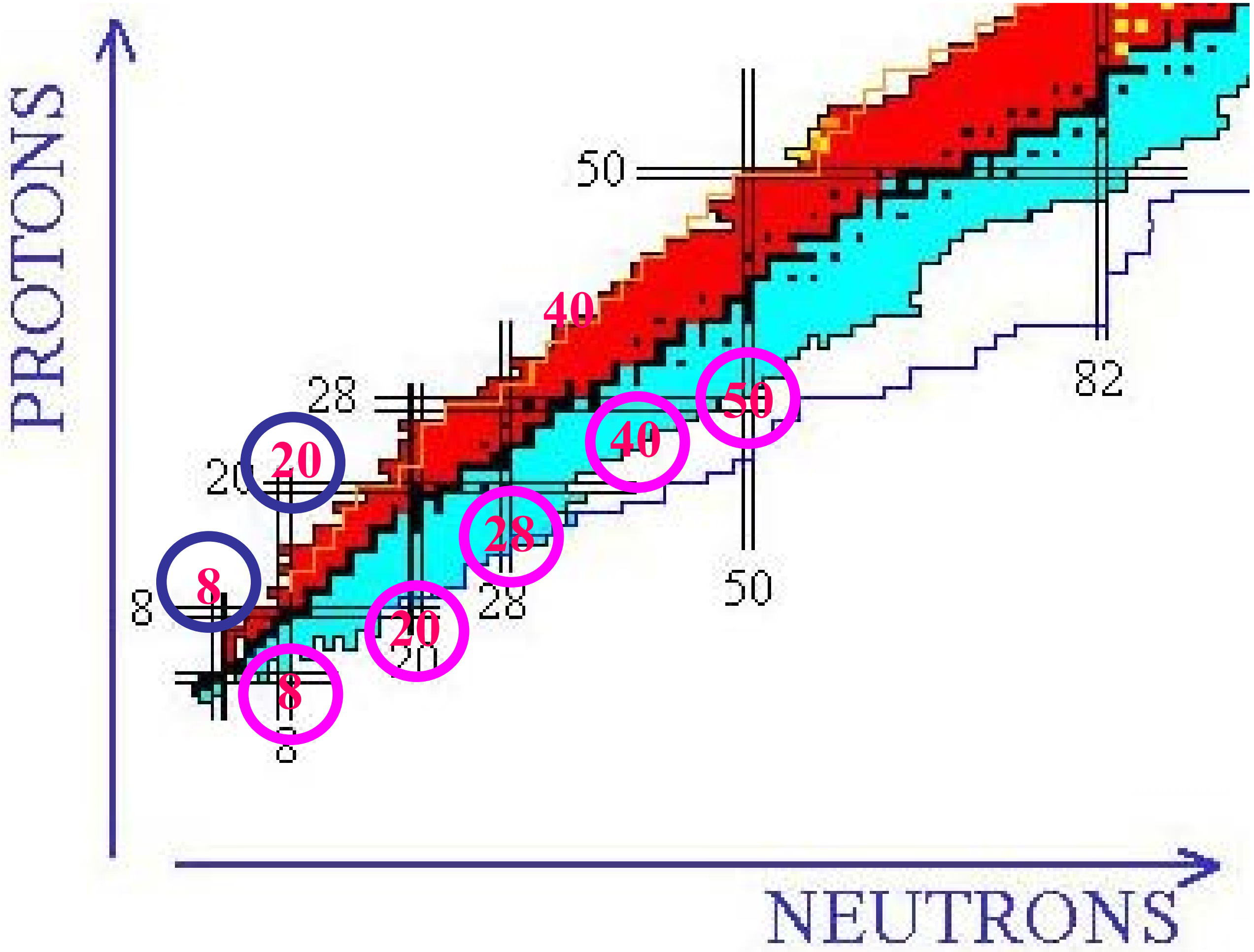
1) In beam γ-spectroscopy at the limits (with reactions at intermediate energies)

2) Everybody should know what is ALTO/TADEM facility at ORSAY!

F.AZAIEZ
IPN-Orsay

Motivation:

Shell structure modifications with large N/Z (around N=8,20,28,40,50)
and experimental evidence for new shells



-First excited states in nuclei of the terra incognita!
-in some cases (even-even) , B(E2)

Studying Shell Structure far from stability:

How?

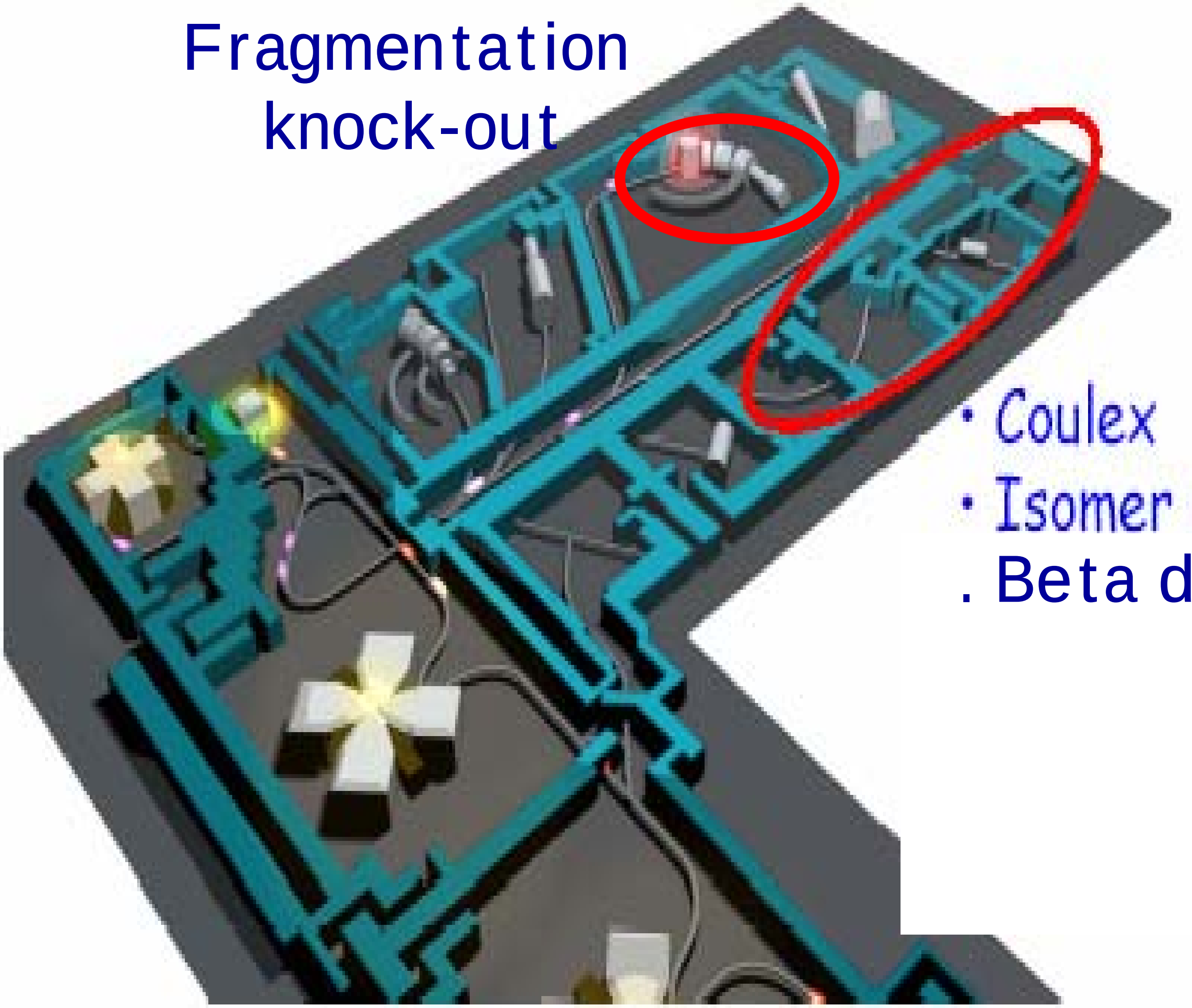
Coulomb excitation of RNB

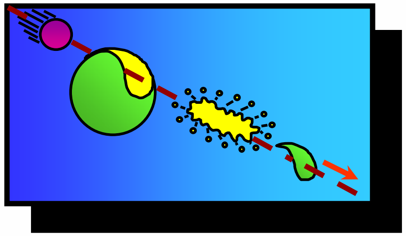
β–γ spectroscopy
Isomer-decay

in-beam γ-spectroscopy with projectile fragmentation reactions of SNB and RNB

in-beam γ-spectroscopy with one and two proton/neutron knock-out

Fragmentation
knock-out



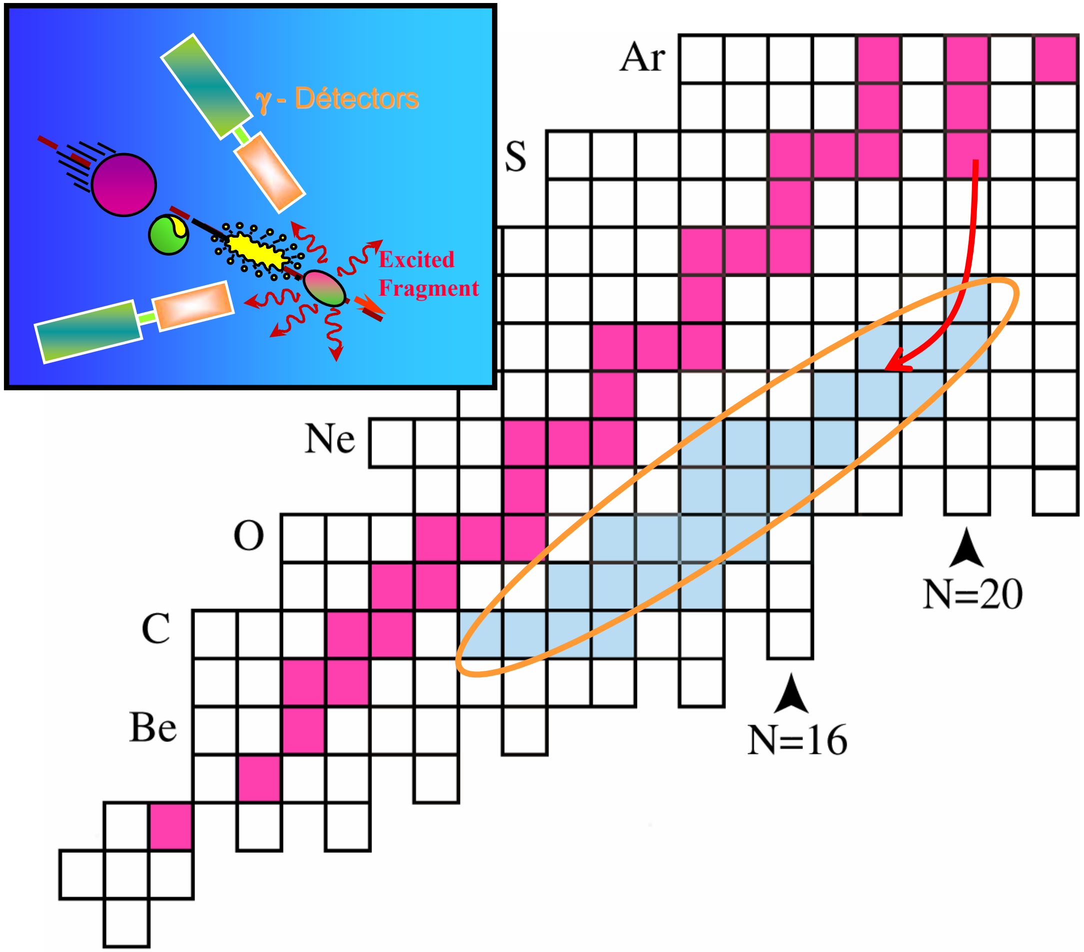


- Coulex
- Isomer decay

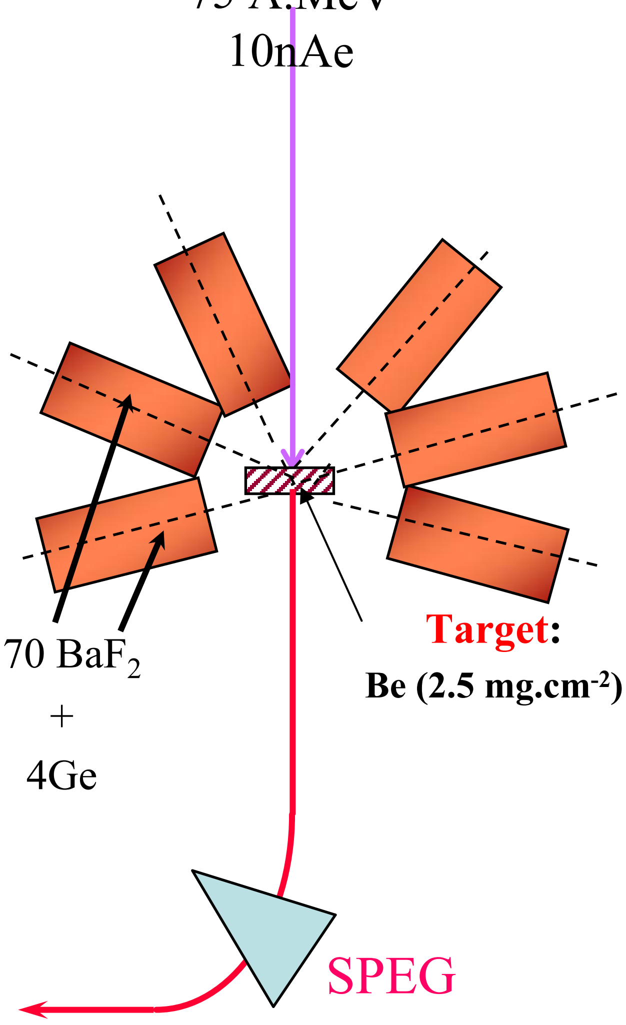
. Beta decay

GANIL

Study of neutron-rich nuclei with **single** step in-beam fragmentation



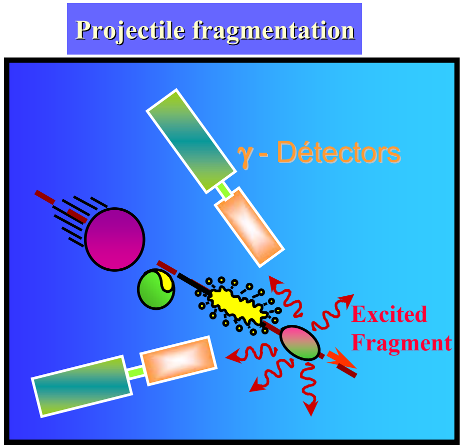
^{36}S (N=20)
^{48}Ca (N=28)
75 A.MeV
10nAe



⊕ Wide range of nuclei produced by fragmentation

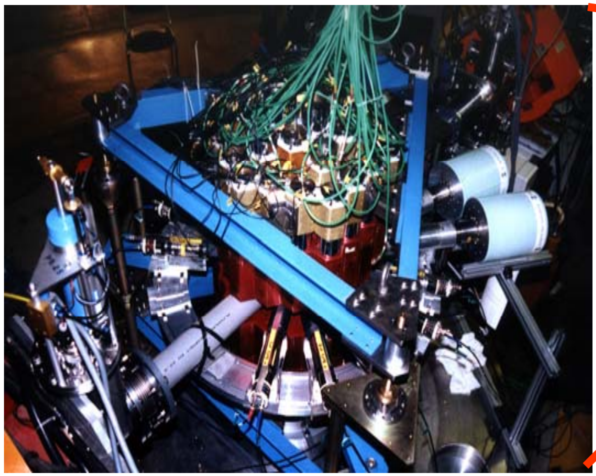
⊖ γ-detectors can withstand a limited beam intensity

The N=20 region:
γ-spectroscopy using In beam fragmentation of ^{36}S beam

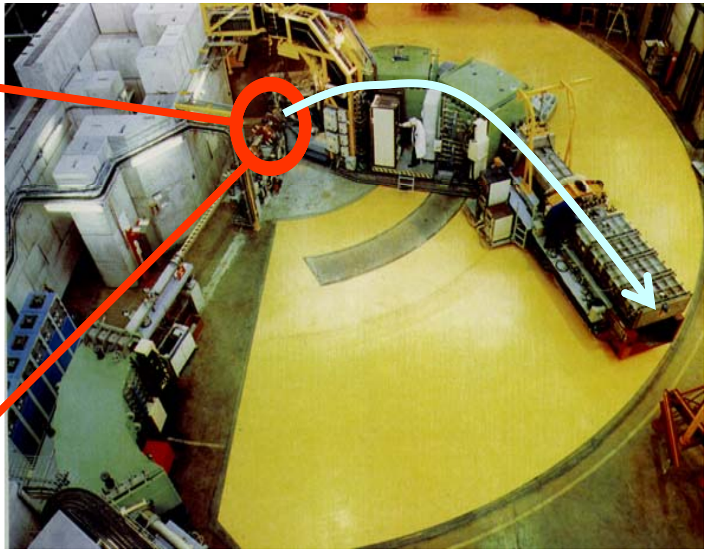


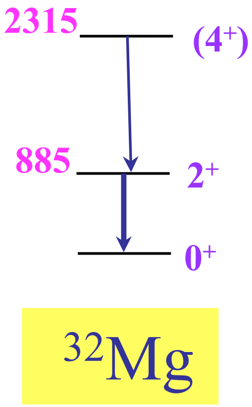
γ detection

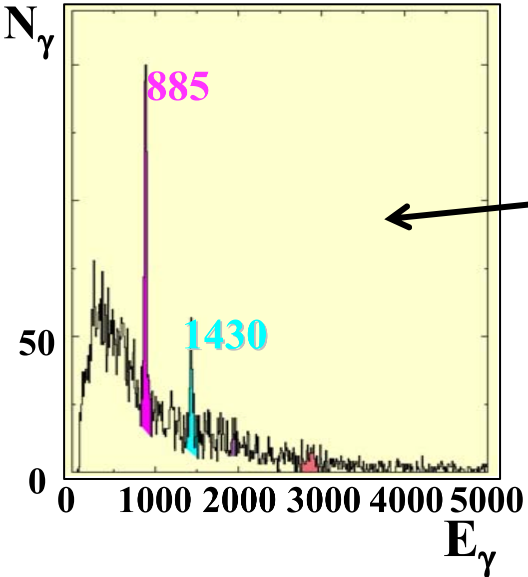
74 BaF_2 + 4 Ge 70%

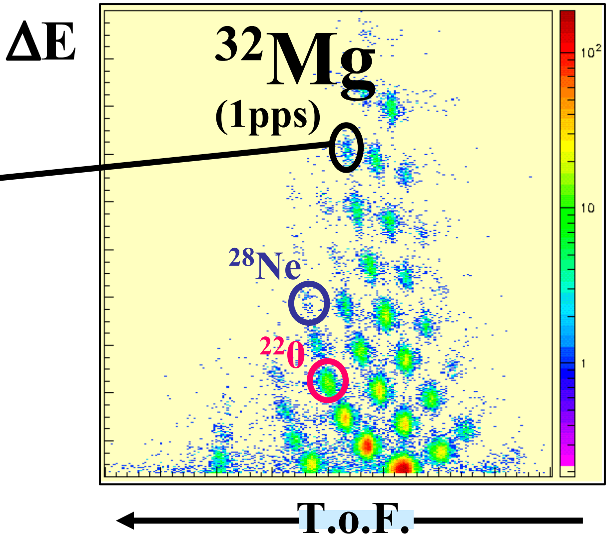


Fragments Identification





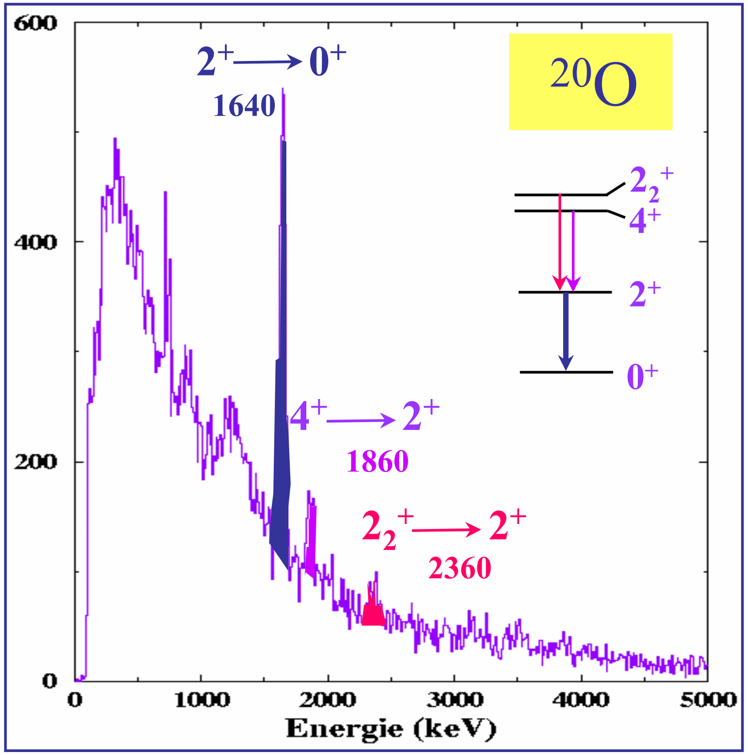




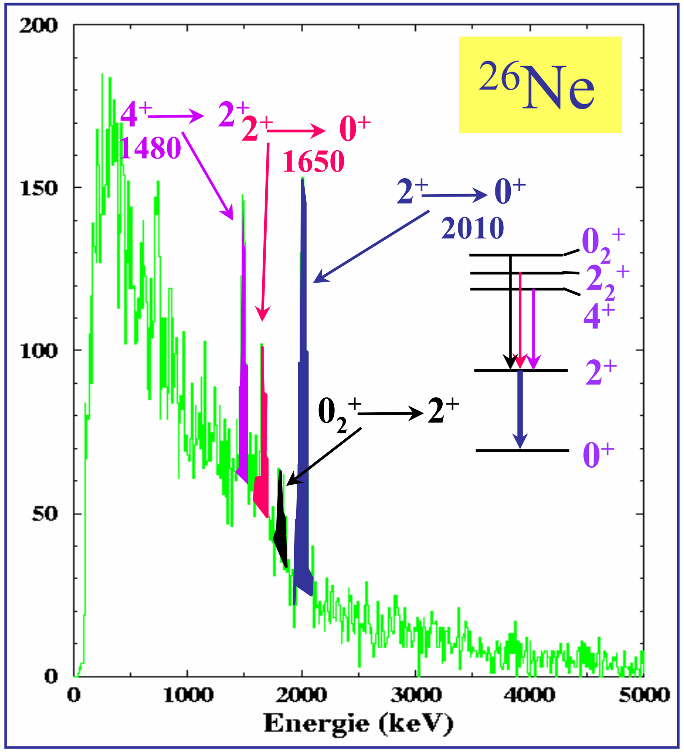
In beam spectroscopy of ^{20}O and ^{26}Ne

Ge spectra, $\varepsilon_{\gamma}\sim 0.4\%$, $\beta\sim 0.33$

20/sec in 15 UT

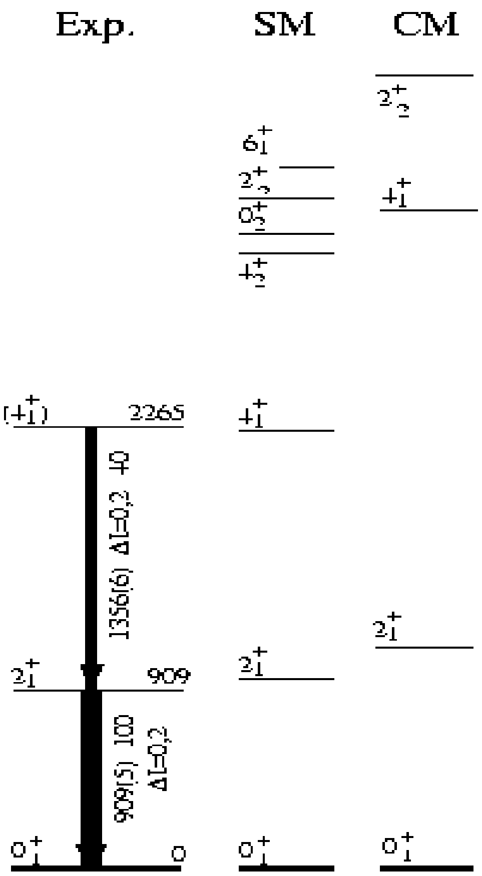


10/sec in 15 UT



Belleguic et al. Nucl.Phys. A682, 136c (2001)

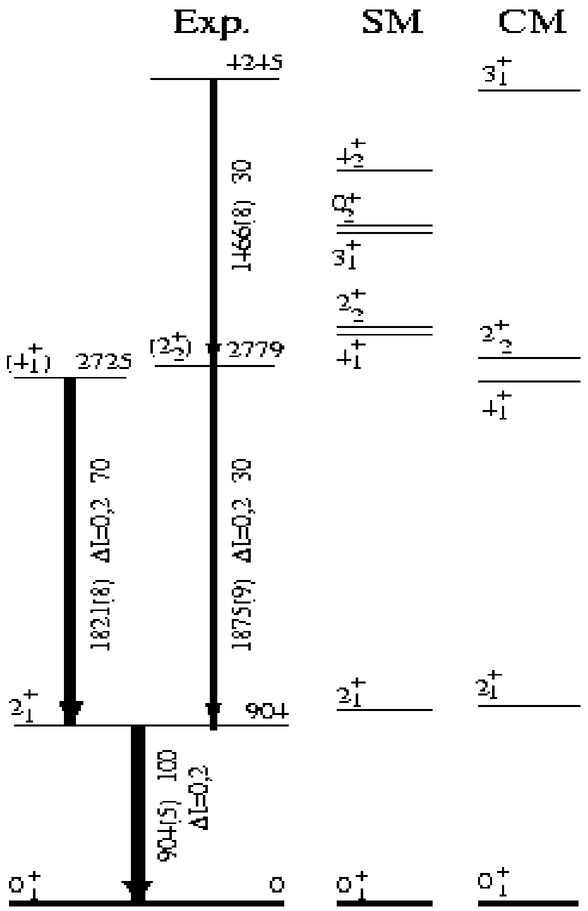
D. Sohler et al. PRC66(2002)054302.



$^{40}S_{24}$

$E(4^+)/E(2^+)=2.5$

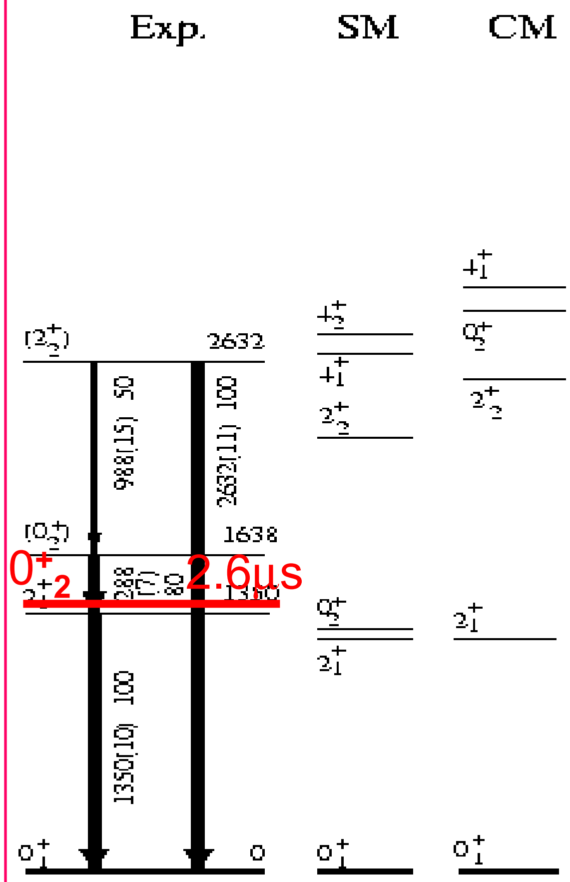
Transitional γ-soft



$^{42}S_{26}$

$E(4^+)/E(2^+)=3.1$

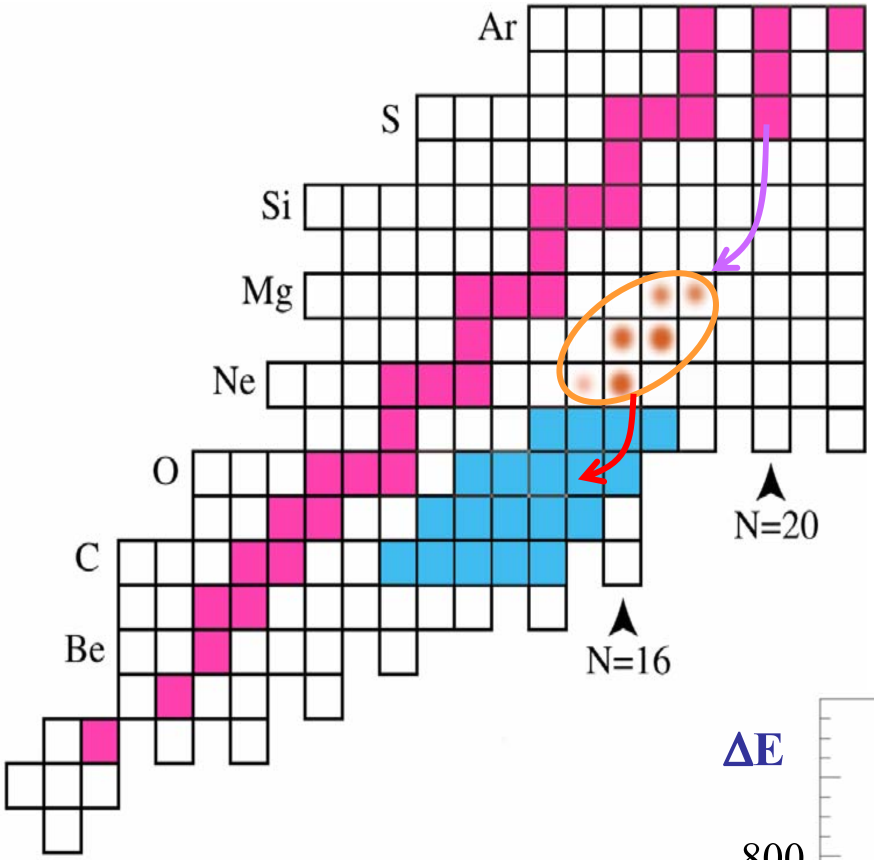
Triaxial rigid rotor (γ=25°)

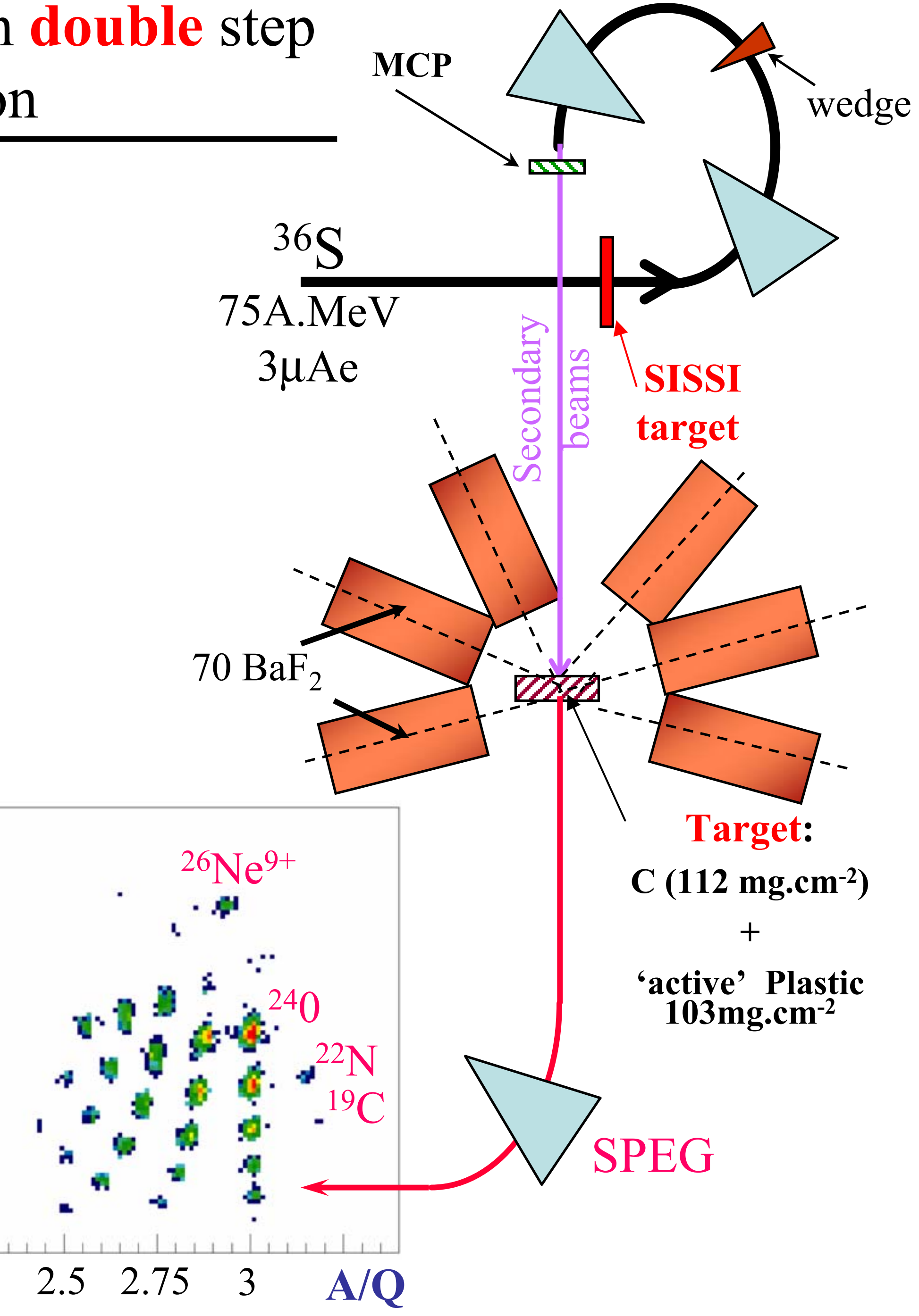


$^{44}S_{28}$

Shape coexistence

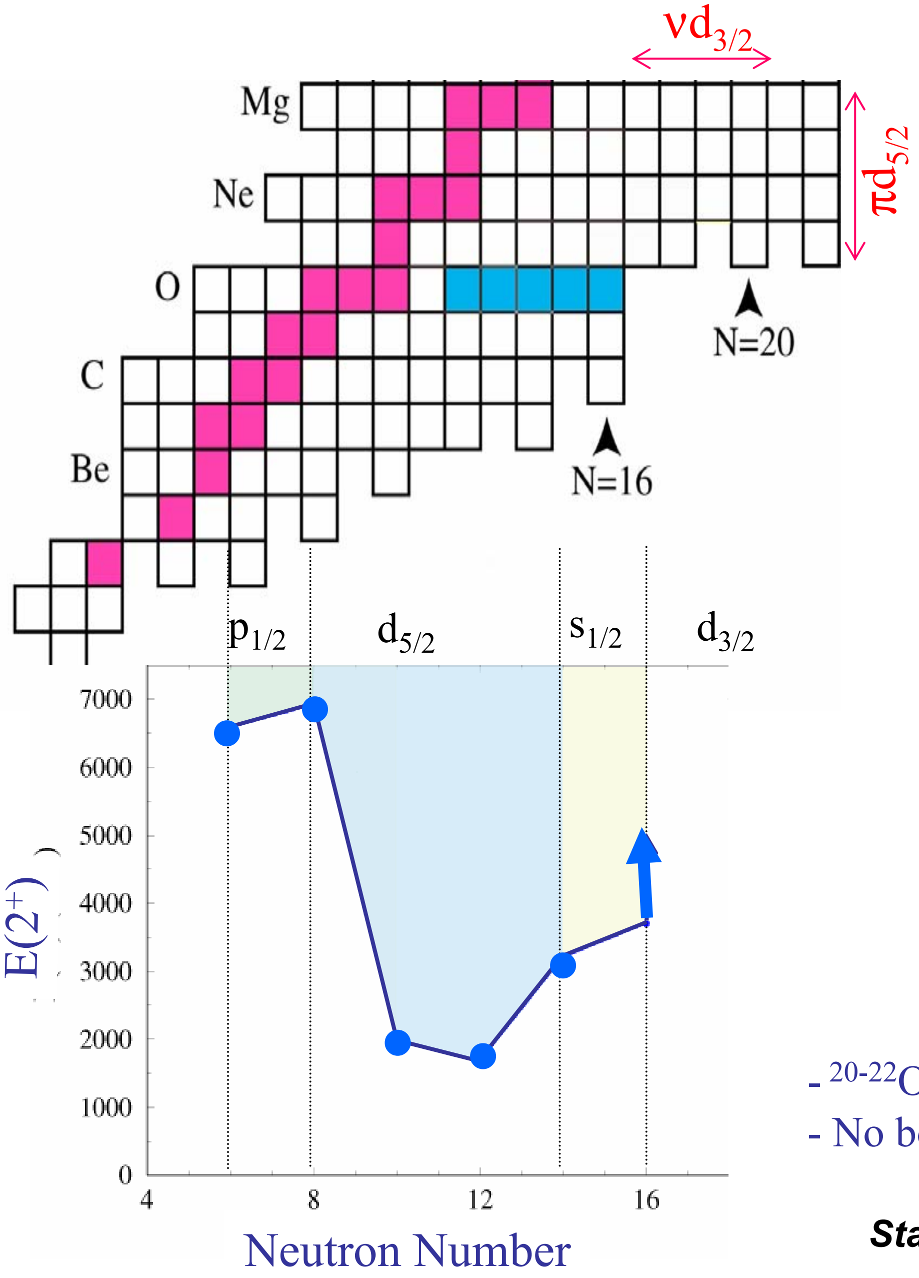
Study of neutron-rich nuclei with **double** step in-beam fragmentation

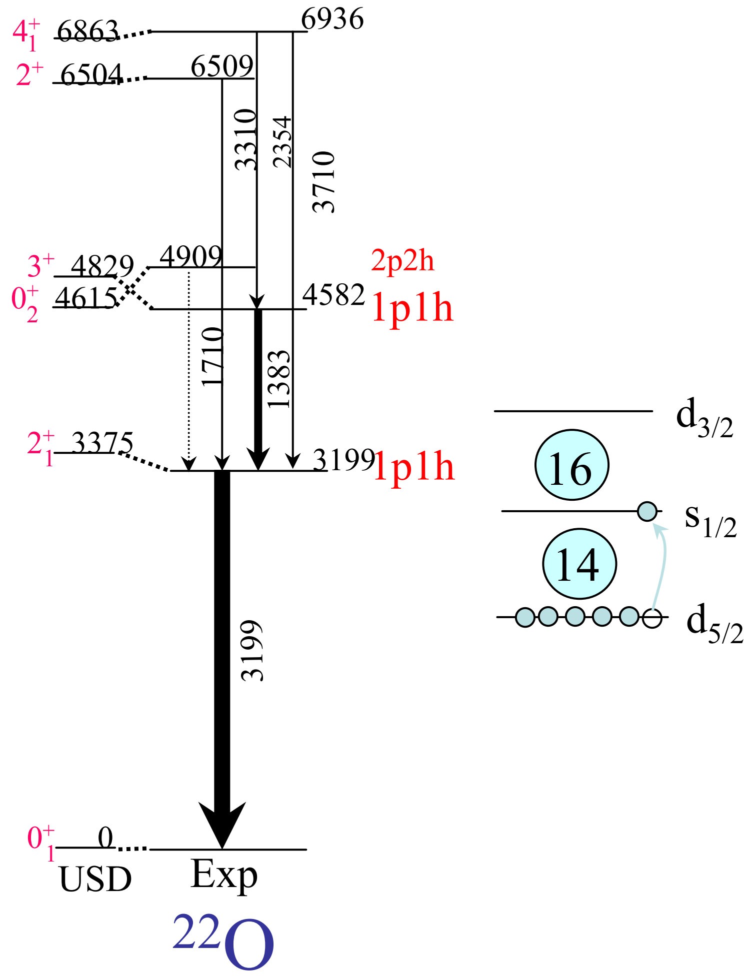




- -Production rate **×10** for ^{24}O
- -Better signal/noise ratio in γ-spectra
- -Feeding of excited states via different projectiles

Magic Nuclei in the Oxygen chain





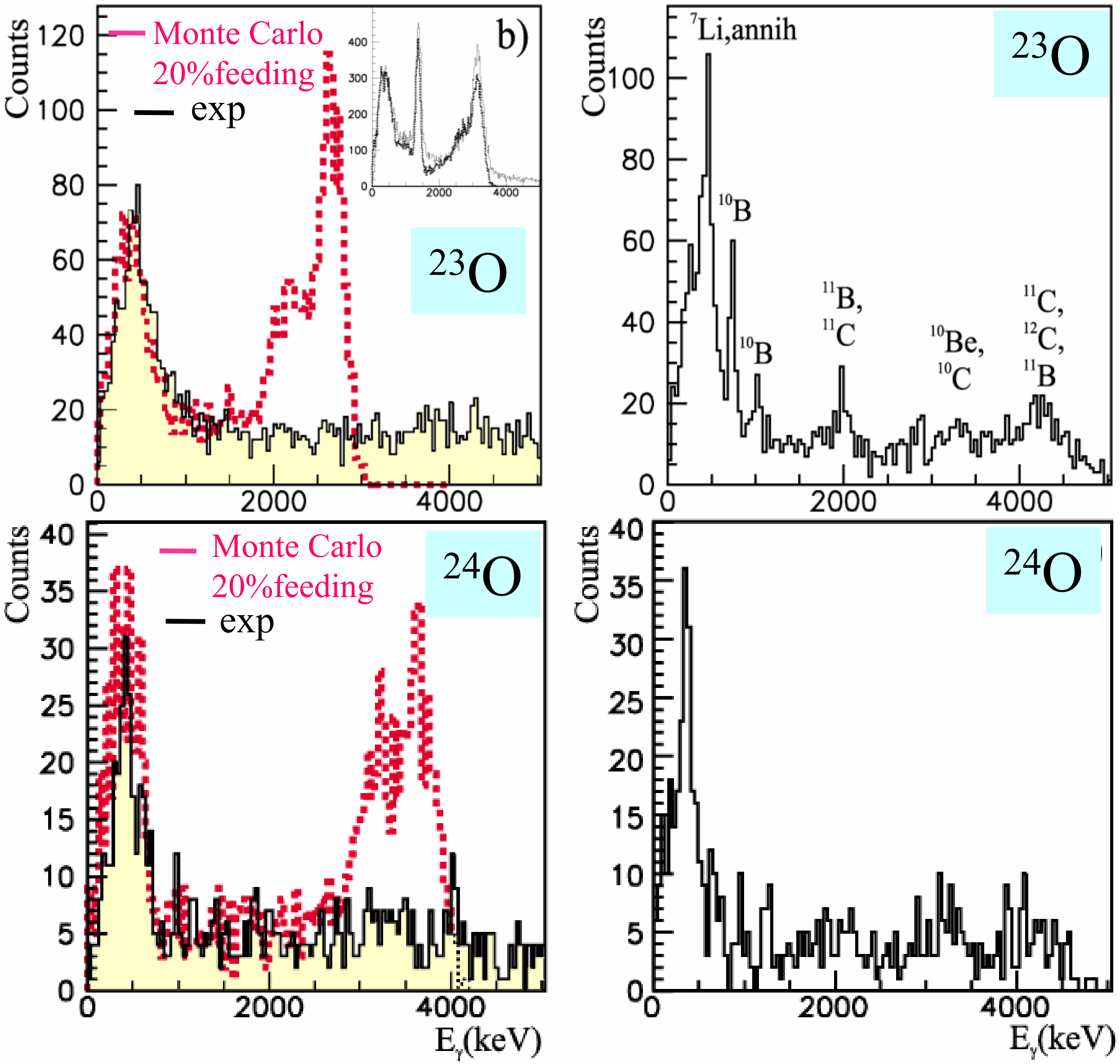
- $^{20\text{-}22}$O level schemes→ Sub-shell gap at N=14
- No bound excited state in ^{23,24}O → Sub-shell gap at N=16

Stanoiu et al. Phys.Rev. C 69, 034312 (2004)

Search for bound excited states in ^{23}O and ^{24}O

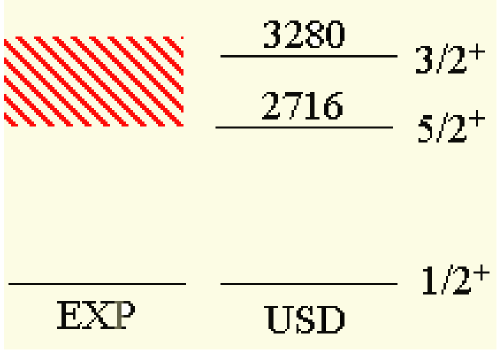
Stanoiu et al. Phys.Rev. C 69, 034312 (2004)

Doppler corrected



23000 nuclei

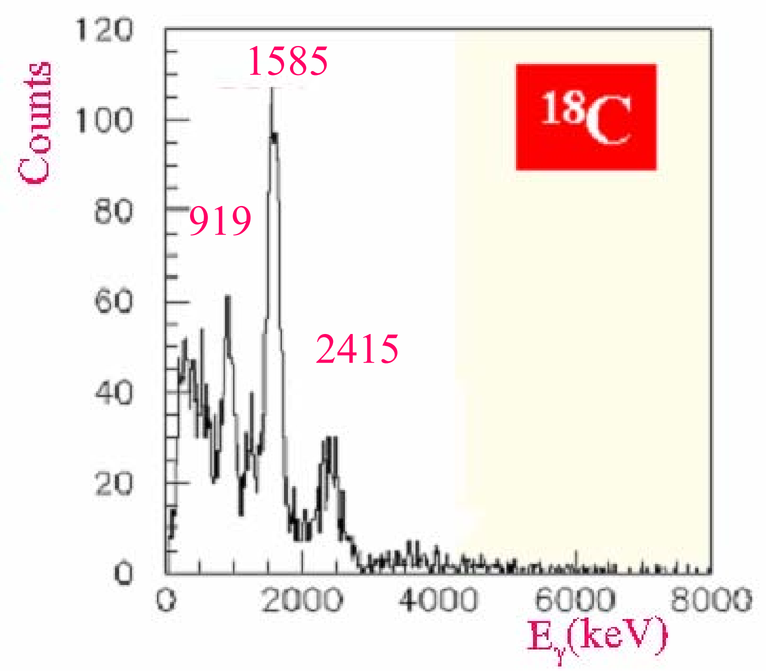
S_n= 2.7(1) MeV

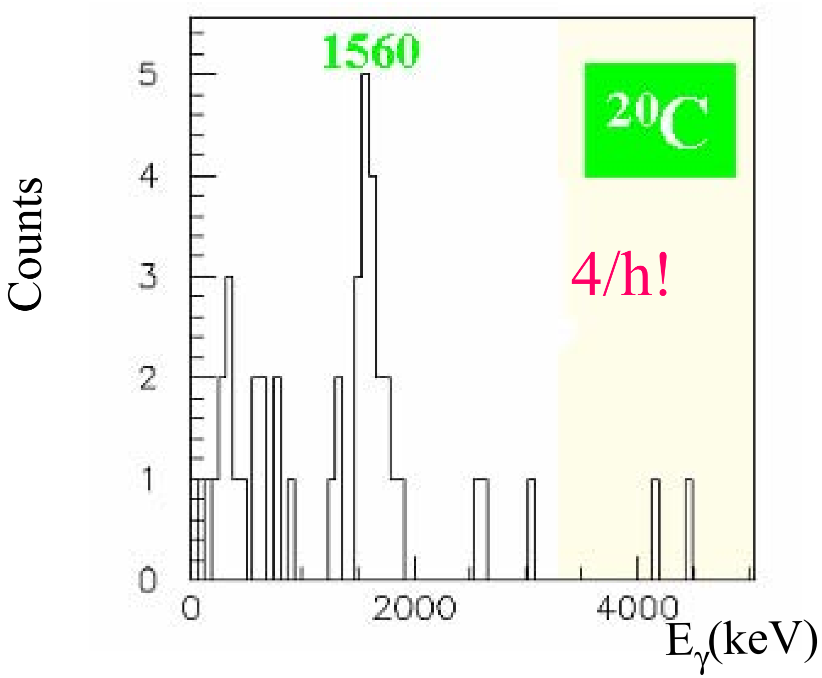


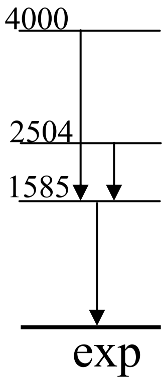
6671 nuclei

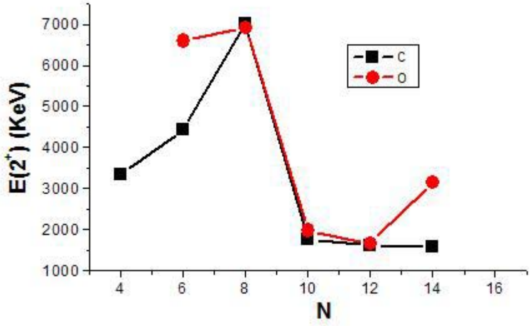
S_n=3.7(4) MeV

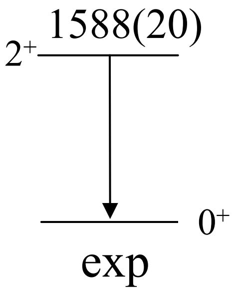
Carbon isotope A=18, 20











Few recent results

- extension up to Si of the 2+ measurement in the N=28 chain of isotones

- the border of the mirror isle of inversion

- The development of quadrupole collectivity in the Ni isotopes

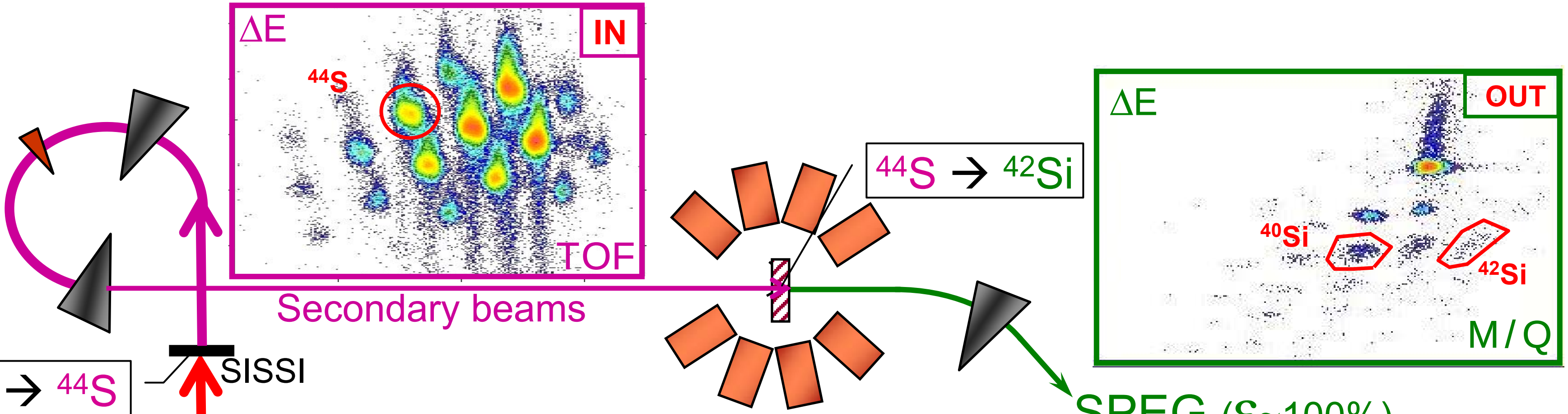
In beam spectroscopy experiment: the experimental setup

➢aim: energy of the 2^+ in ^{42}Si and spectroscopy of the neighbors nuclei

- COULEX: minimum 100 pps
- ^{48}Ca → ^{42}Si: maximum ~ 1 pps

↳ in-beam spectroscopy

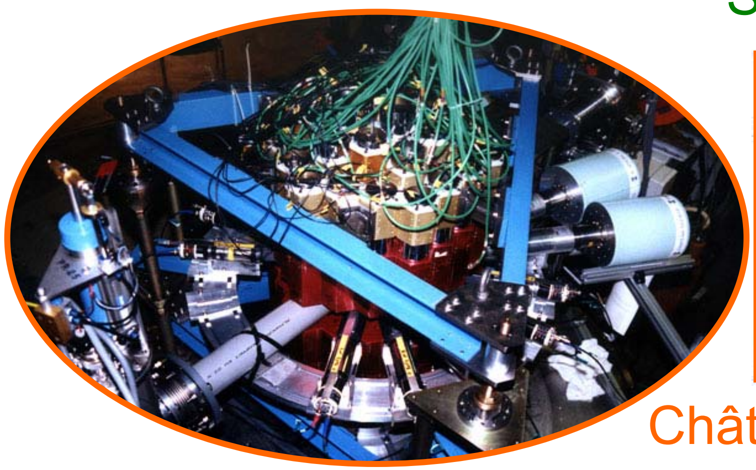
^{48}Ca (>10^{12} pps) → ^{44}S (100-150 pps) → ^{42}Si* (8/day) → ^{42}Si + γ

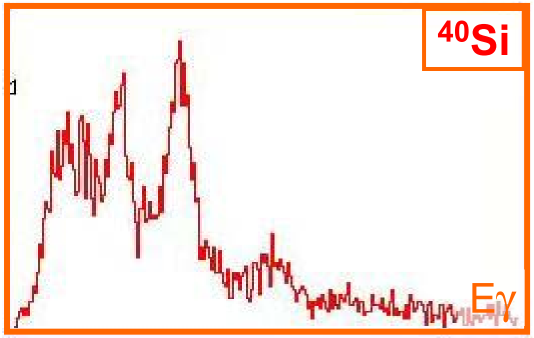


^{48}Ca → ^{44}S

SPEG (ε~100%)

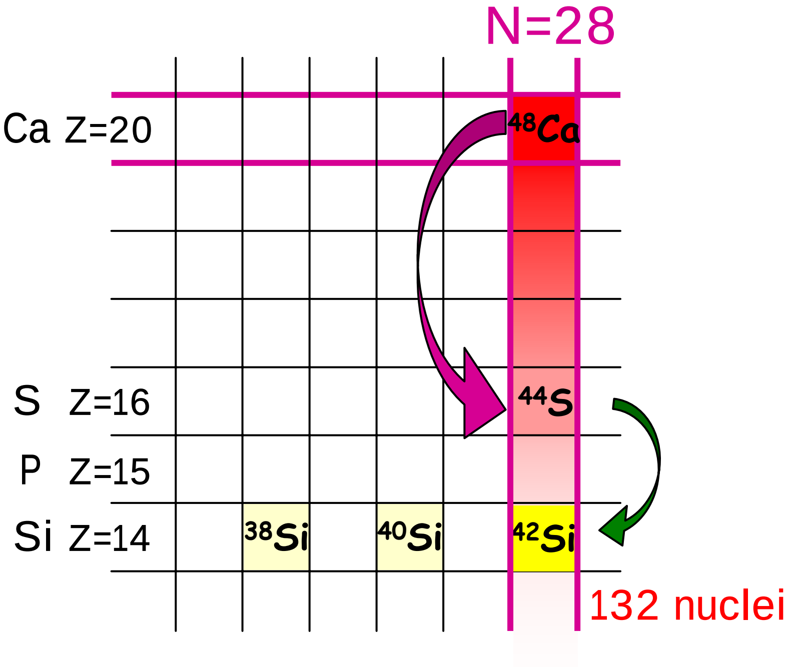
- **I(^{48}Ca) ~ 4 μAe - 60 A.MeV**
- **C and Ta production targets (~180 mg/cm²)**
- **^{44}S ~ 100-150 pps**



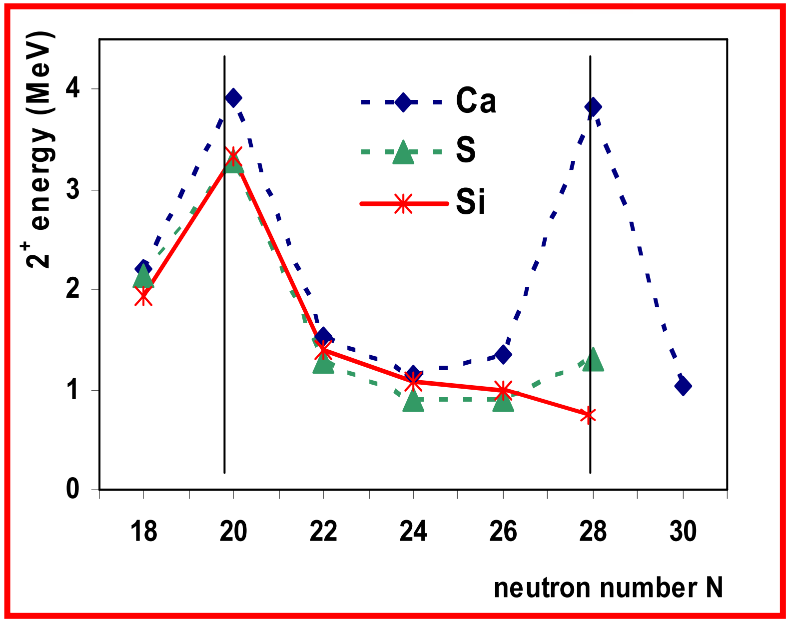


Château de Crystal (ε~40%)

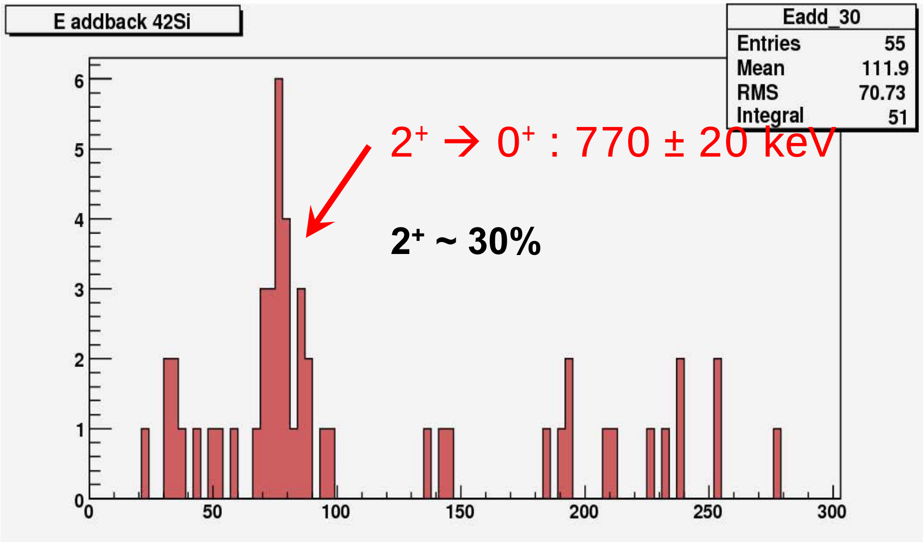
In beam spectroscopy : the Si isotopes



132 nuclei



One gamma per shift!



$2^+ \rightarrow 0^+$: 770 ± 20 keV

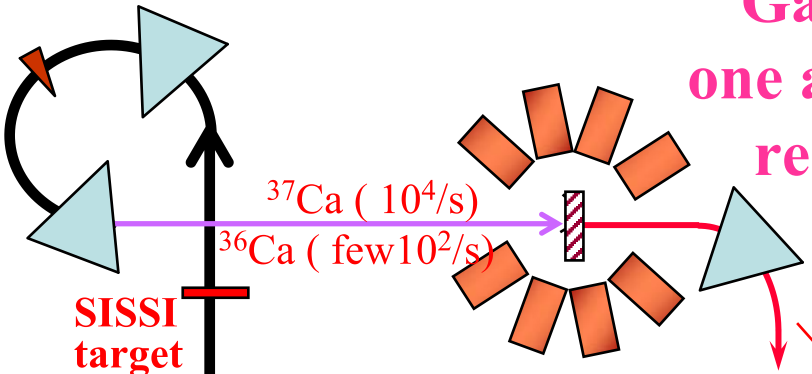
2^+ ~ 30%

S. Grévy et al. – to be submitted to PRL

^{42}Si is not doubly magic!

^{34,36}Ca: the border of the Z=20 'mirror isle of inversion'

Gamma spectroscopy using one and two neutron knock-out reactions from RNB ^{37,36}Ca



^{37}Ca (10^4/s)

^{36}Ca (few10^2/s)

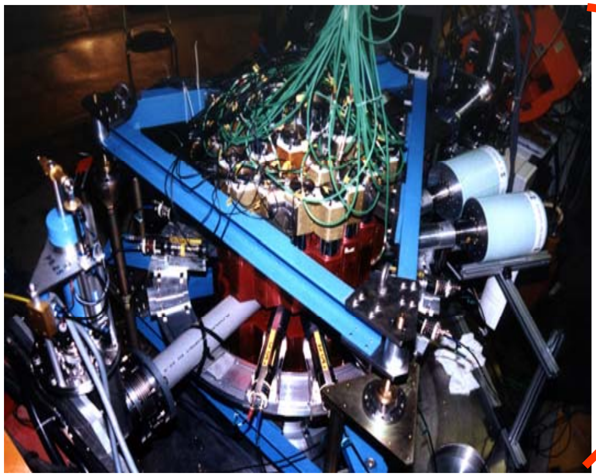
SISSI target

^{40}Ca (60MeV/u)

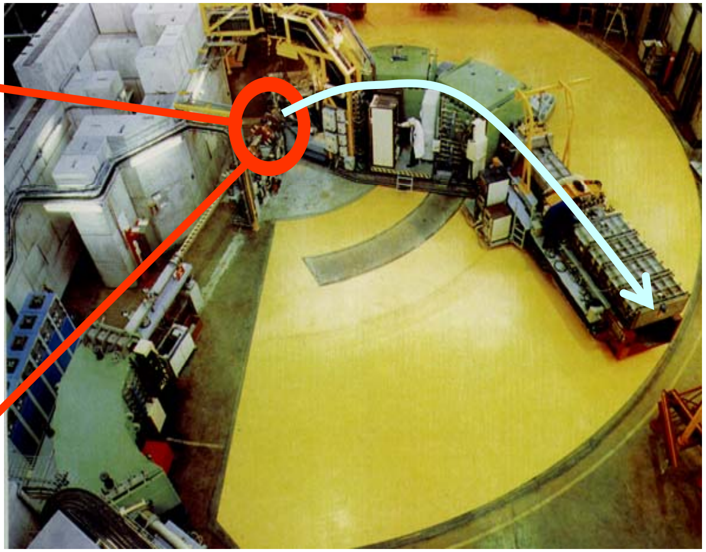
Thick target and 74 BaF_2

γ detection

74 BaF_2 + 4 Ge Clover detectors

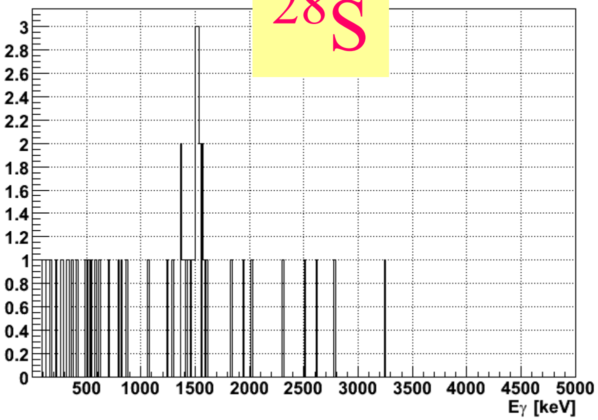


Fragments detection SPEG

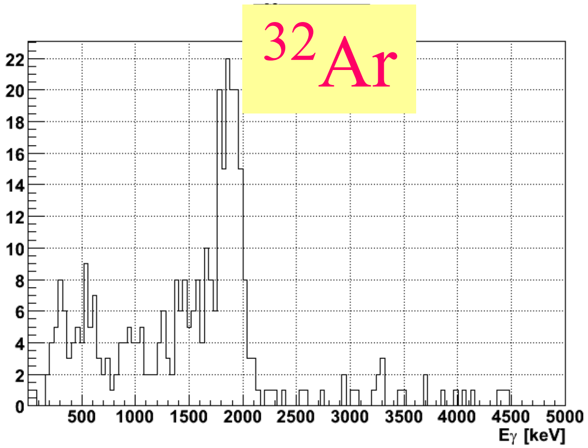


γ-spectroscopy at the proton drip line

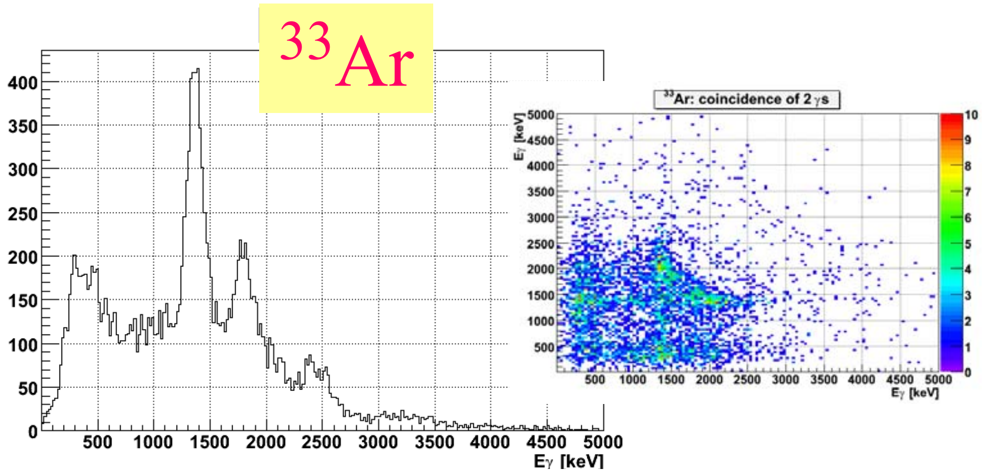
A.Burger et al.



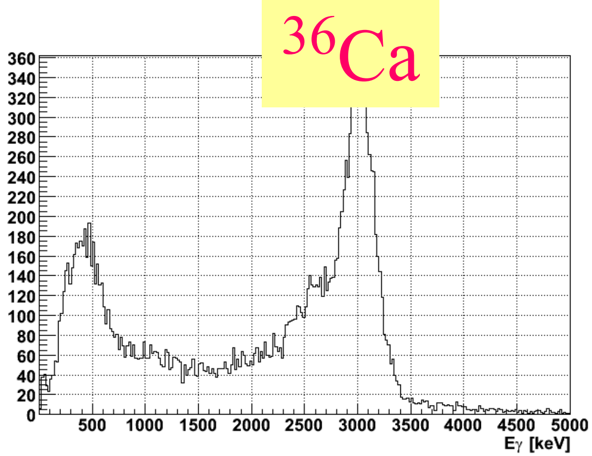
^{28}S



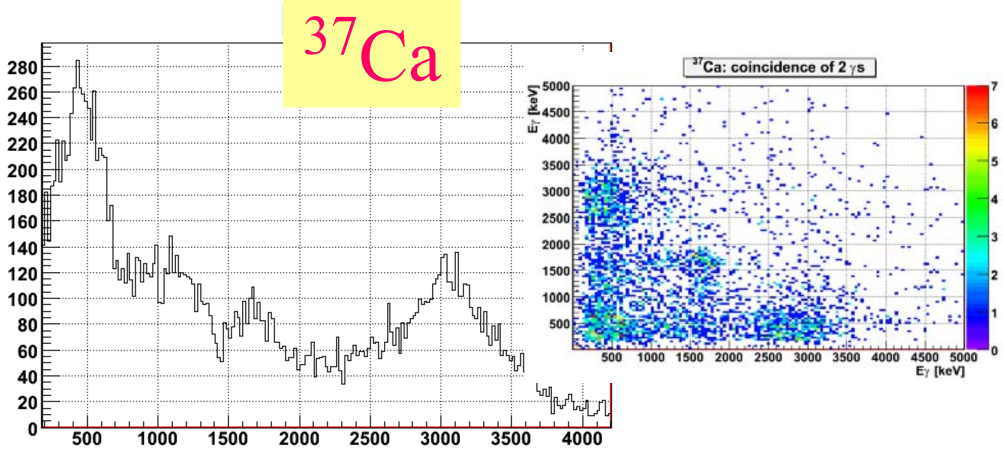
^{32}Ar



^{33}Ar

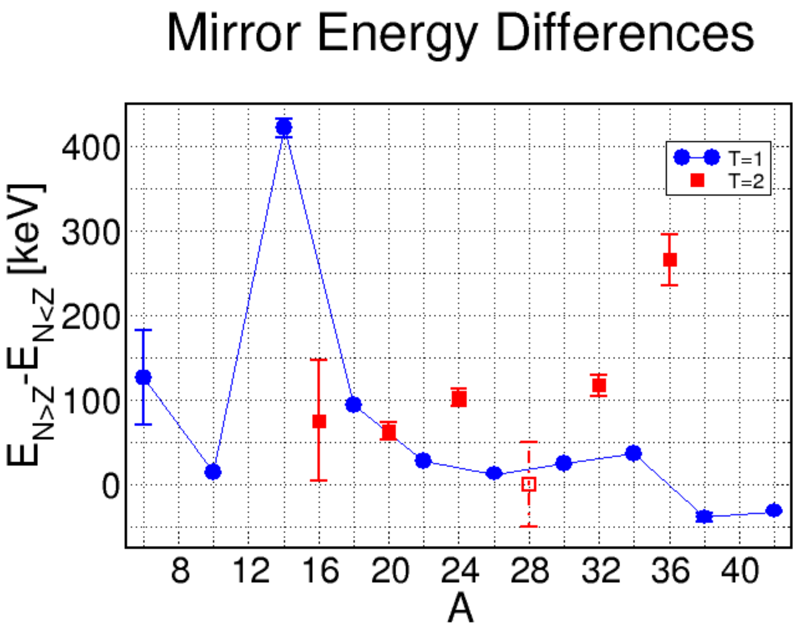


^{36}Ca

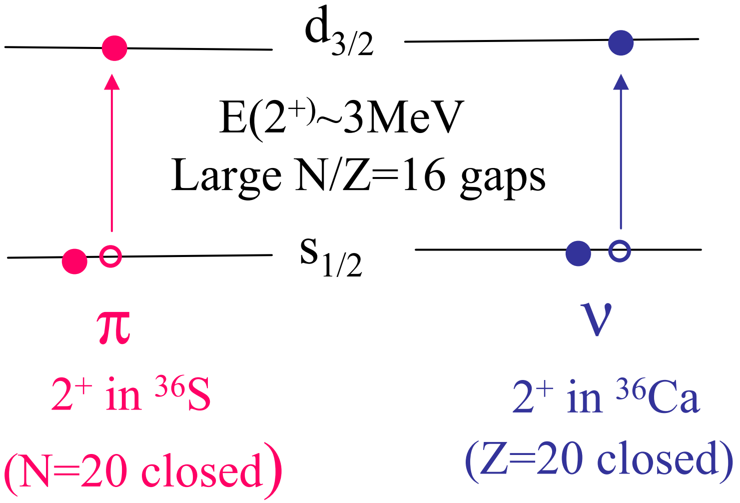


^{37}Ca

Comment on the large MED difference in T=2, A=36



Mirror Energy Differences



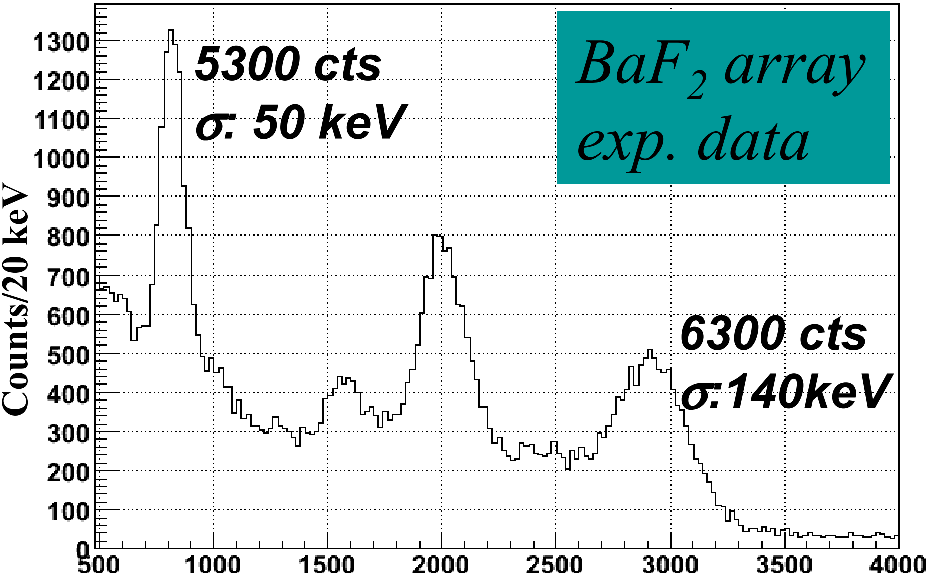
E(2^{+})~3MeV
Large N/Z=16 gaps

2^{+} in ^{36}S
(N=20 closed)

2^{+} in ^{36}Ca
(Z=20 closed)

-Coulomb energy difference of s and d orbits:
In the T=1/2, A=29 (^{29}Si,^{29}P) the MED of the 3/2+ to the gs:1/2+ transition is 111keV!
-In A=29 the gap $s_{1/2}$-$d_{3/2}$ in much smaller than in A=36
(single particle nature in ^{36}S and ^{36}Ca and not in ^{29}Si and ^{29}P!)
-If one modifies the single particle energy of the s orbit by 300keV in order to reproduce the MED in A=29, one obtains in A=36 an MED of 270 keV !

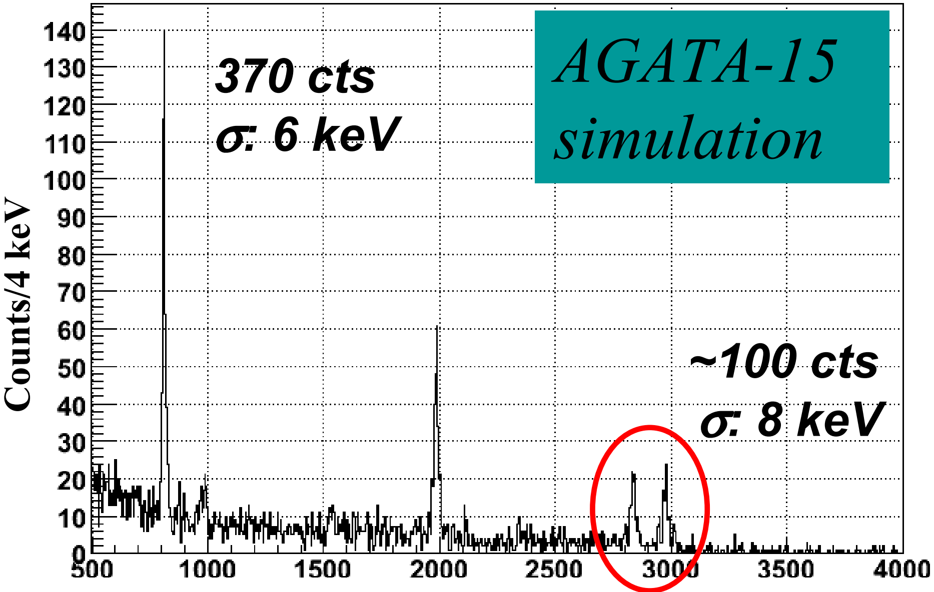
AGATA vs. BaF_2 array
fragmentation reaction : $^{37}Ca \rightarrow {}^{33}Cl$



BaF_2 array exp. data

5300 cts
σ: 50 keV

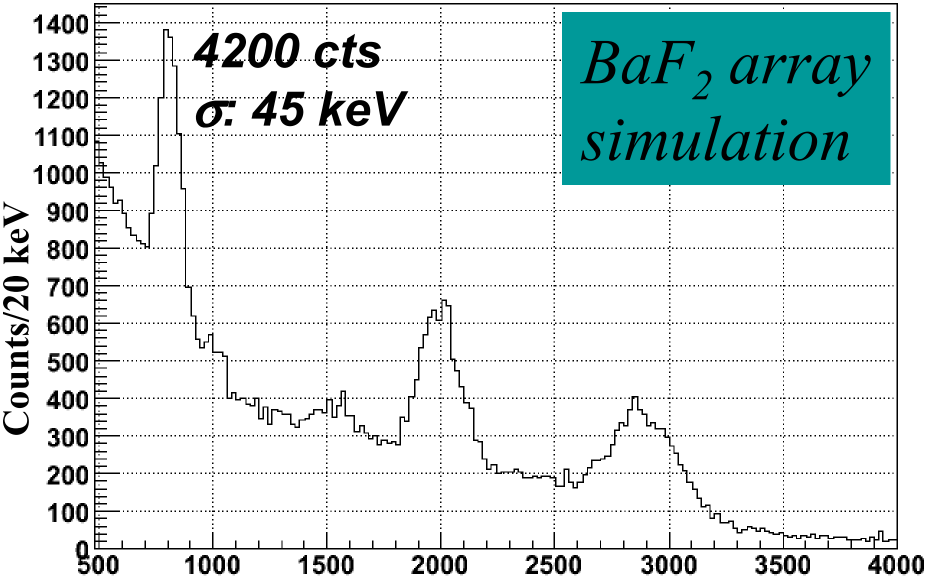
6300 cts
σ:140keV



AGATA-15 simulation

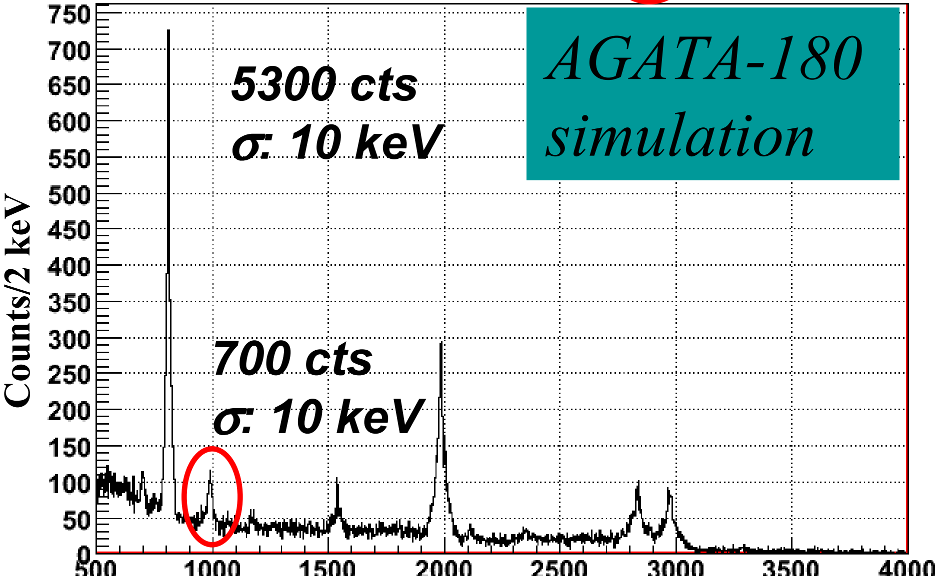
370 cts
σ: 6 keV

~100 cts
σ: 8 keV



BaF_2 array simulation

4200 cts
σ: 45 keV



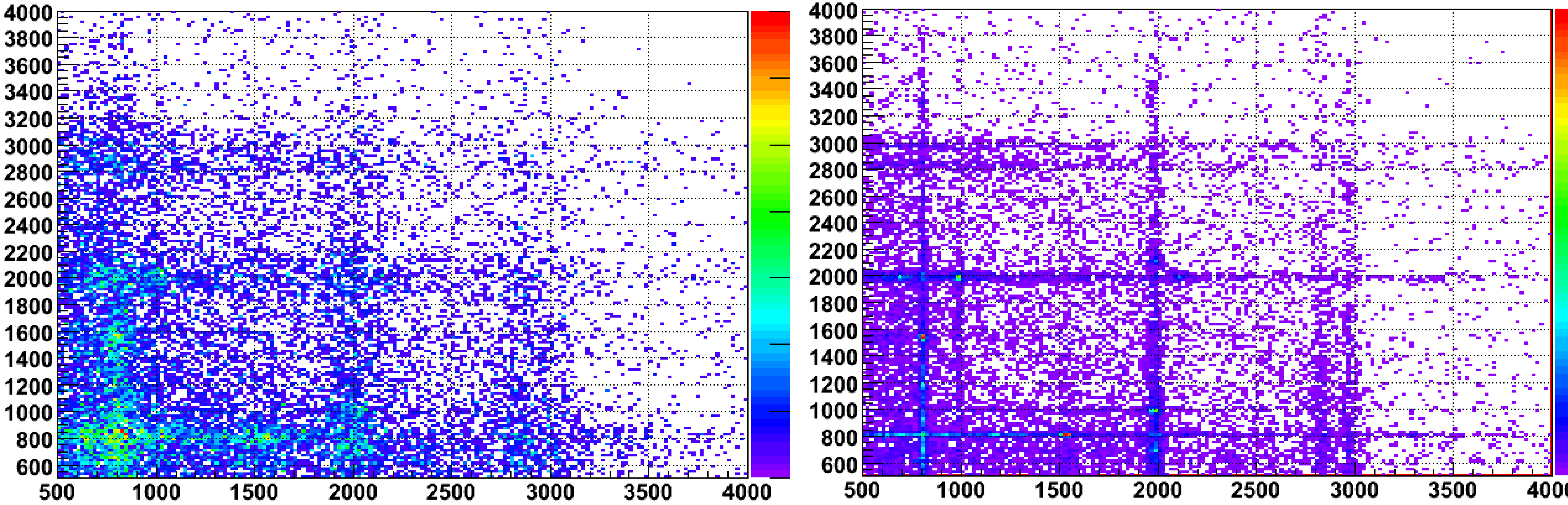
AGATA-180 simulation

5300 cts
σ: 10 keV

700 cts
σ: 10 keV

AGATA vs. BaF_2 array
knock-out reaction : $^{37}Ca \rightarrow {}^{33}Cl$

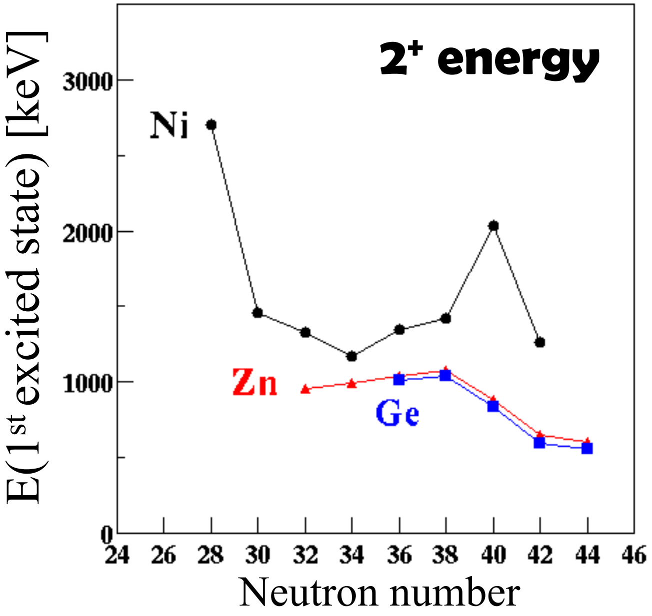
Gamma-gamma coincidence matrices

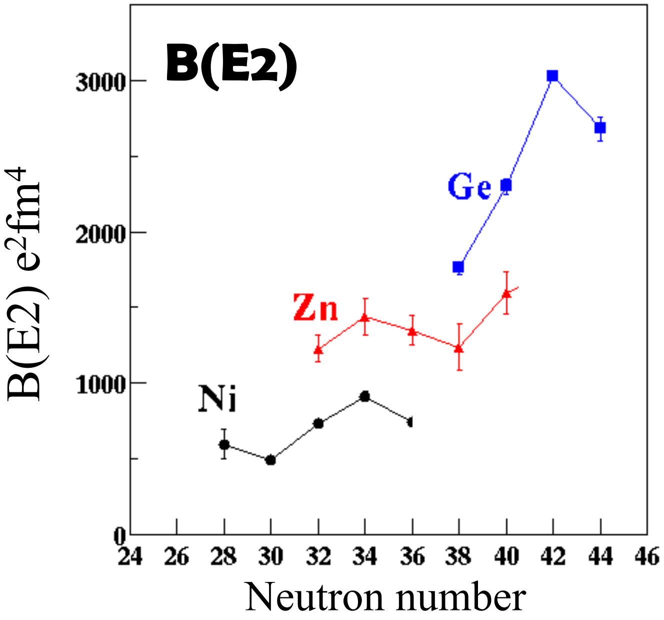


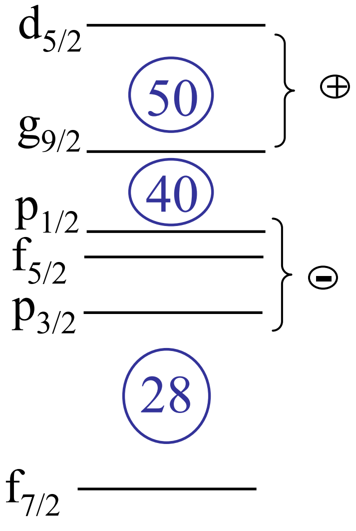
BaF_2 array

AGATA

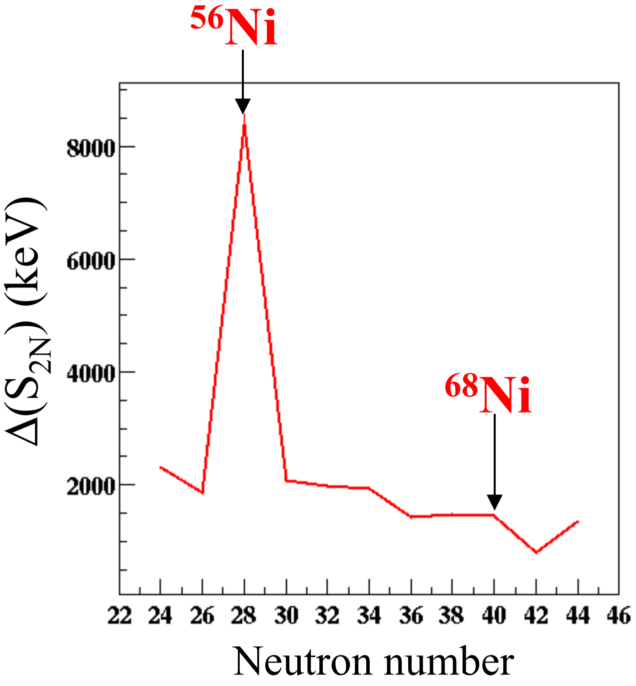
neutron-rich Ni at and beyond Z=40







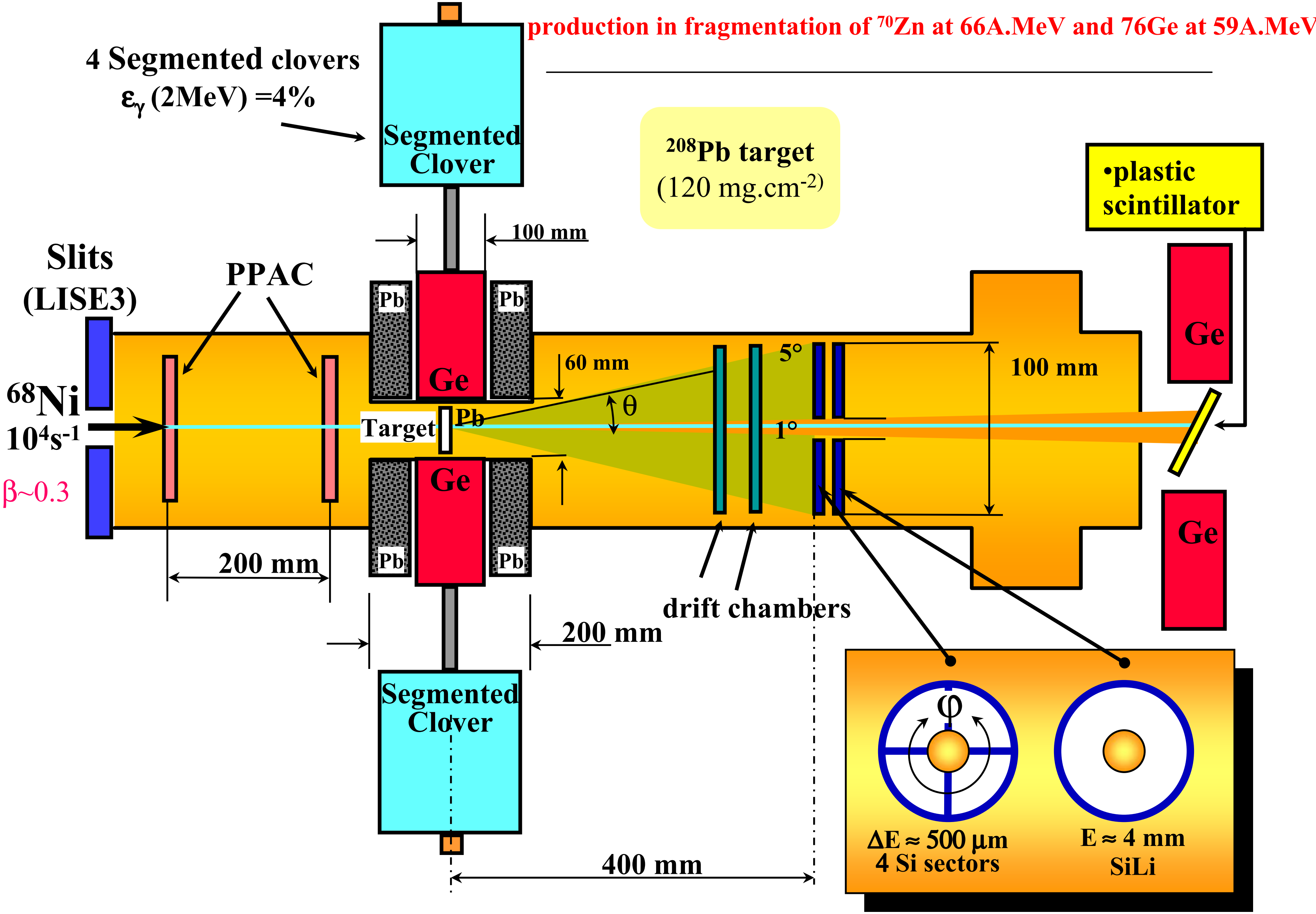
ν s.p. levels



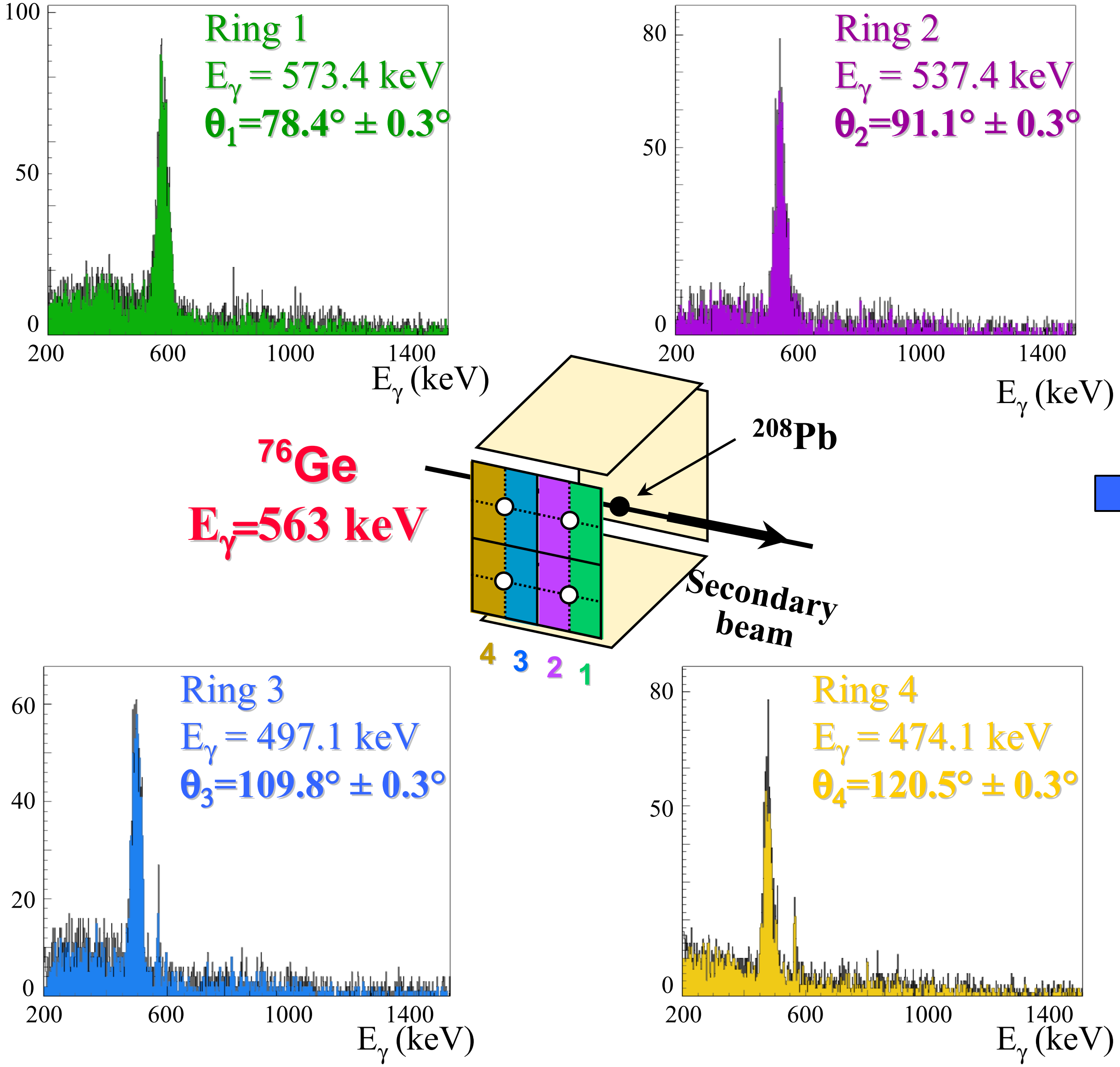
Coulex of ^{66,68,70}Ni !

Coulomb excitation of ^{66,68,70}Ni

production in fragmentation of ^{70}Zn at 66A.MeV and 76Ge at 59A.MeV

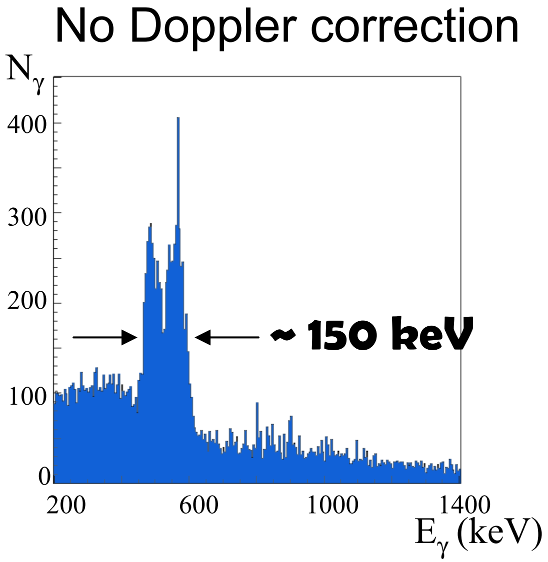


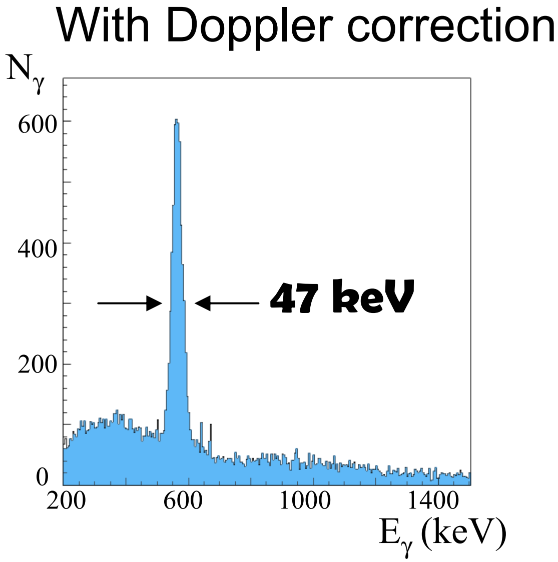
Experimental results



^{76}**Ge**

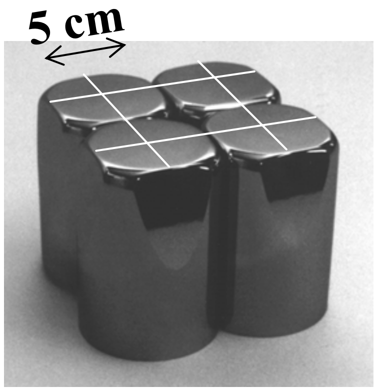
E_γ**=563 keV**



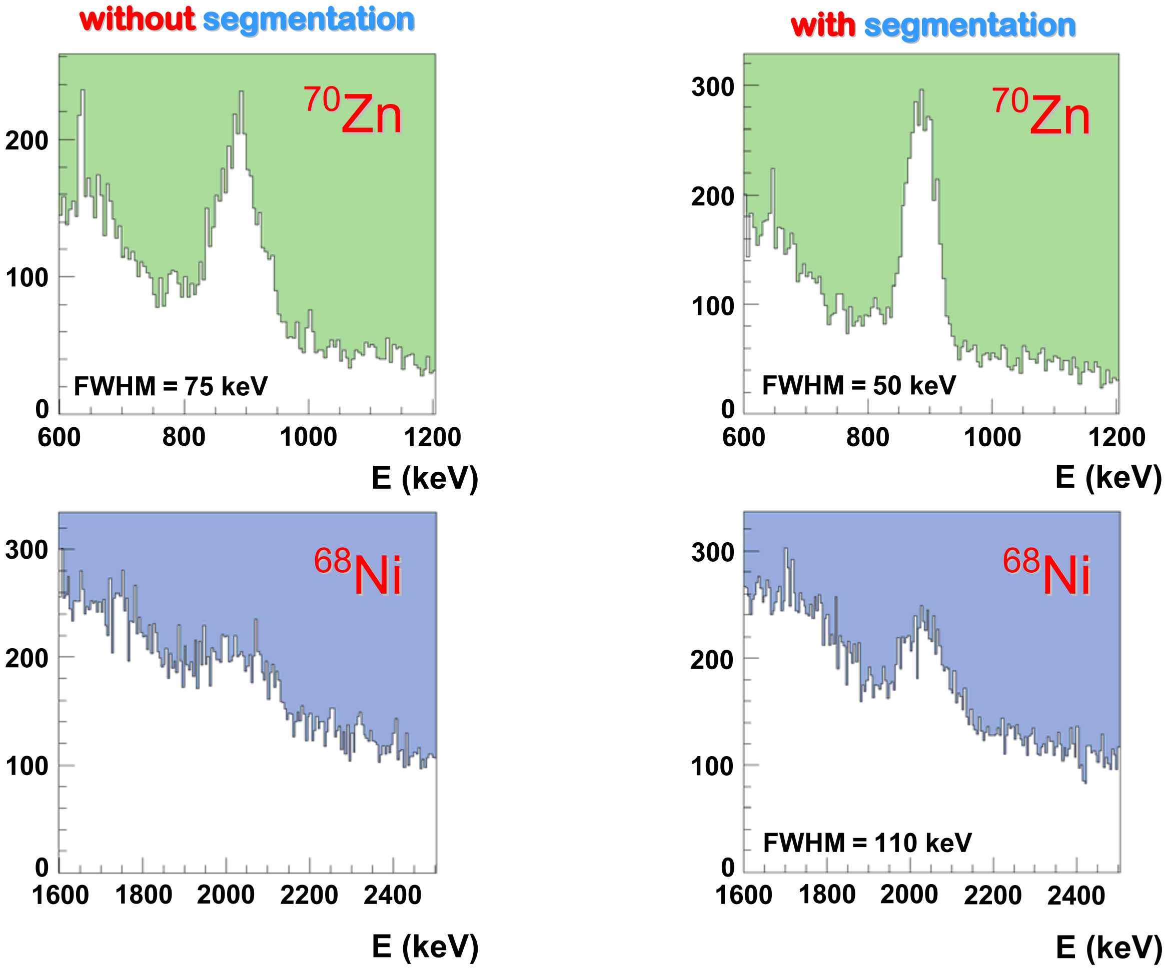


Experimental results

View of one Ge clover

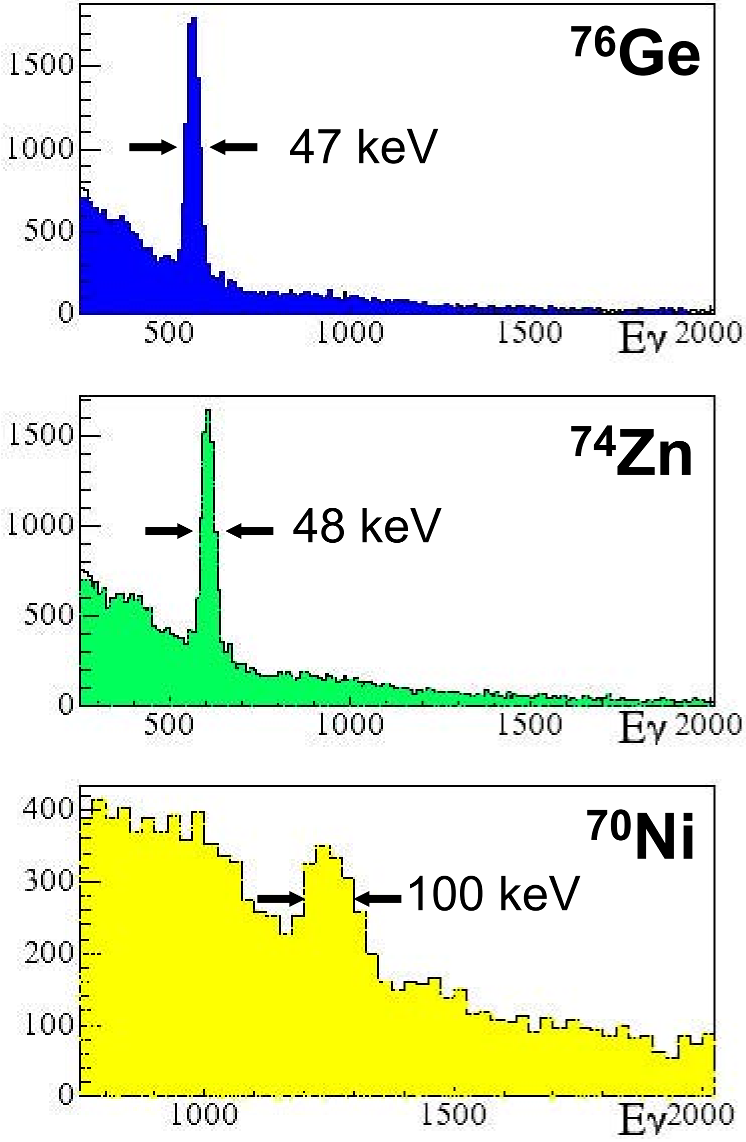


4 crystals electronically segmented

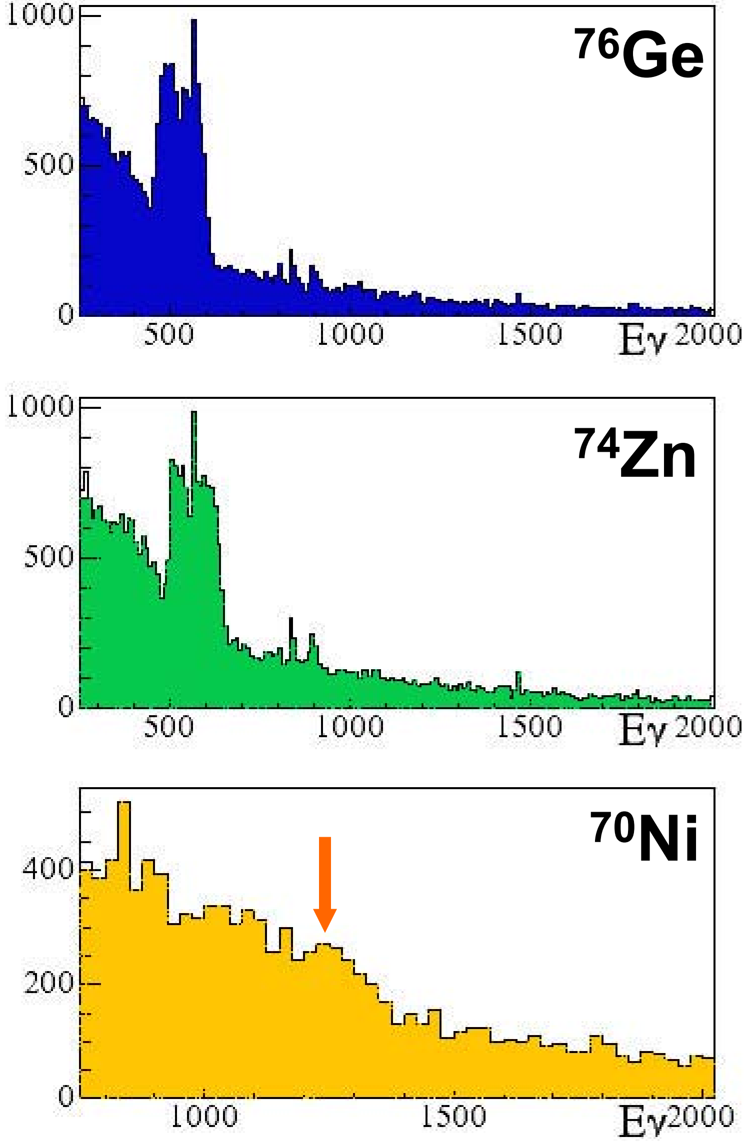


Experimental results

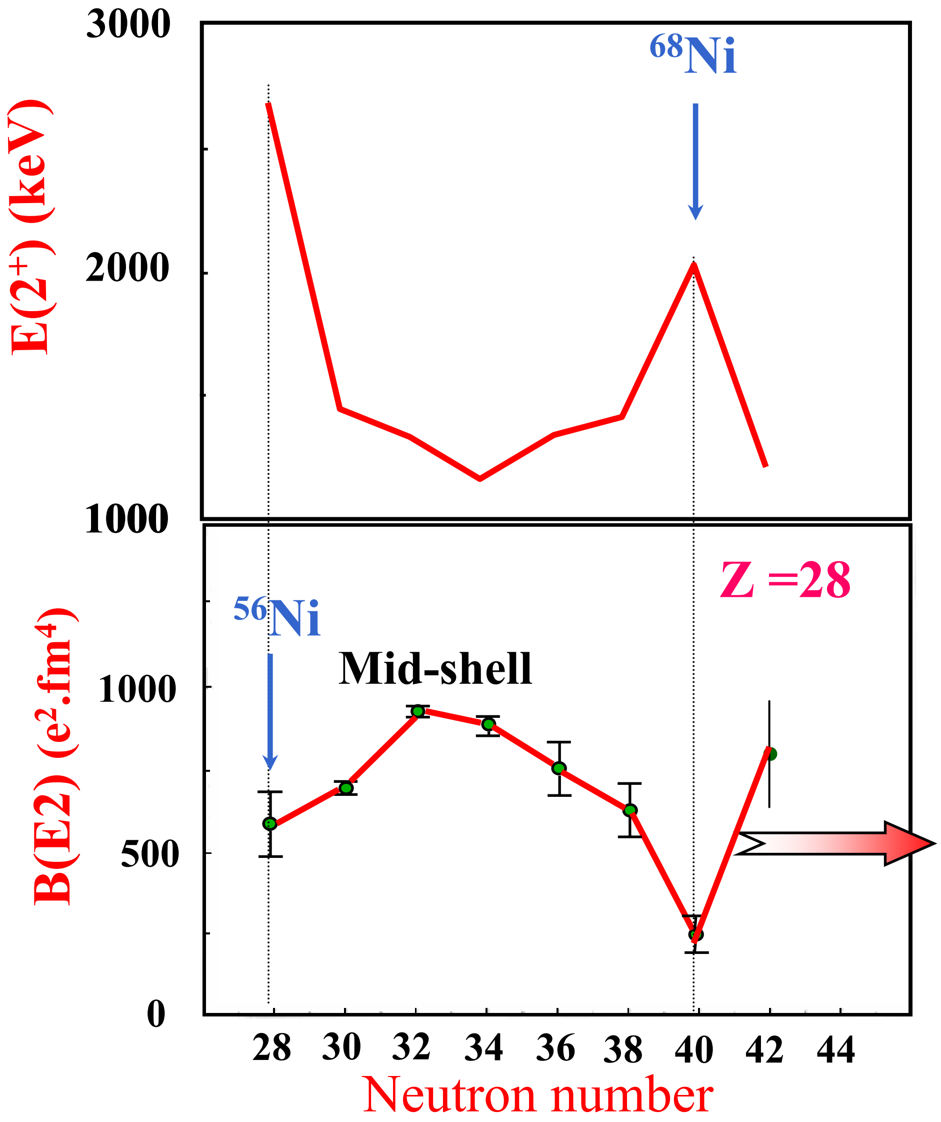
With Doppler correction

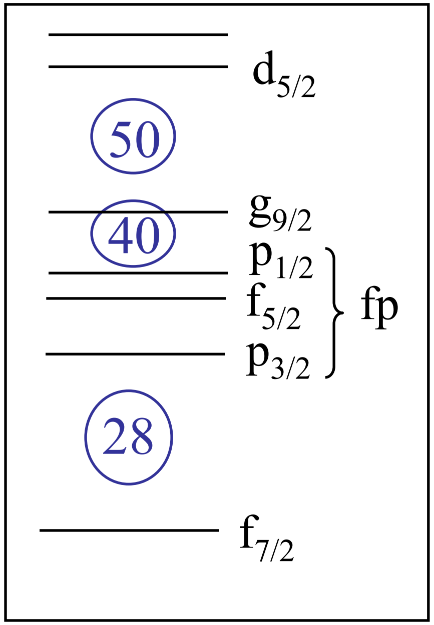


Without Doppler correction



^{68,70}Ni unusual rigidity and polarization!





^{68}Ni the most rigid Ni isotope !

- **Parity-forbidden excitations**
- **10.5/12 neutrons in fp space**

1.5 neutrons in $g_{9/2}$ due to pairing

-unusual and enhanced proton core polarization (due to the decrease of the Z=28 gap)!

Fragmentation beams at GANIL are unique and provide through in-beam-gamma spectroscopy an excellent way to study nuclear structure very far from stability!

In near future: -upgrade the GANIL to be able to reach even more exotic nuclei
-Cristal ball (J. Gerl)

the ultimate goal is to use AGATA
with the upgraded fragmentation beams at GANIL

Collaboration:

IPN-Orsay, France
INR-Debrecen, Hungary
GANIL, France
Nucl. Phys. Inst. Rez, Czech Republic
FLNR/JINR Dubna, Russia
NBI Copenhagen, Denmark
LPC Caen, France
University of Milano, Italy
IFIN Bucharest, Romania
Royal Inst. Of Technology, Stockolm, Sweden
GSI Darmstadt, Germany
Dep. of Physics, Univ. Of Surrey, Guilford, UK
CSNSM Orsay, France
IReS Strasbourg, France
Mac-Gill university, Montréal
IFP, Mayence universty
Laboratoire Aime-Cotton

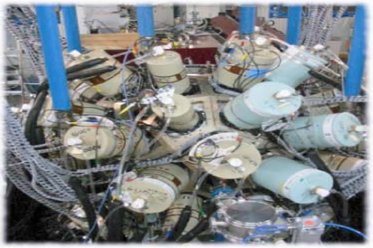
+

ALTO
Accélérateur Linéaire auprès du Tandem d'Orsay

10^{11} fissions per second

ORGAM+BACCHUS

OSCAR

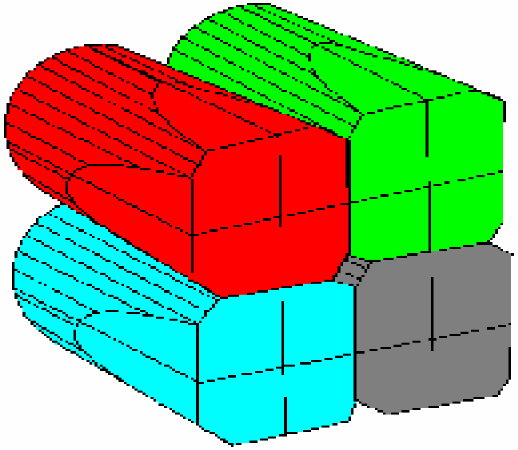


ORGAM

15 MV Tandem
From p to Au
Beams of 14C and 48Ca
Cluster beams

At the tandem:

Dedicated set-up for compaigns with sufficient beam time!

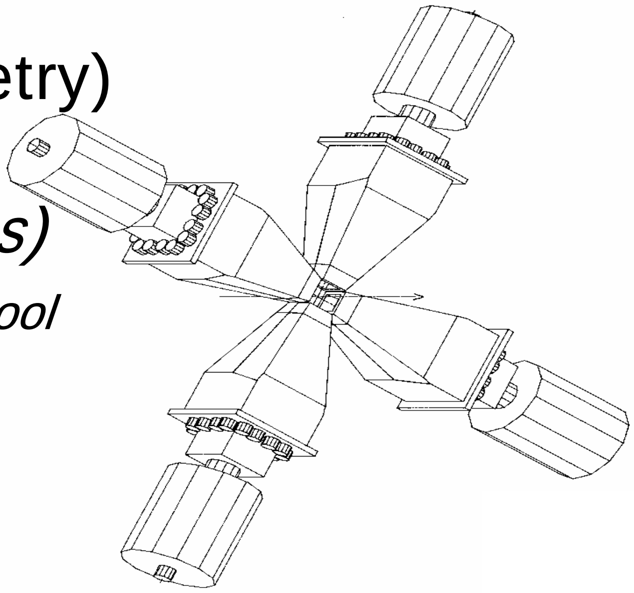


Gamma spectroscopy:

- **OSCAR**: Orsay Segmented Clover Array

  γ-Ring : 4 segmented clovers @ 6cm

- **ORCA**: Orsay Clover Array
  (16 clover Ge array: EXOGAM like geometry)

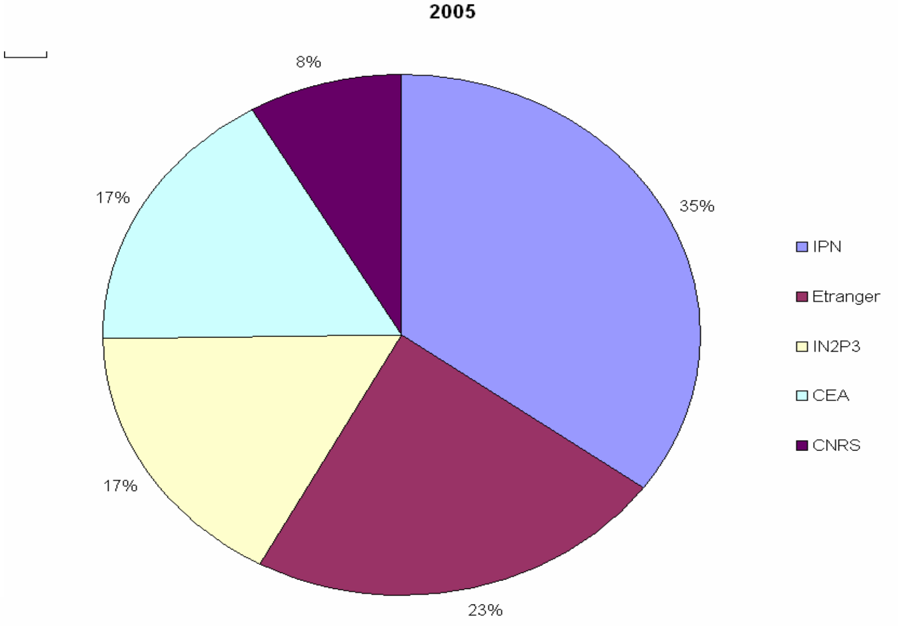


* *digital electronics (higher counting rates)*

see developments at Ires, CSNSM,Liverpool

* *time stamping (universal clock)*

2005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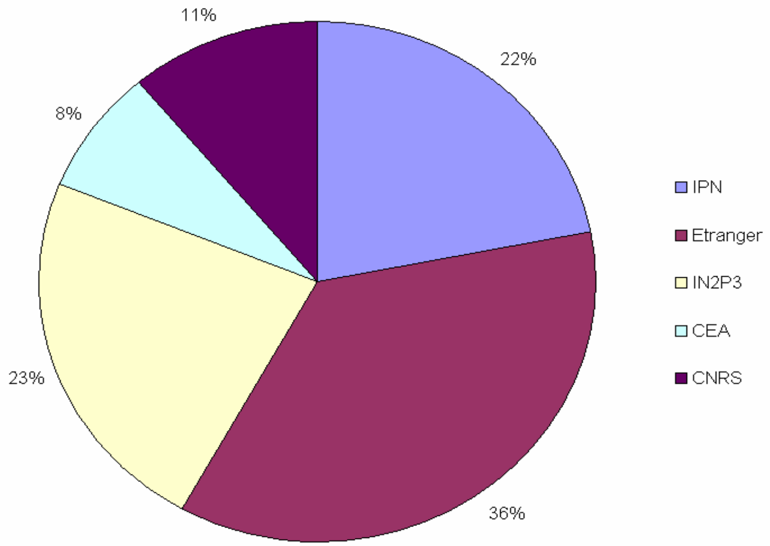
Etranger
IN2P3
CEA
CNRS

2006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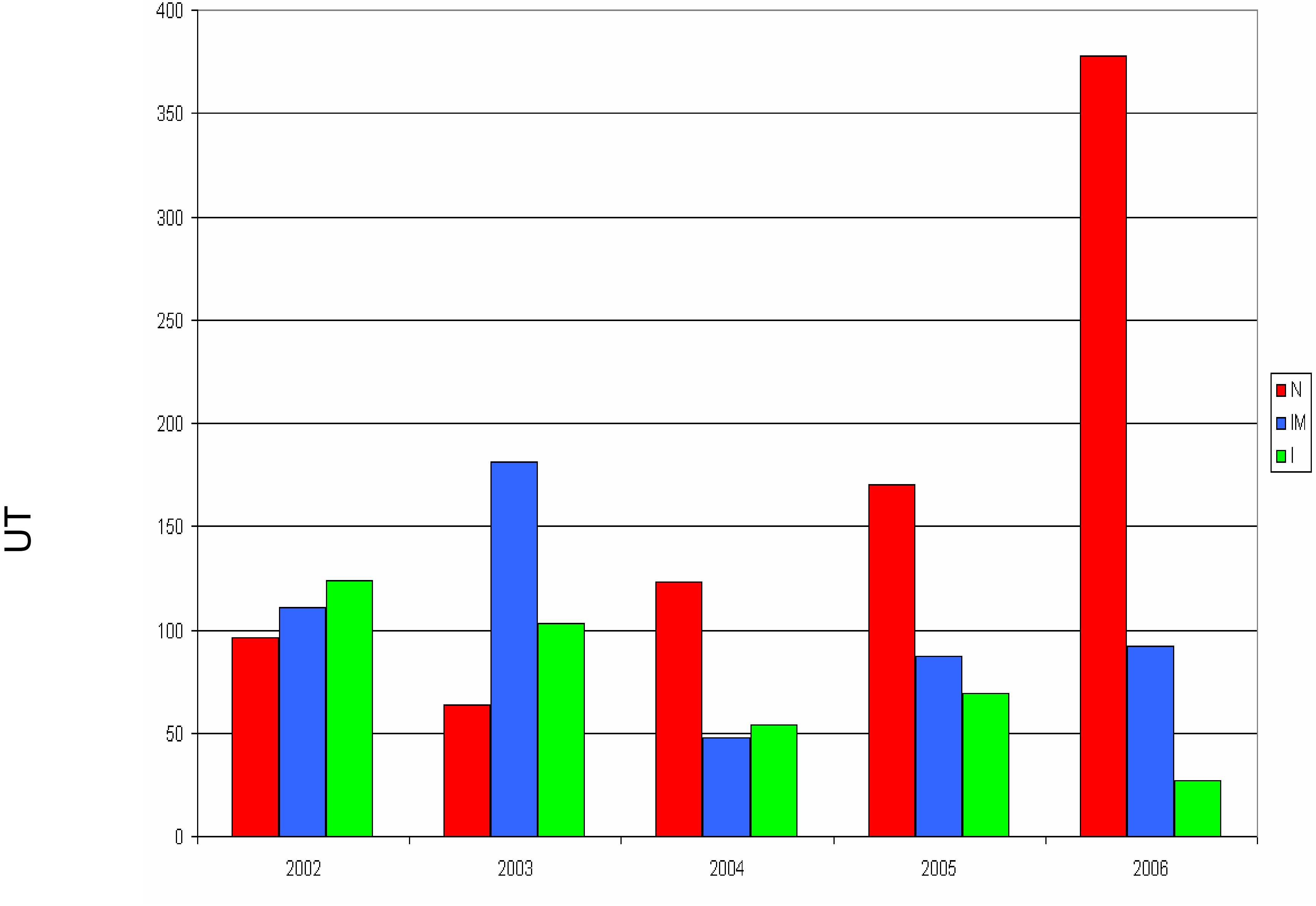
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