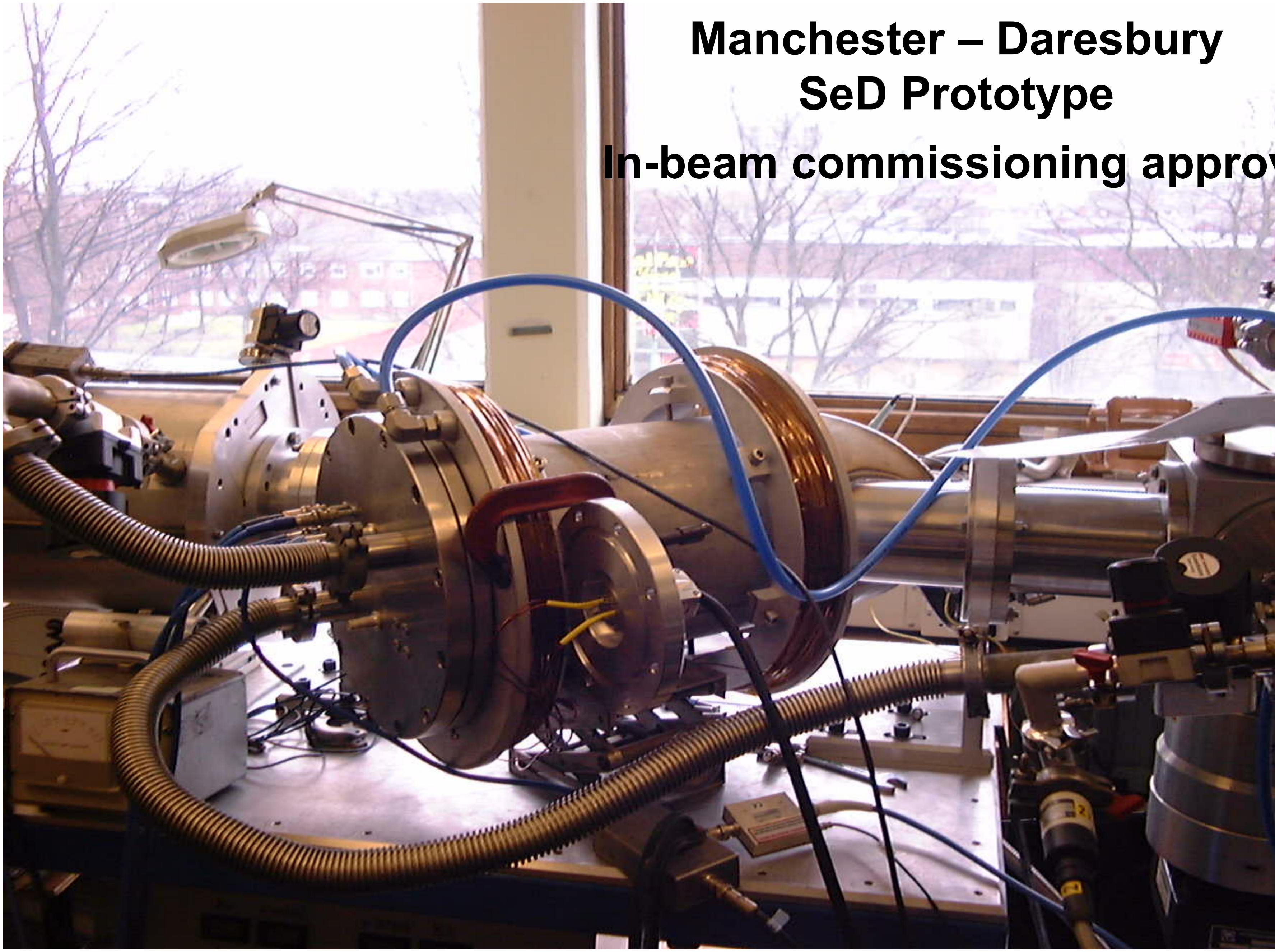


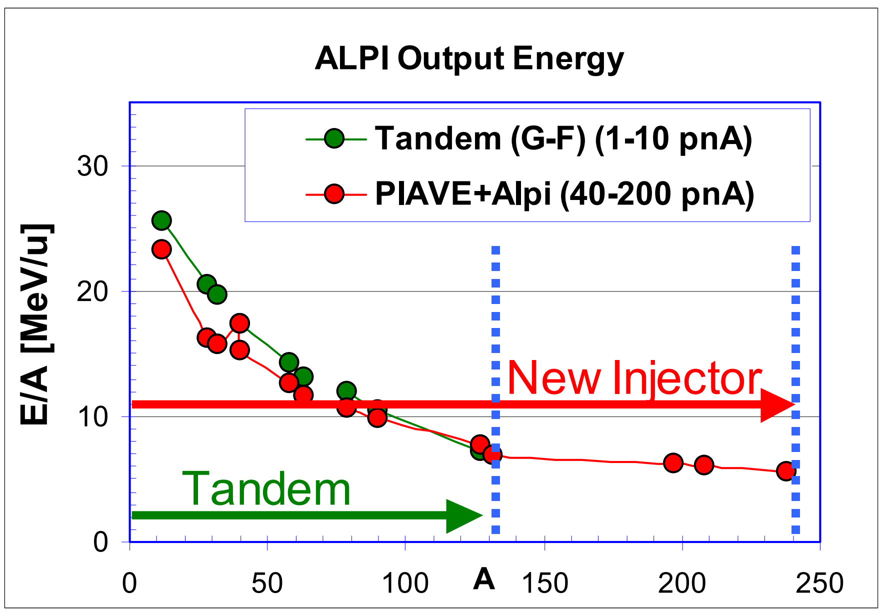
Δt ~ 150 ps
ΔX, ΔY ~ 2 mm

Collaboration of several U.K.groups
Manchester - Daresbury - Paisley

Manchester – Daresbury
SeD Prototype

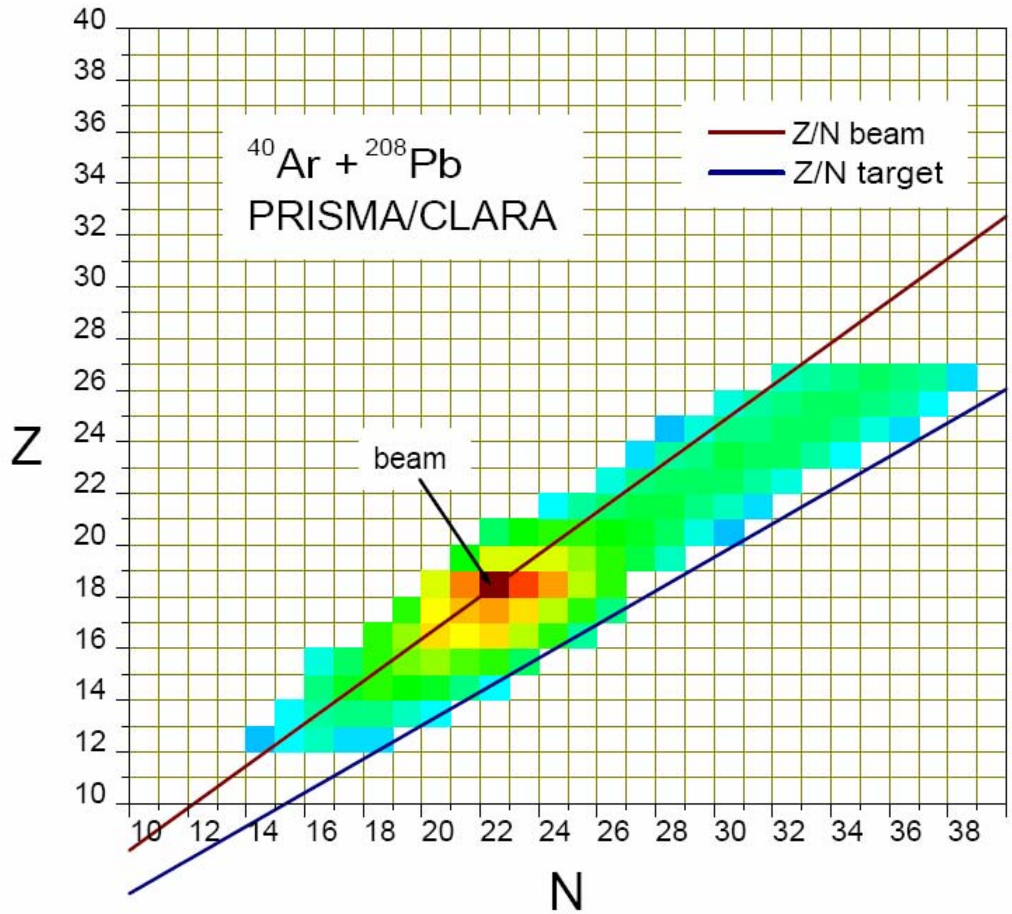
In-beam commissioning approved

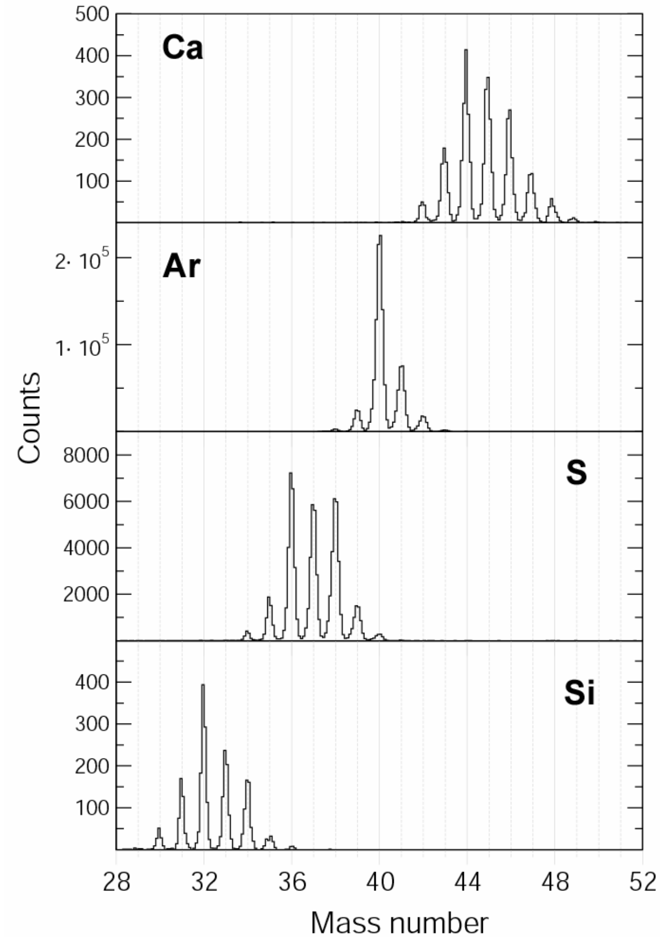




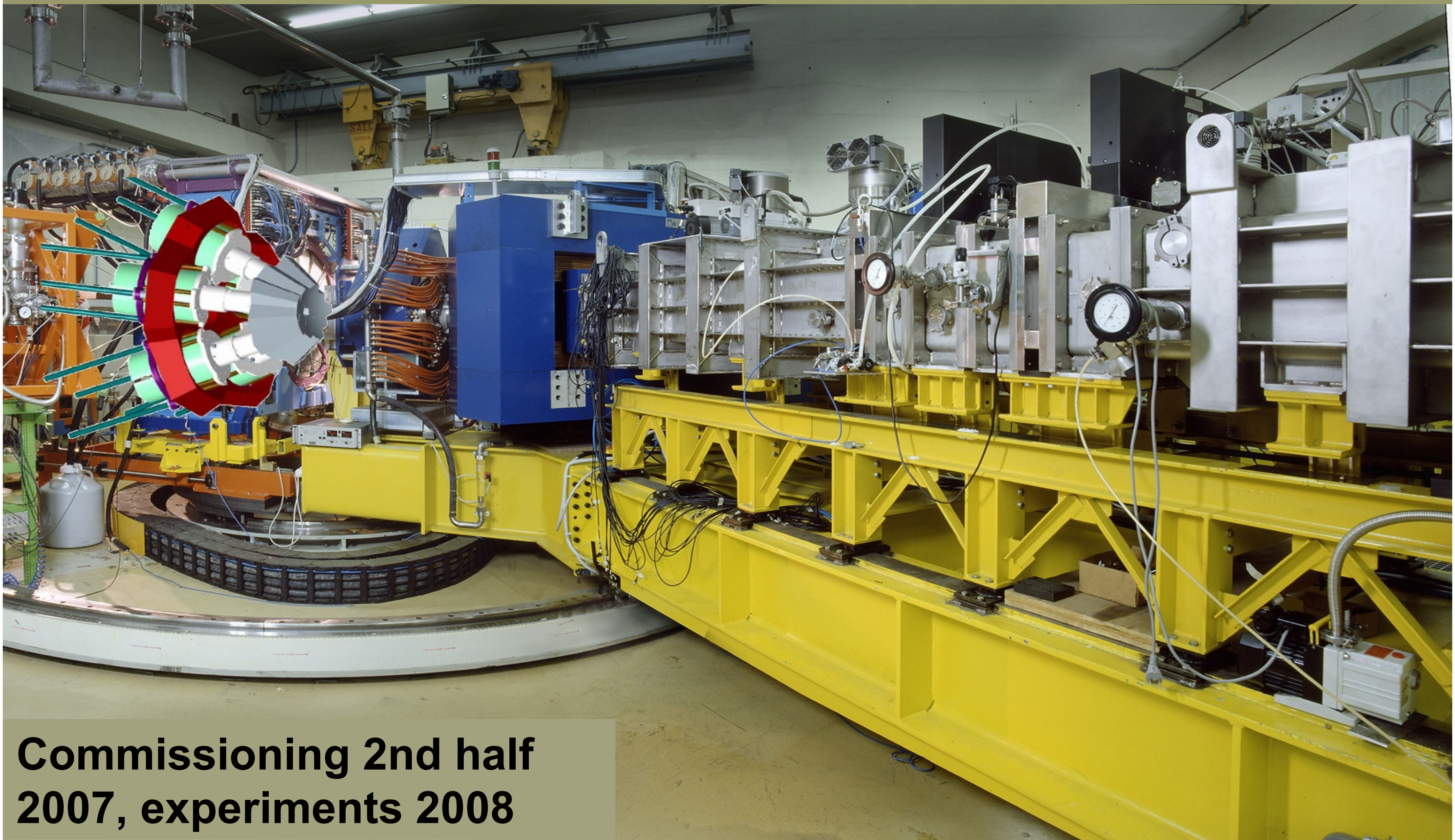
Positive ion injector ECRIS + PIAVE commissioned
Last quarter 2005 - first quarter 2006: Ne, Ar and Kr beam delivered to the experimental areas for test.
PIAVE beams for users during second semester 2006.

^{40}Ar (238 MeV) PIAVE-ALPI beam test
CLARA-PRISMA, January 2006





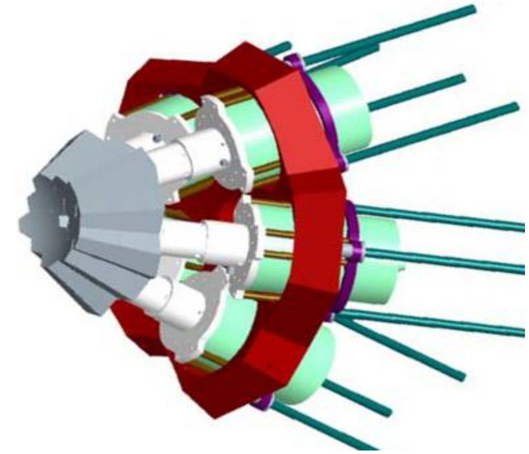
AGATA Demonstrator – PRISMA setup

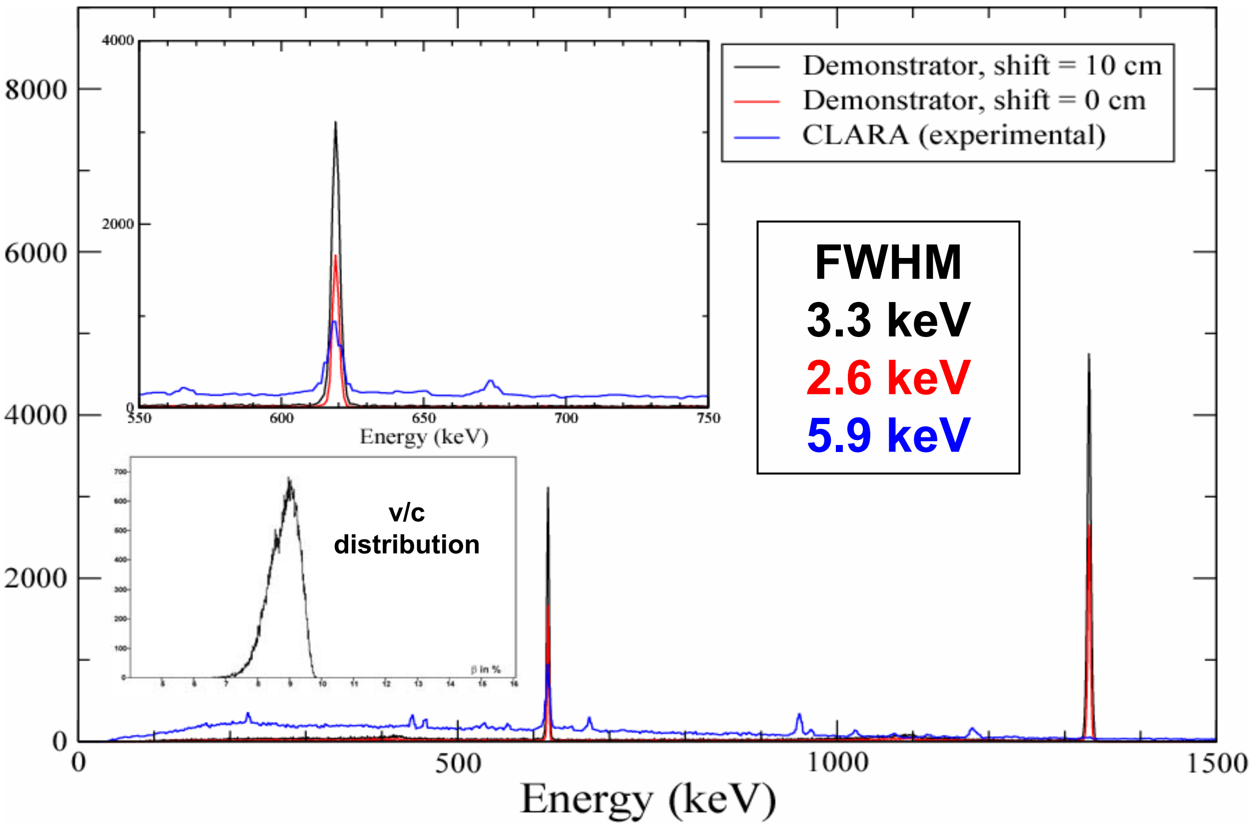


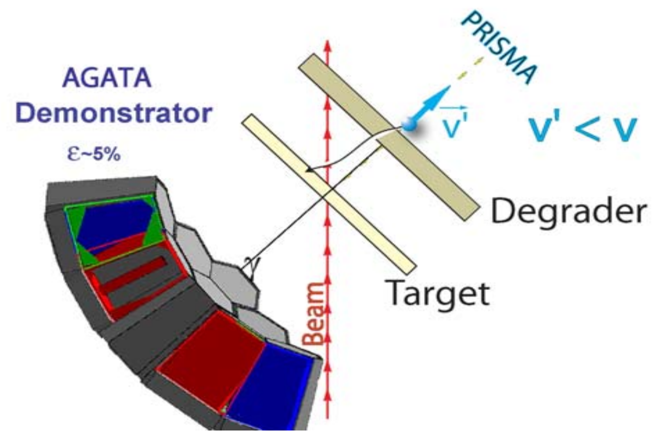
Commissioning 2nd half 2007, experiments 2008

AGATA Demonstrator at PRISMA

Efficiency at 1MeV: ~6% at 14cm
Peak/Total: ~50%
Angles covered: from ~135^{o} to 180^{o}
FWHM, β~10%, 1MeV: <4 keV

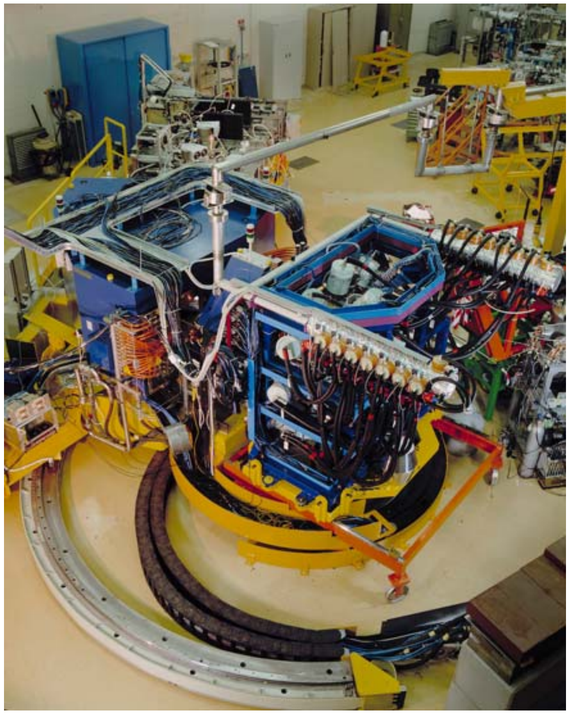




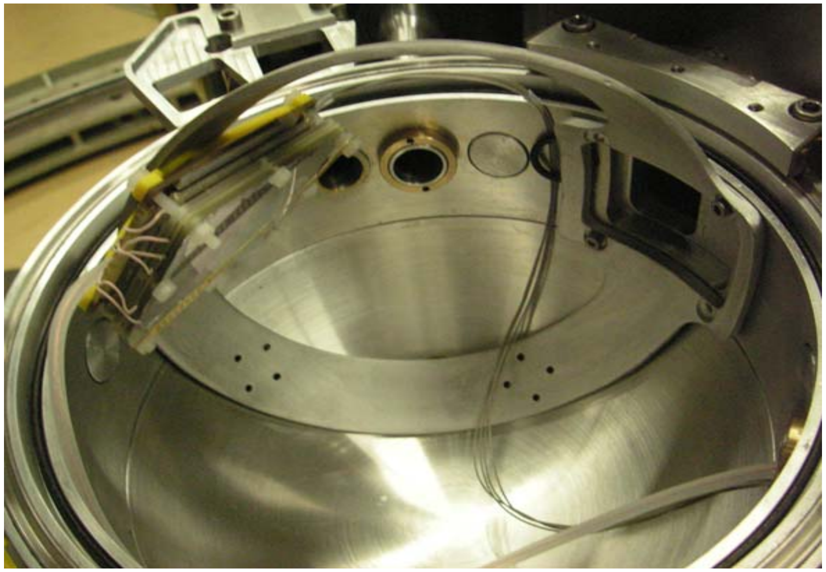


The full demonstrator at 14cm (6% efficiency) can be used for RDDS lifetime measurements

Conclusions:



-Spectroscopy with grazing reactions, using the combination of a gamma- array and a large acceptance spectrometer (as CLARA-PRISMA), provides valuable structure information on moderately n-rich nuclei.
-Differential RDDS technique been developed in collaboration with IKP-Koeln,



-CLARA has been upgraded with an ancillary array to perform “in beam” γ–γ coincidences with Doppler correction.

-New SeD based FPD for PRISMA are under development (U.K. – INFN)

-Runs using the CLARA-PRISMA setup with the medium-mass and heavy beams from PIAVE-ALPI during the second semester 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

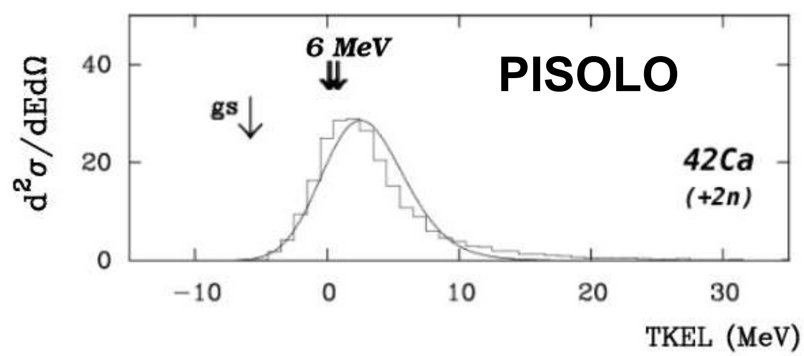
INFN LNL-Legnaro
INFN and University Padova
INFN and University Milano
INFN and University Genova
INFN and University Torino
INFN and University Napoli
INFN and University Firenze
University of Camerino

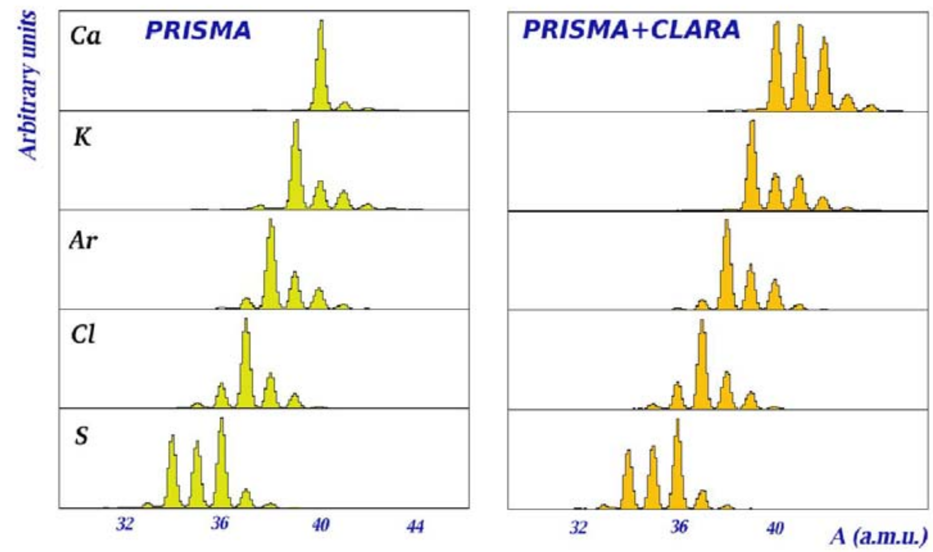
•Spain

University of Salamanca

•Romania
Horia Hulubei NIPNE Bucharest

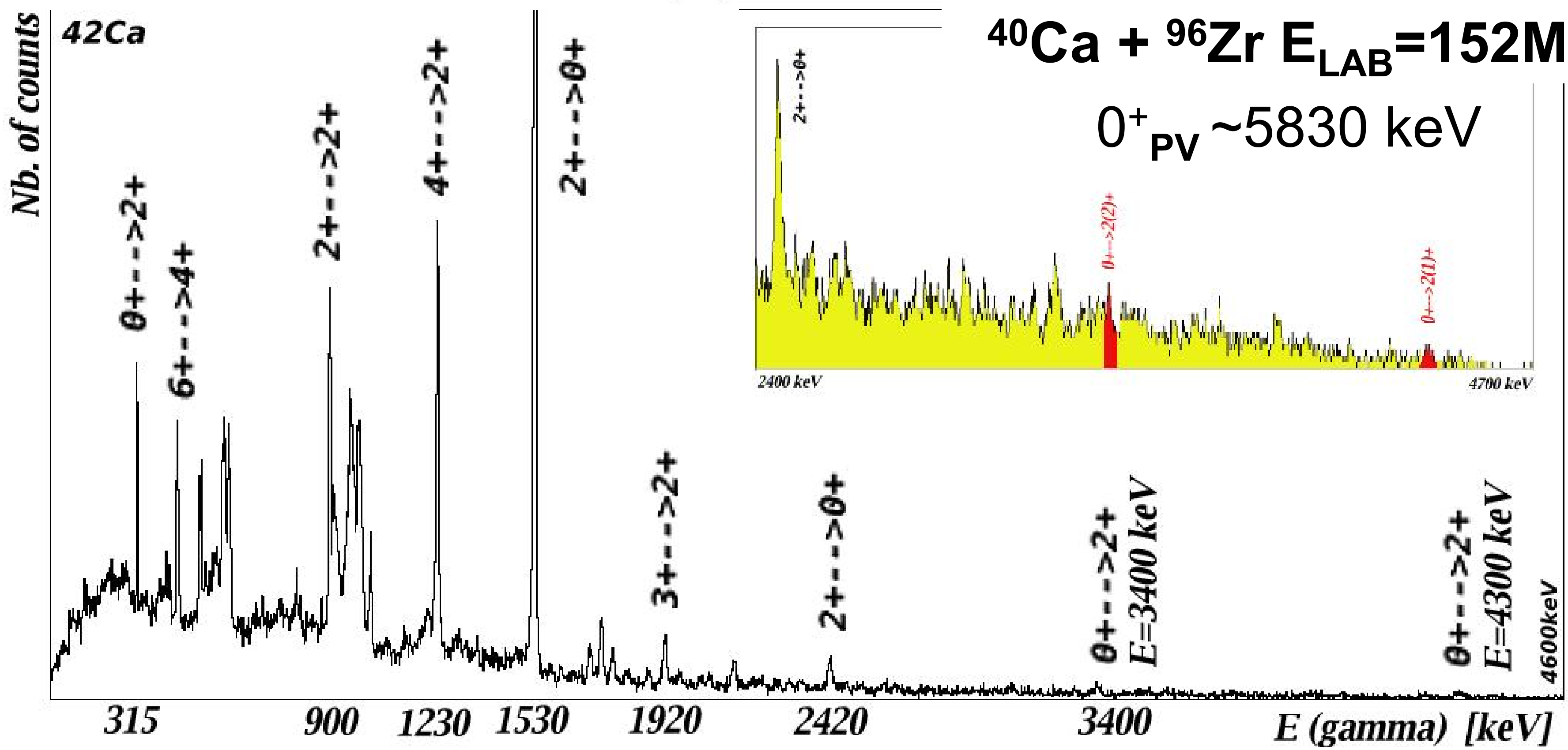
Pairing-vibration states in ^{42}Ca
S.Szilner (LNL and Zagreb)



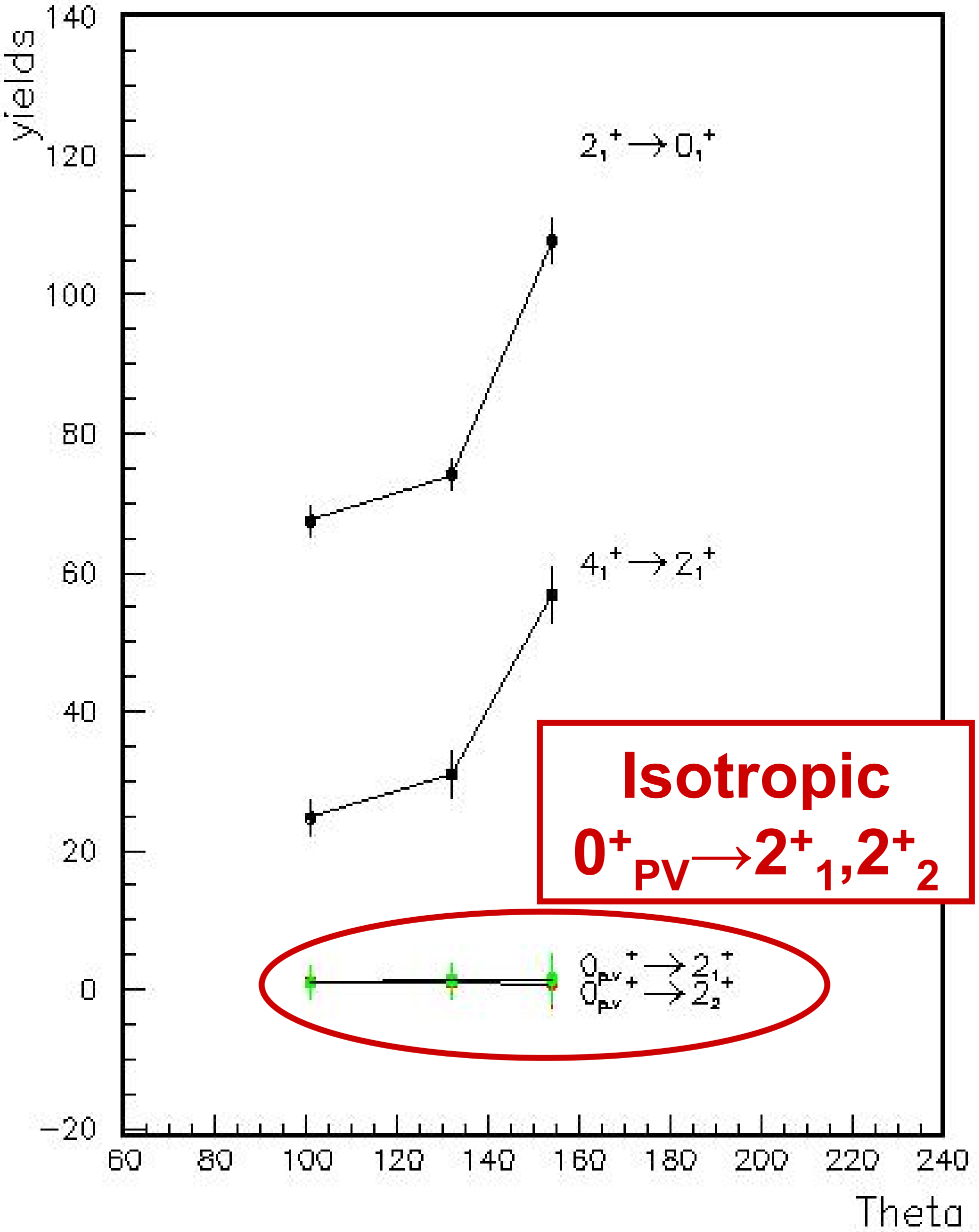


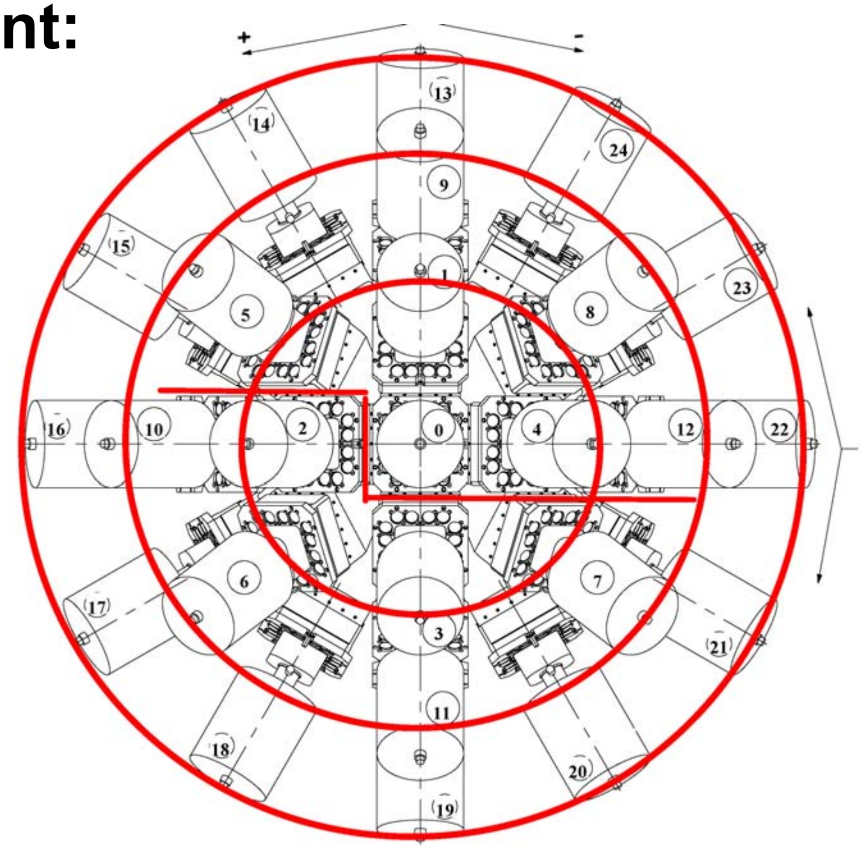
^{40}Ca + ^{96}Zr E_{LAB}=152MeV

0^+_{PV} ~5830 keV



Angular Distribution measurement:





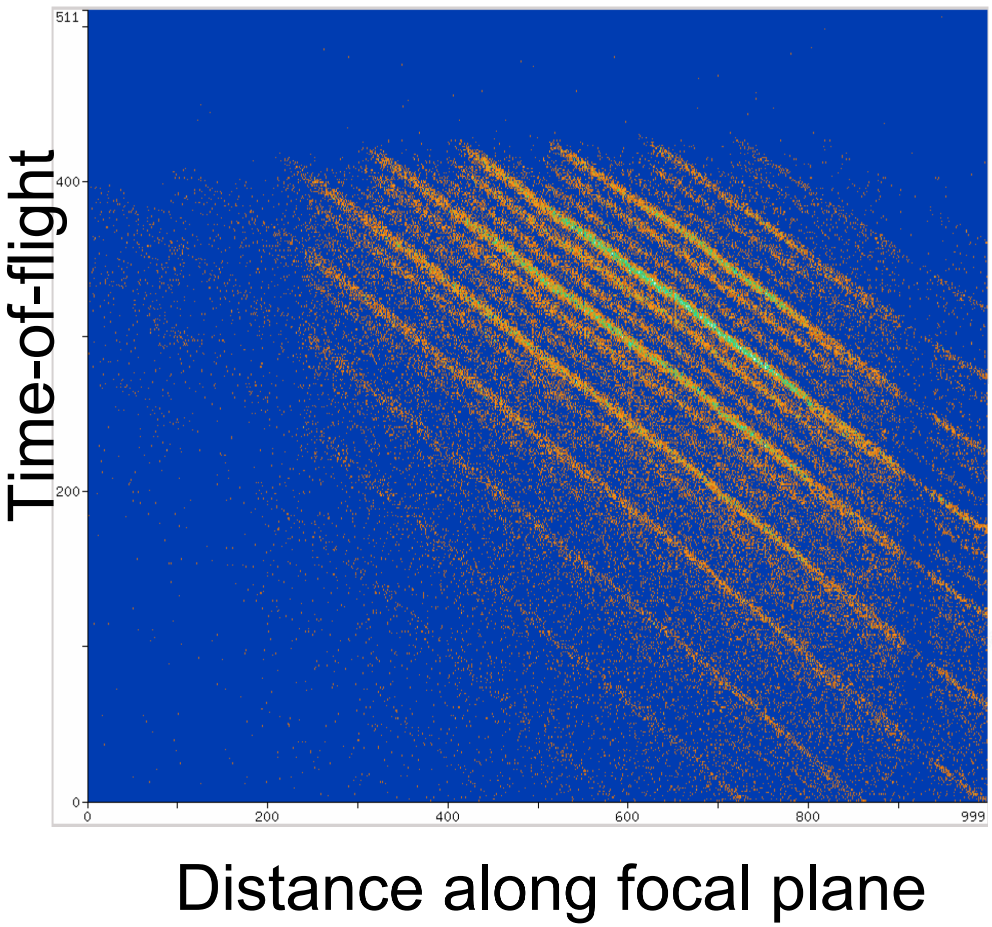
Angular Distribution of $4^+ \rightarrow 2^+$ and $2^+ \rightarrow 0^+$ transitions indicates: $\sigma/J \sim 0.3$

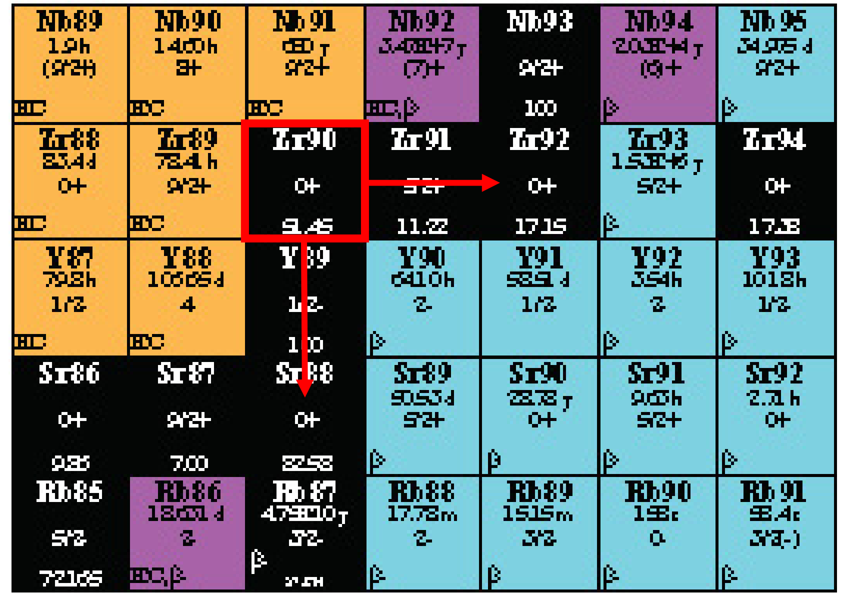
S.Szilner, LNL & Zagreb

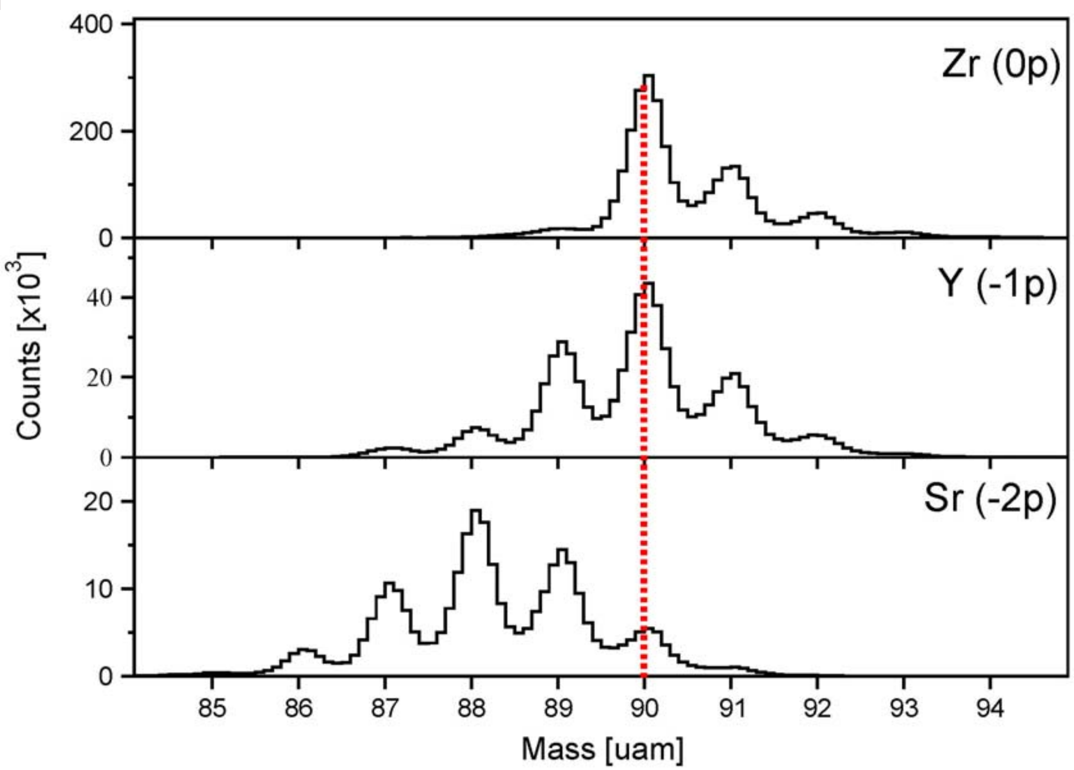
^{90}Zr 560MeV + ^{208}Pb

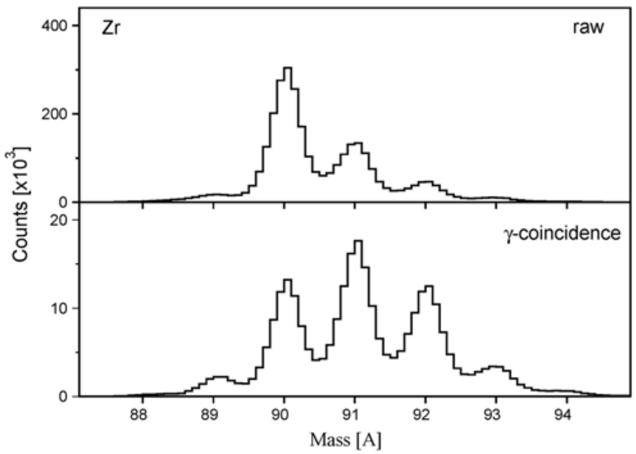
1 day beam time

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



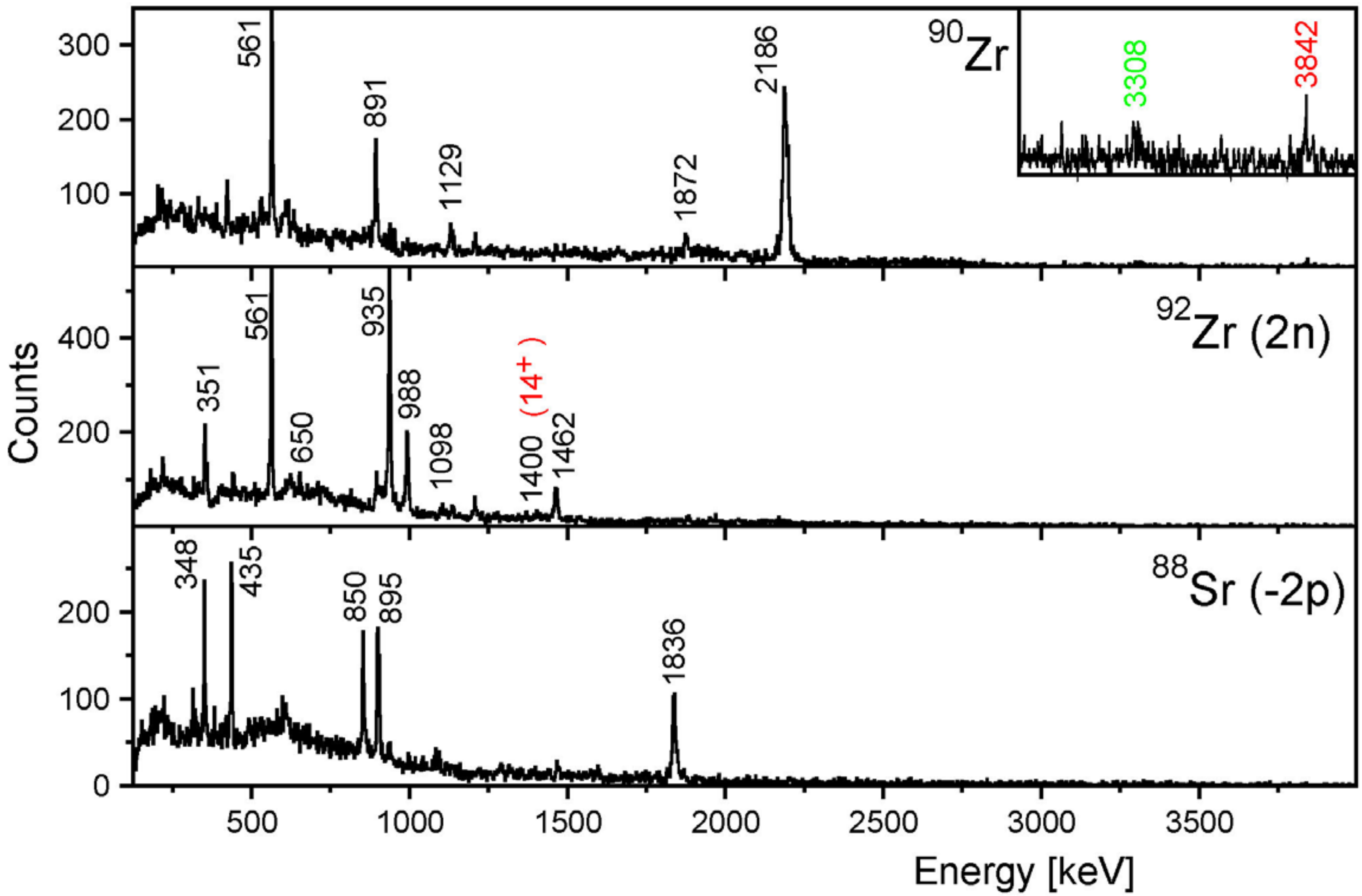


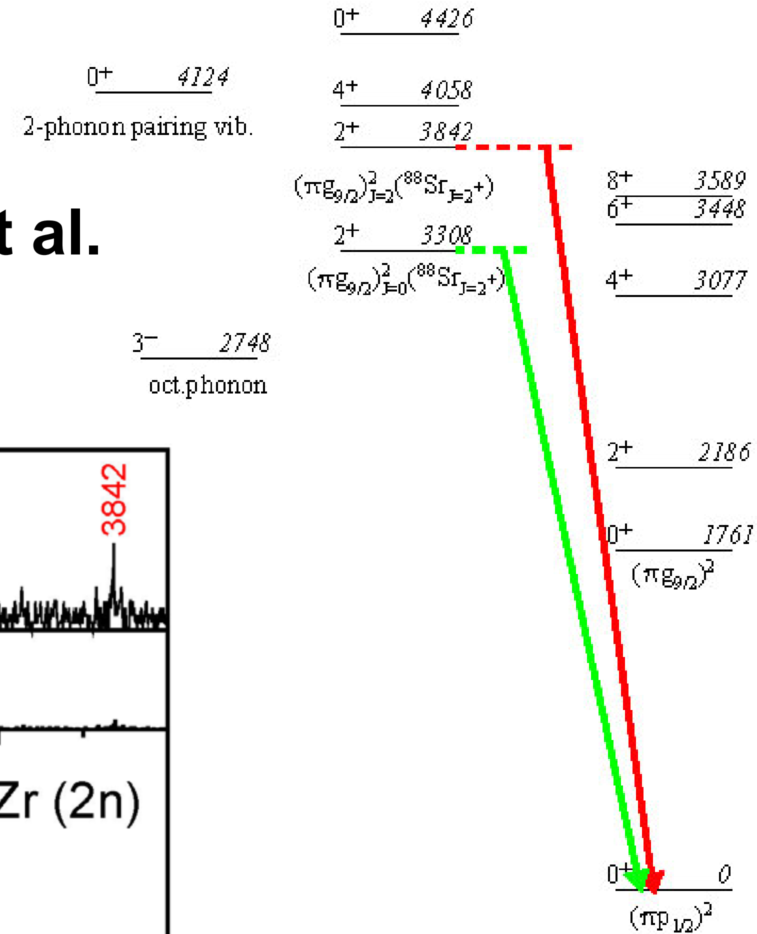




^{90}Zr 560MeV + ^{208}Pb

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



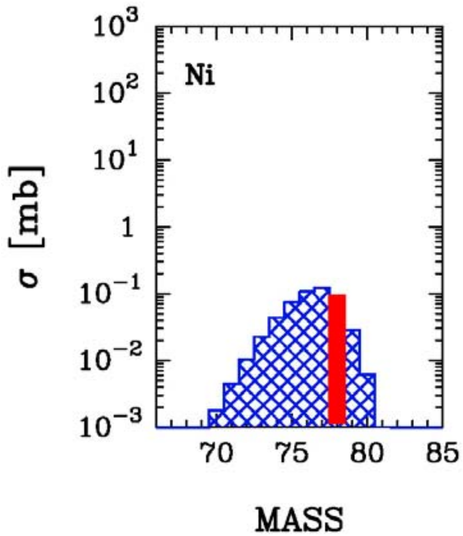


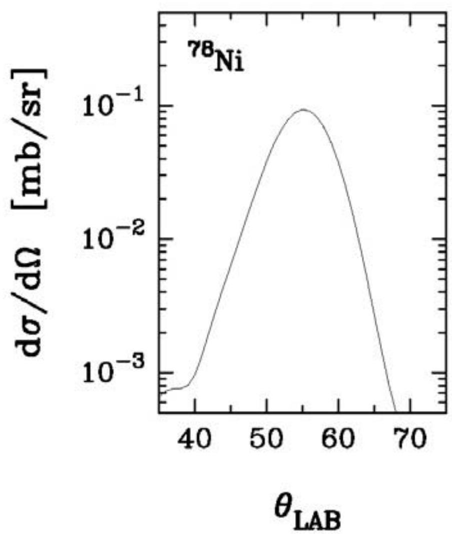
Level Scheme from:
^{90}Zr(n,n`γ)
P.E.Garrett et al.,
Phys.Rev.C68
(2003)024312

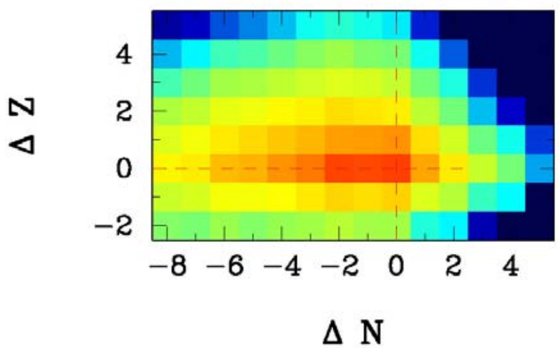
Transfer with Radioactive Beams at Coulomb barrier Energies

$^{80}Zn + ^{238}U$ (460 MeV)

Calculations by G.Pollarolo



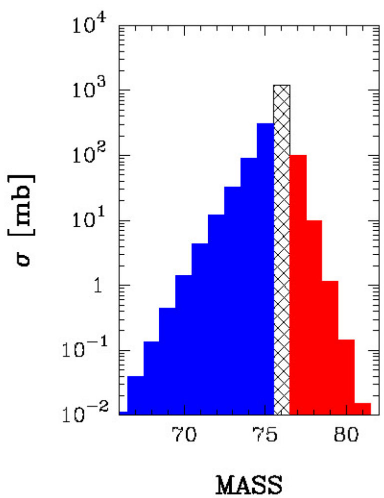


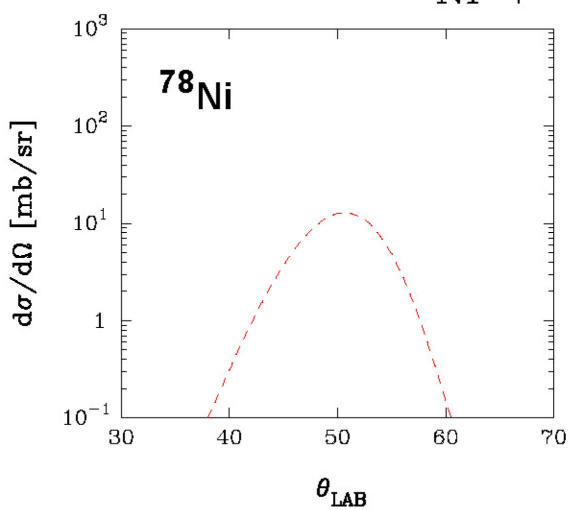


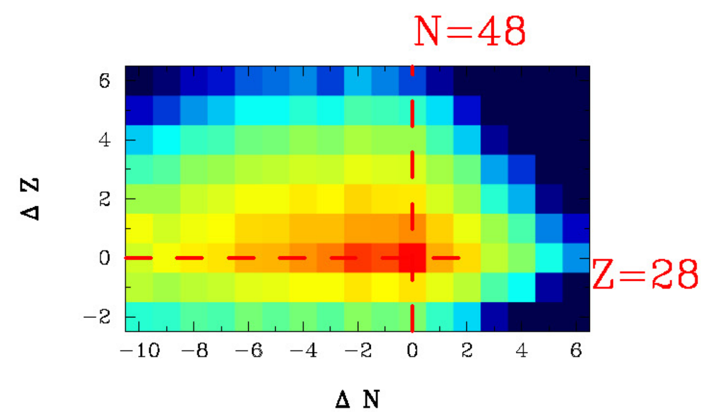
$d\sigma/d\Omega = 100\mu b$

$d\sigma/d\Omega = 10 mb$

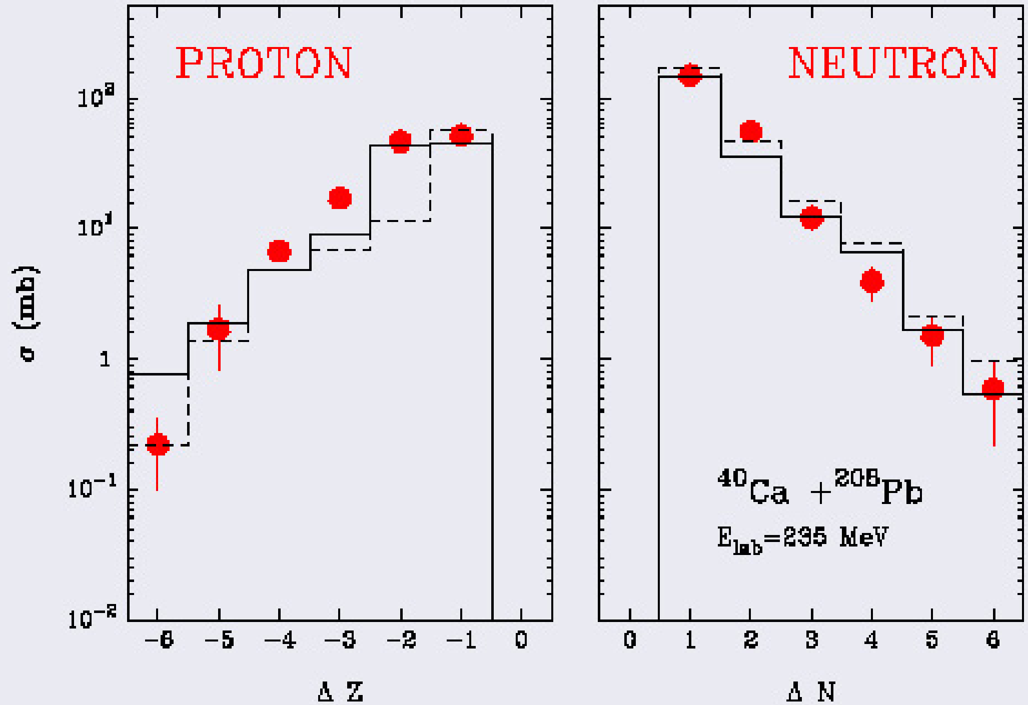
$^{76}Ni + ^{238}U$ (450 MeV)







Pure neutron, proton transfer channels



Simultaneous transfer:

Is achieved by adding a PAIR-MODE $(\delta n_{fi} = \pm 2,\ \delta z_{fi} = \pm 2)$

$$F_{fi}^{pair}(r) = \beta_p \frac{\partial V^{opt}(r)}{\partial A}$$

where the strength β_p is adjusted to the experiment.

DANTE

(Detector Array for multi Nucleon Transfer Ejectiles)

INFN-LNL, INFN-Milano, FLNR-Dubna, INFN-Padova,

- **Start detector of PRISMA ⇒ No possible to place PPACs**
- **DANTE (heavy ion detector based on MCP) reveals the position interaction of the recoils ⇒ Doppler correction.**
- **DANTE placed at the grazing angle, has a high efficiency ⇒ γ-γ coincidences ⇒ No need of extra experiments to build up a level scheme.**