Multinucleon transfer reactions : present status and perspectives

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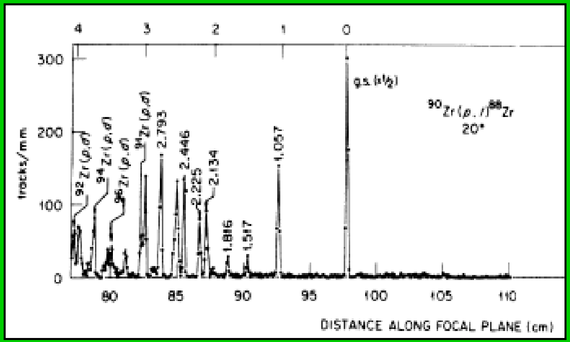
EMIS2012, Matsue (Japan)
3-7 December, 2012

Performance of the large solid angle spectrometers

Magnetic spectrometers for transfer reaction studies

70's	80's - 90's	recent years
Light ions (Q3D)	**Heavy ions spectrometers**	**Tracking spectrometers**

Light ions (Q3D)

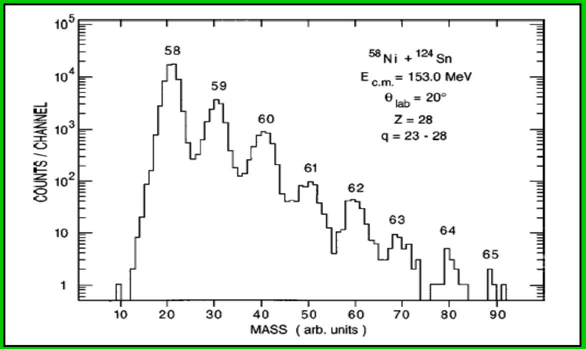


single particle levels (shell model)

nucleon-nucleon correlations (pair transfer)

3-5 msr

Heavy ions spectrometers



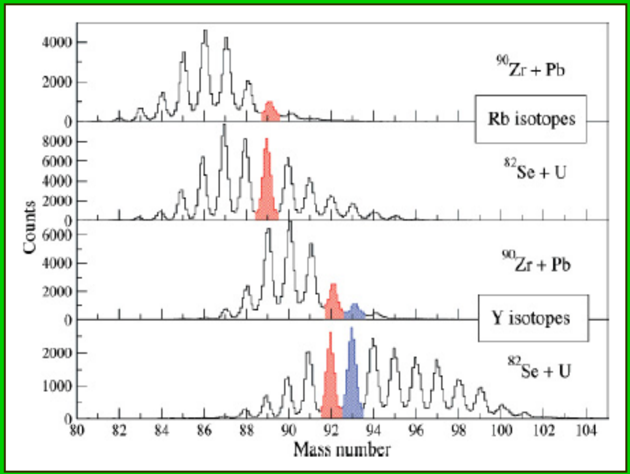
A,Z yields

cross sections

Q-value distributions

5-10 msr

Tracking spectrometers



Reaction mechanism

Gamma spectroscopy

80-100 msr

THE PRISMA SPECTROMETER coupled to CLARA and AGATA DEMONSTRATOR GAMMA ARRAY

INFN exp. PRISMA (LNL,PD,TO,Na)

INFN exp. GAMMA (LNL,PD,Fi,MI,Na,Pg)

+ broad Int. Collaboration (UK,F,D,Pl,Sp,Ro,Hr)

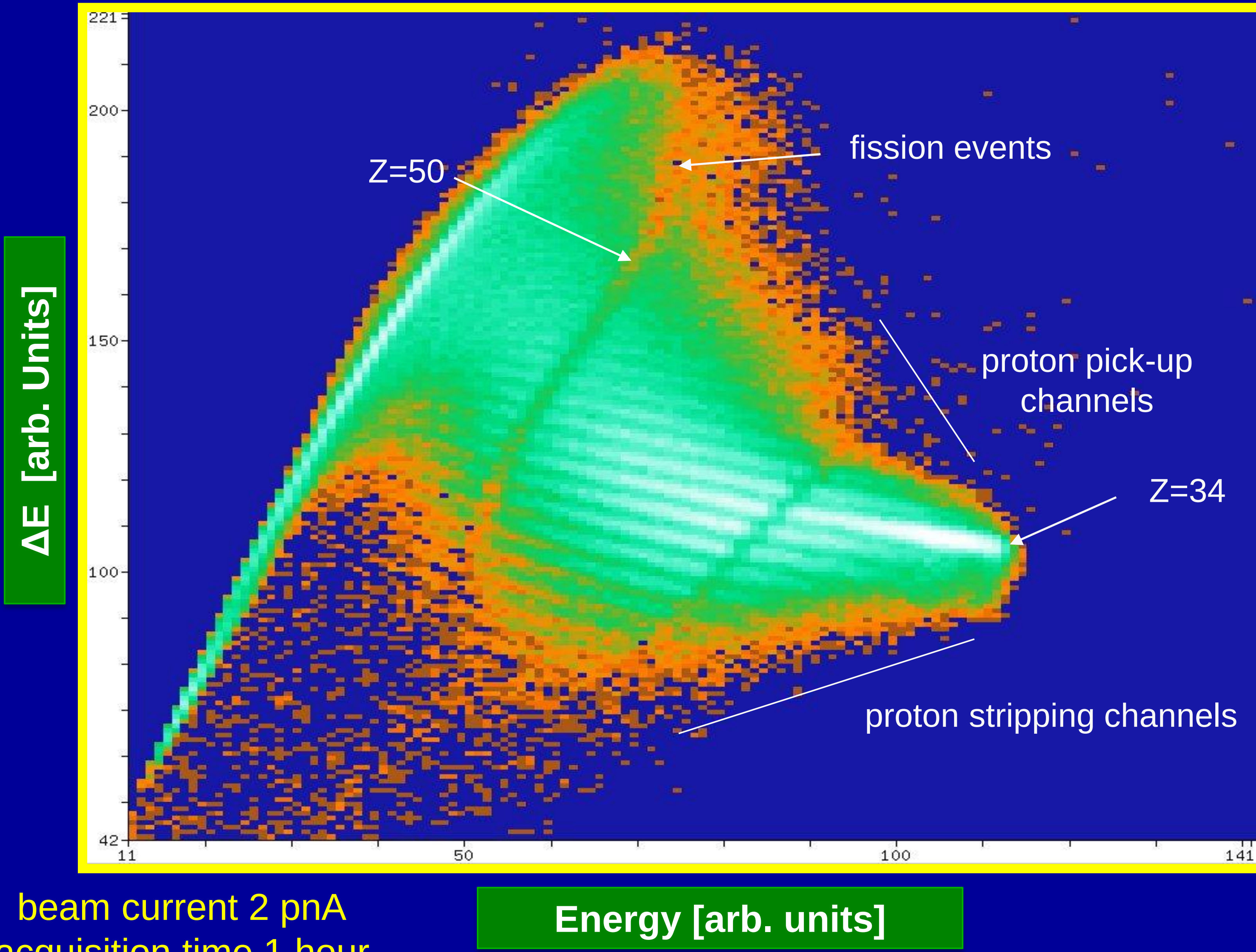
PRISMA: a large acceptance magnetic spectrometer

$\Omega \approx 80$ msr; $B\rho_{max} = 1.2$ Tm

$\Delta A/A \sim 1/200$

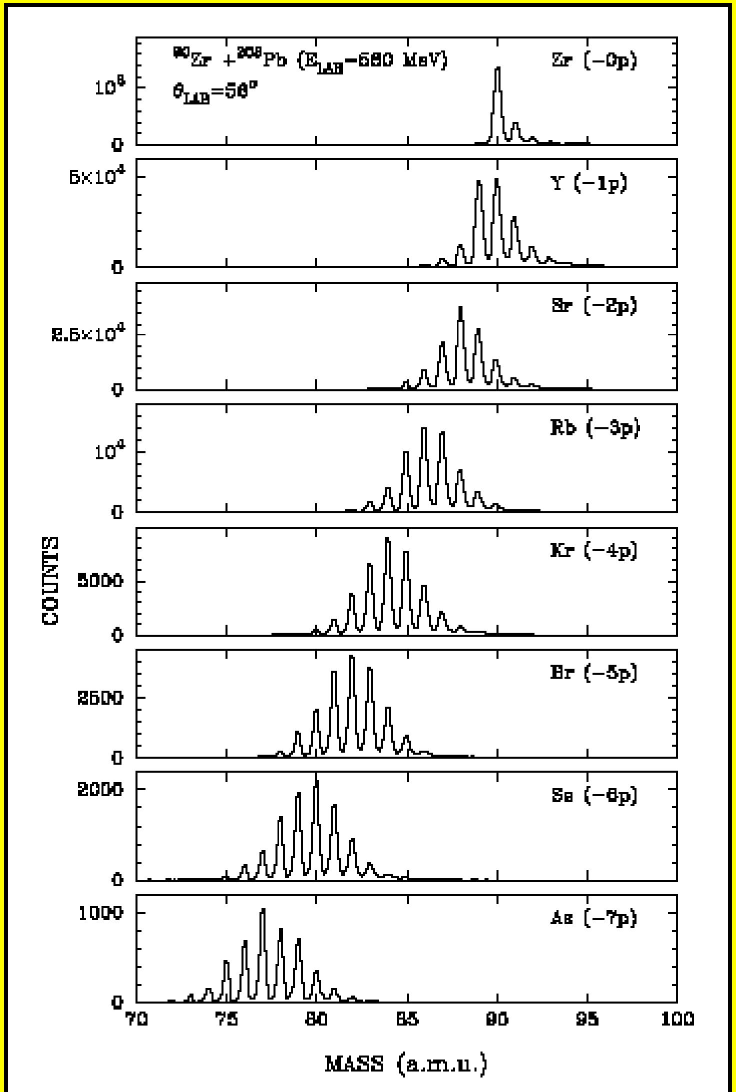
Energy acceptance $\sim \pm 20\%$

ΔE – E matrix in $^{82}Se+^{238}U$ at E_{lab}=505 MeV, θ_{lab} = 64°



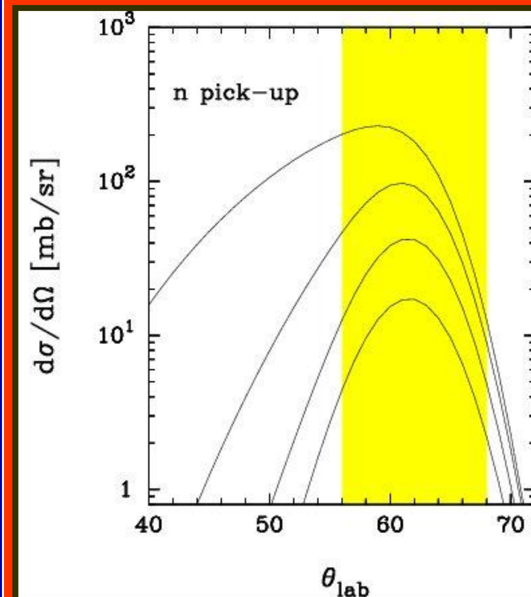
beam current 2 pnA
acquisition time 1 hour

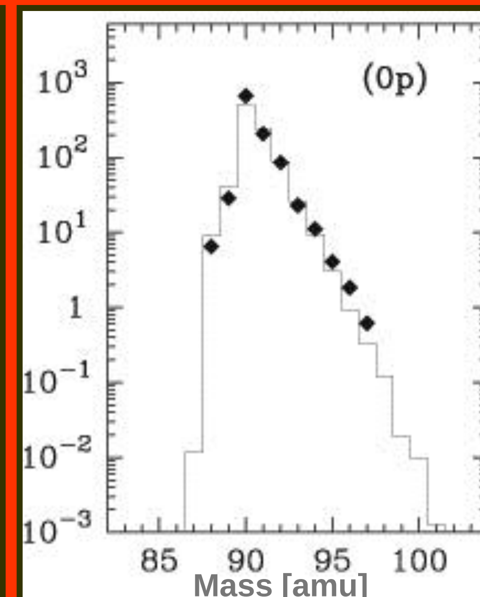
Multineutron and multiproton transfer channels near closed-shell nuclei



$^{90}Zr+^{208}Pb$ E_{lab}=560 MeV

pure neutron pick-up channels



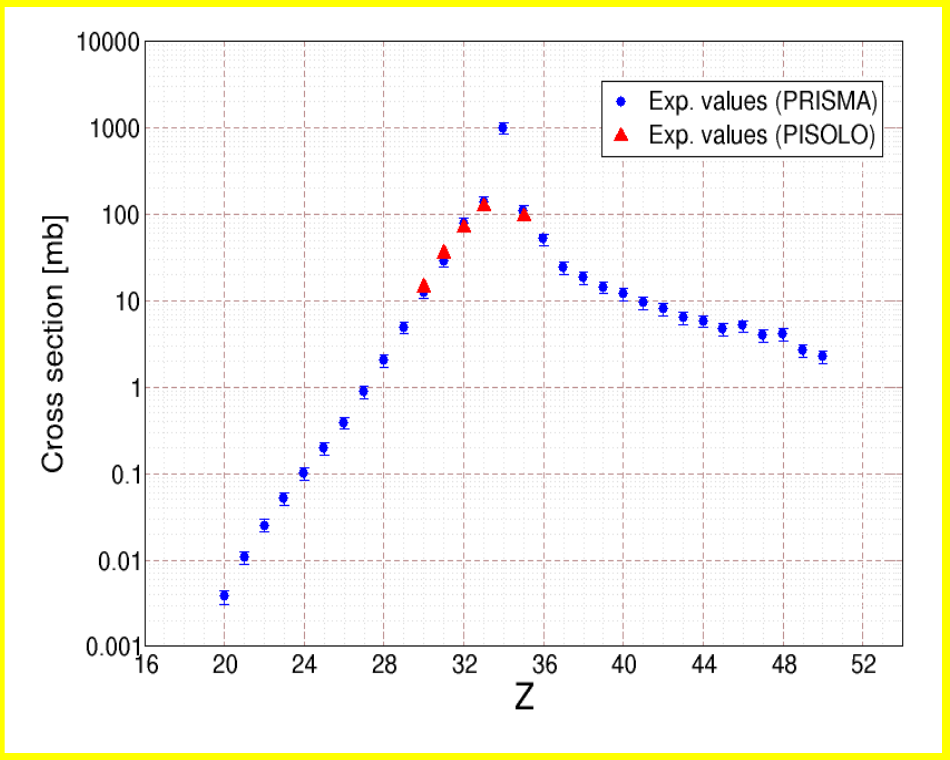


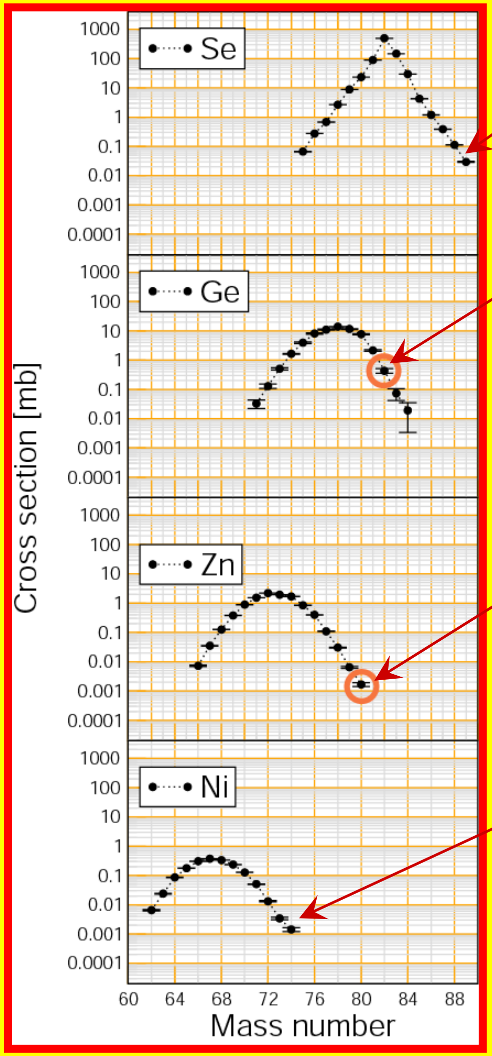
PRISMA spectrometer data

GRAZING code calculations

S.Szilner et al, Phys.Rev.C76(2007)024604

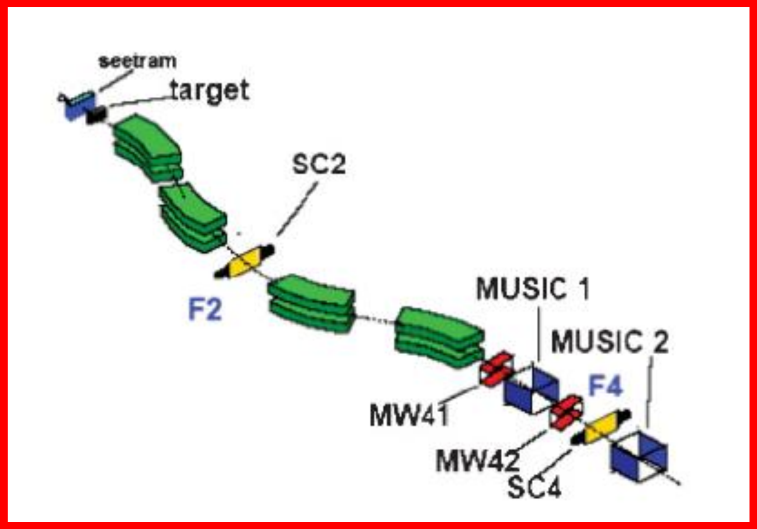
Cross section measurements in $^{82}Se+^{238}U$ at E_{lab}=505 MeV

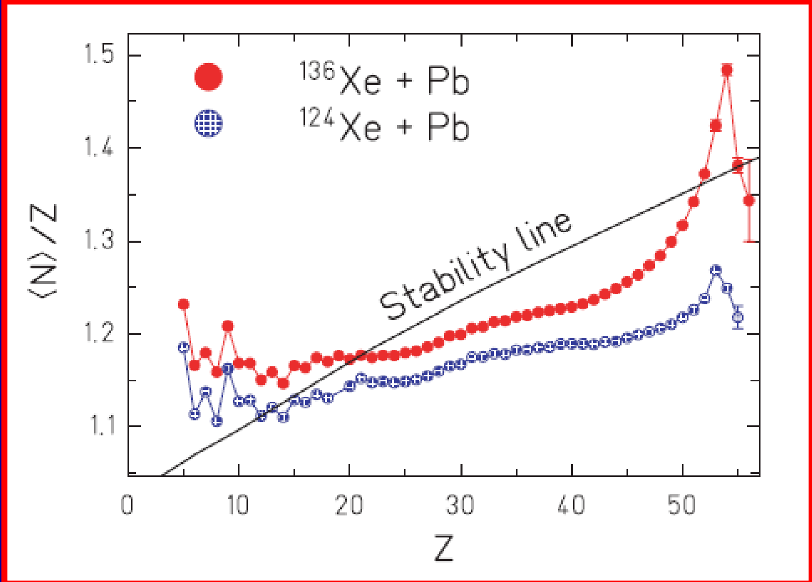




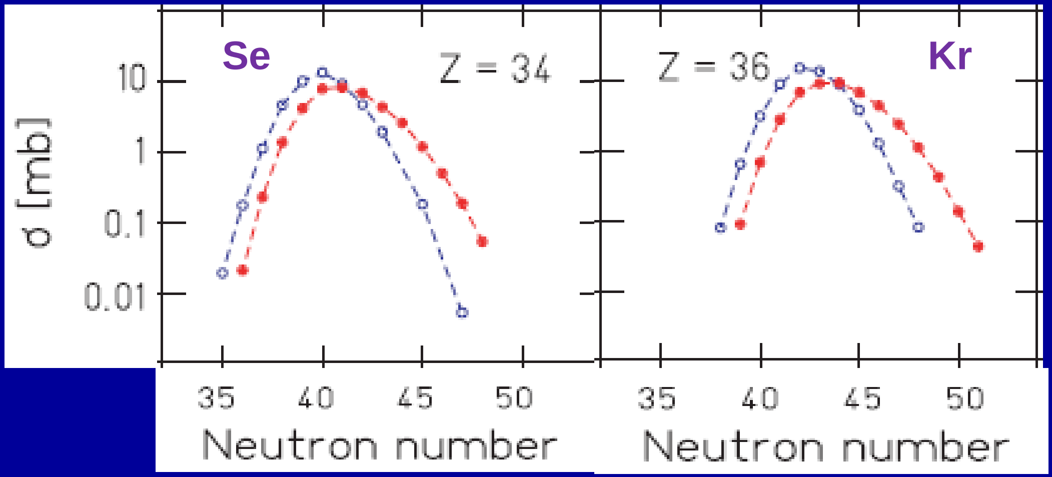
Cross sections for exotic nuclei like the N=50 ^{82}Ge or ^{80}Zn could be mesaured down to few μb level

Fragmentation reactions of Xe isotopes at 1 A GeV on heavy targets





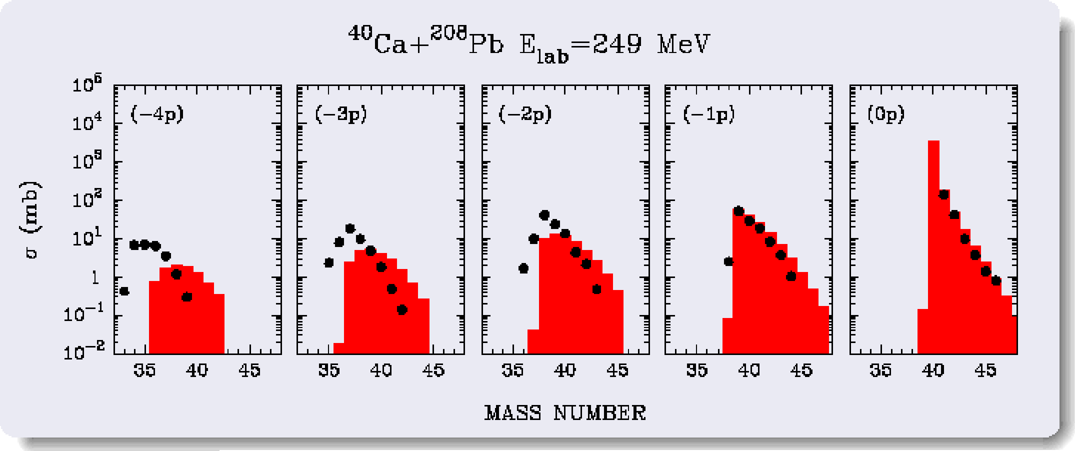
In fragmentation reactions on heavy targets one gets strongly decreasing yields of medium mass neutron rich isotopes, due to neutron evaporation and other complex secondary processes



D.Henzlova et al, Phys.Rev.C78(2008)044616

Studies of light partner reaction products

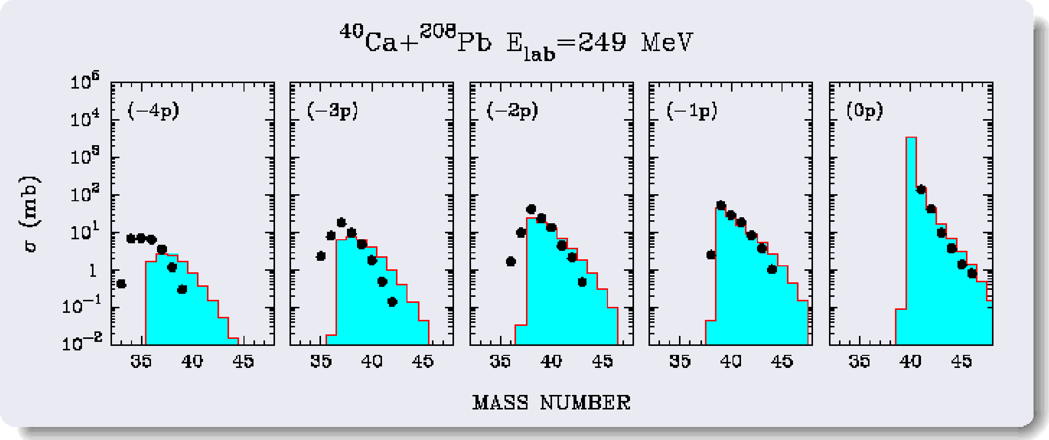
multinucleon transfer : experiment vs. theory



1pt

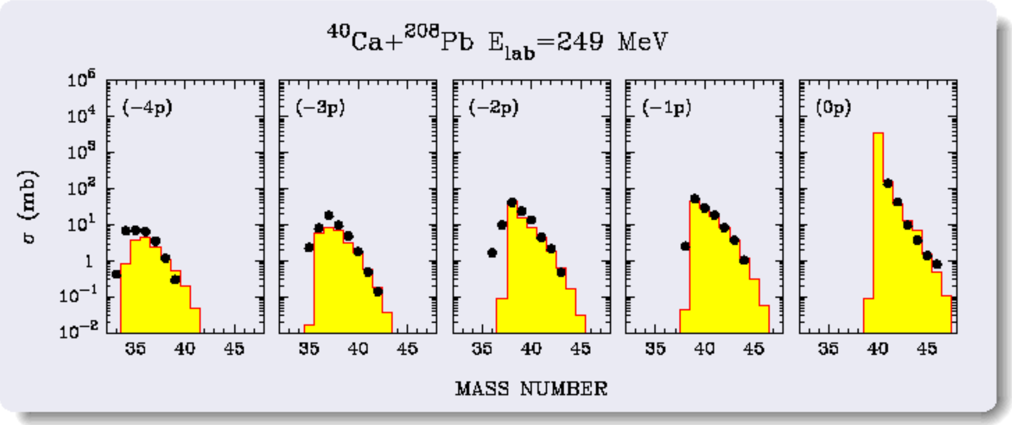
data : LNL

theory : GRAZING code and CWKB



1pt+2pt

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



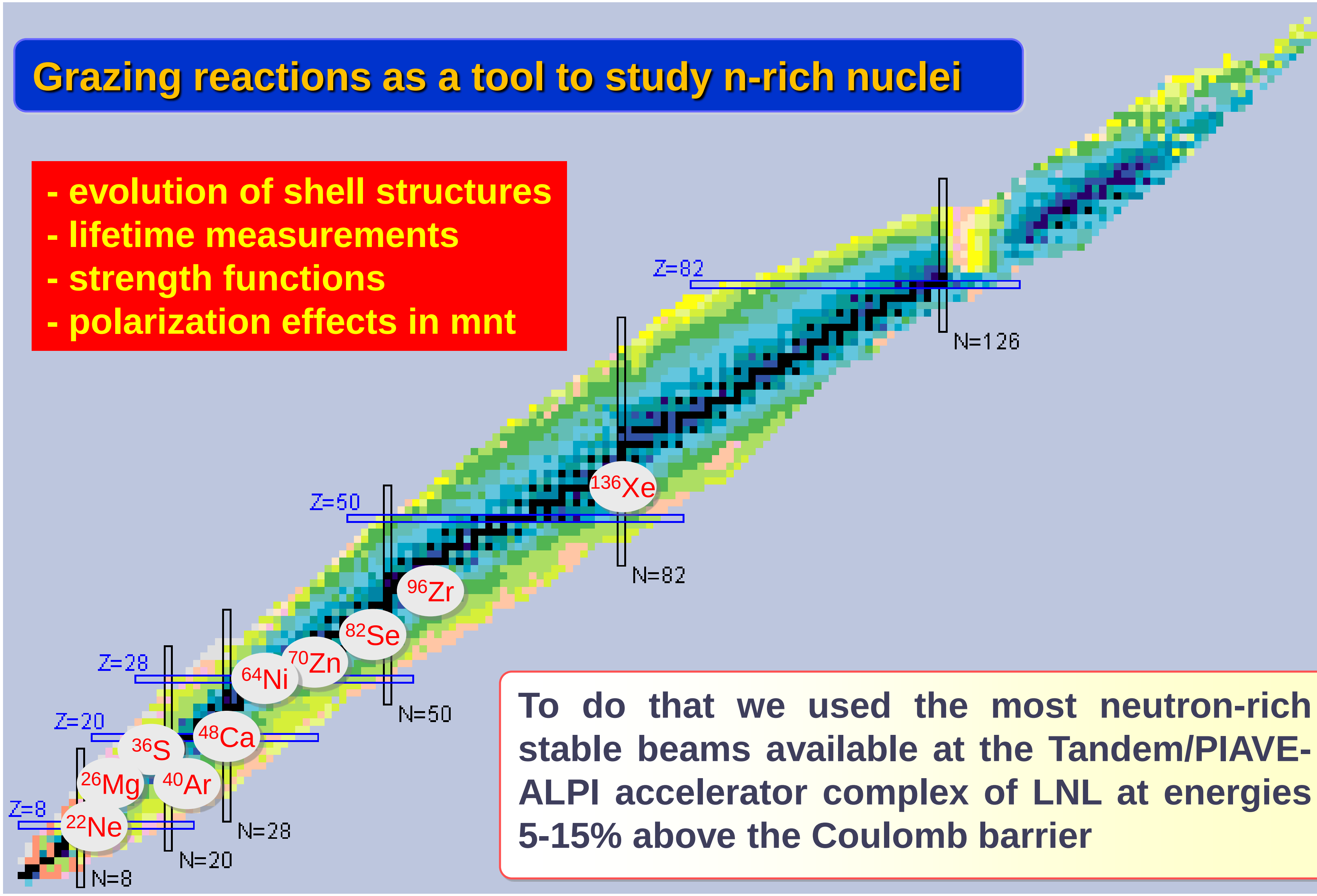
+Evap.

L.Corradi et al, J.Phys. G36(2009)113101 (Topical Review)

THE PRISMA + CLARA/AGATA CAMPAIGN

Grazing reactions as a tool to study n-rich nuclei

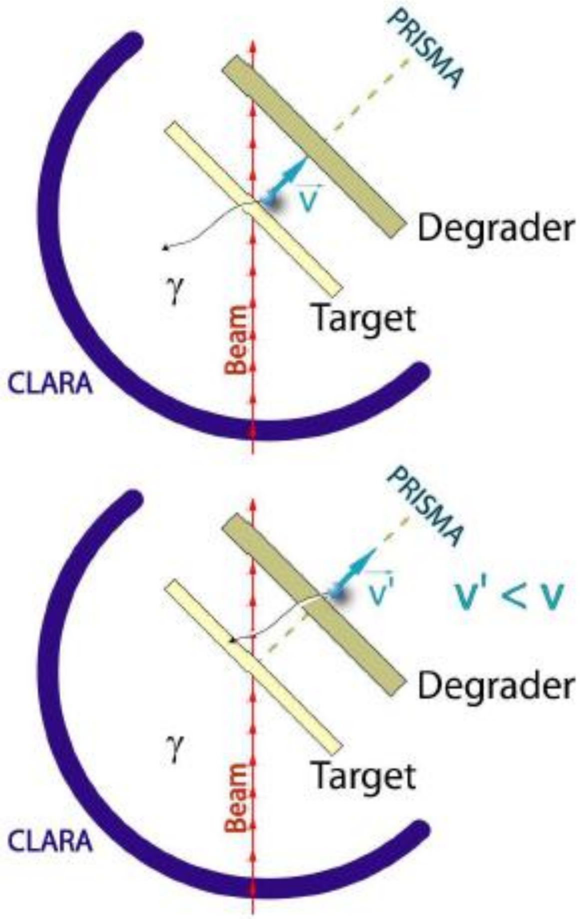
- evolution of shell structures
- lifetime measurements
- strength functions
- polarization effects in mnt

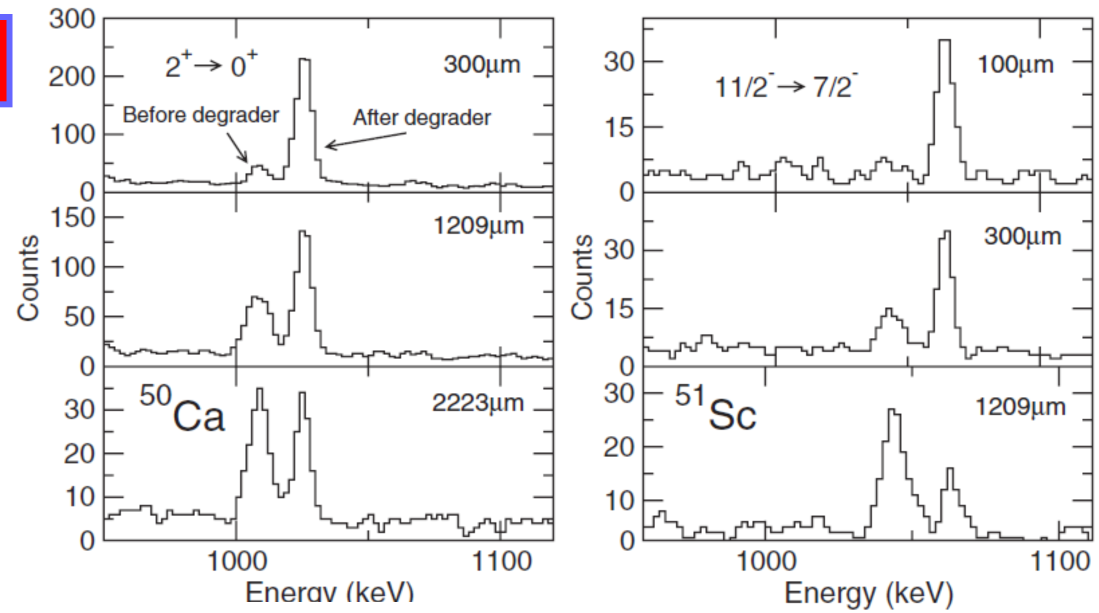


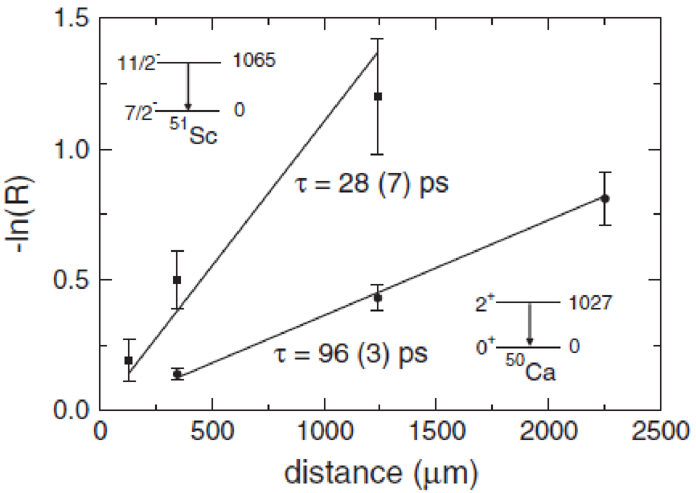
To do that we used the most neutron-rich stable beams available at the Tandem/PIAVE-ALPI accelerator complex of LNL at energies 5-15% above the Coulomb barrier

Lifetimes measurements in $^{48}Ca+^{208}Pb$ at E_{lab}=310 MeV

Differential Plunger Method



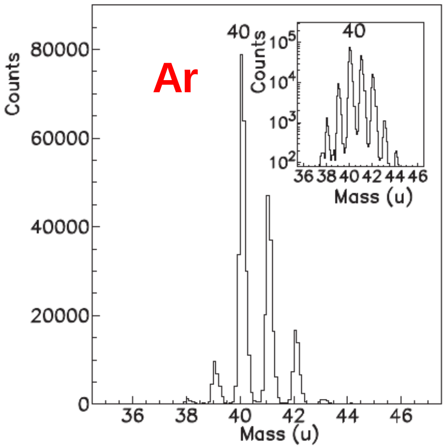




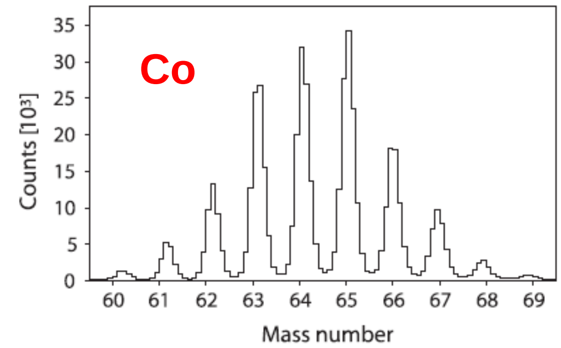
comparison of deduced B(E2) with large scale shell model calculations

J.J.Valiente-Dobon et al, PRL102(2009)242502

Spectroscopy on neutron rich nuclei produced in $^{40}Ar+^{208}Pb$ and $^{70}Zn+^{238}U$ multinucleon transfer reactions

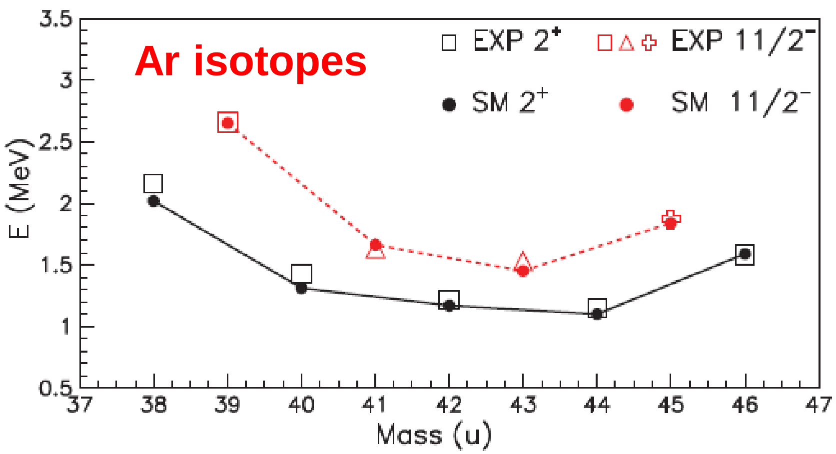


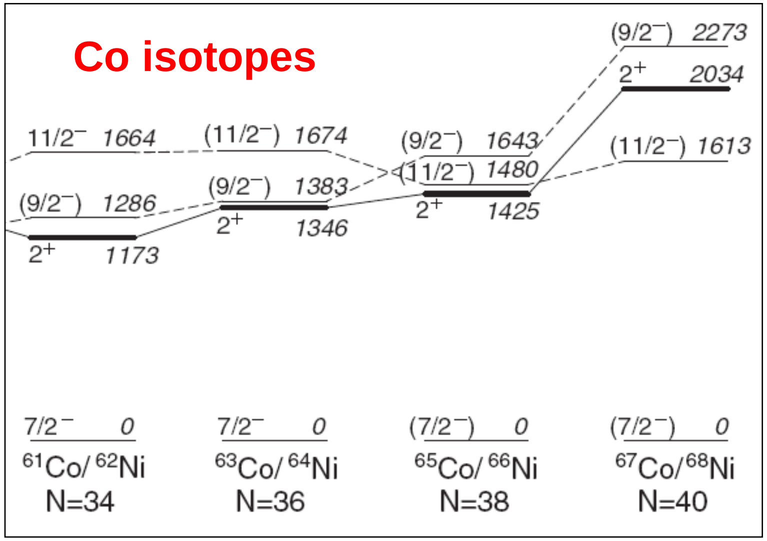
with the good mass identification and high detection efficiency, spectroscopy could be performed in large isotopic chains



toward the N=40 subshell closure, shell model description of spherical and deformed states

interplay between single-parttcle and collective excitations in Ar isotopes





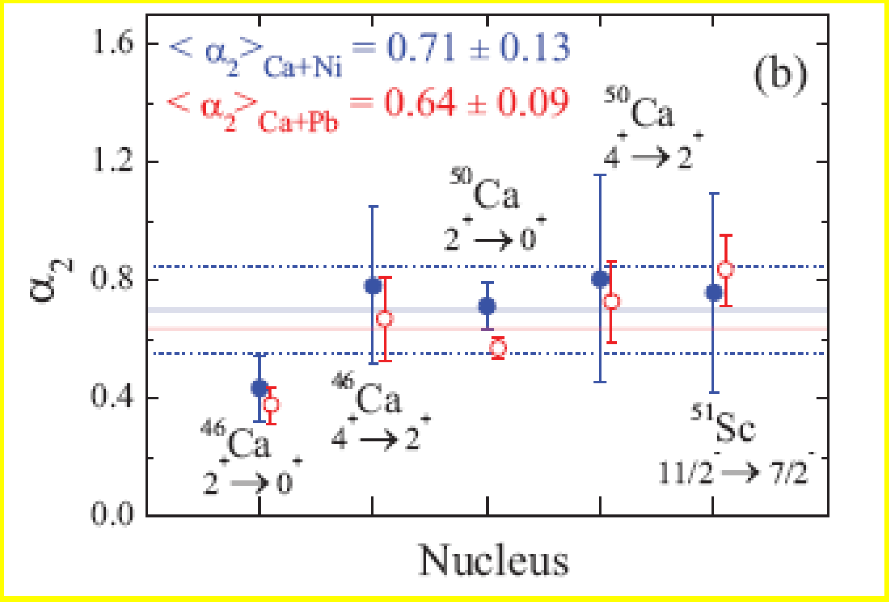
S.Szilner et al, PRC84(2011)014325

F.Recchia et al, PRC85(2012)064305

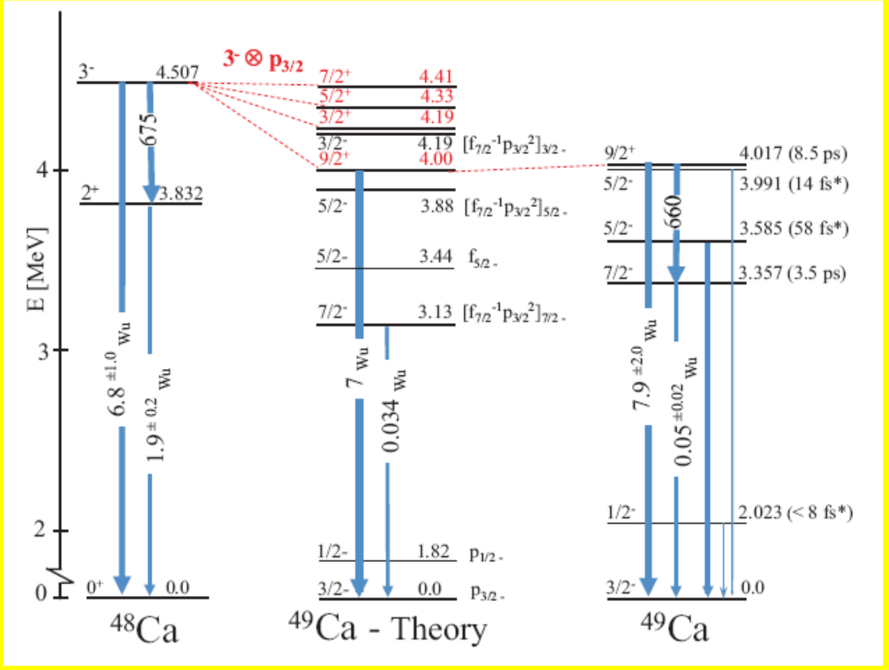
Spin alignment in $^{48}Ca+^{64}Ni$ and $^{48}Ca+^{208}Pb$ mnt reactions

mnt reactions produce a large degree of spin alignment, which allows to study decay properties of populated states

fraction of full spin alignment

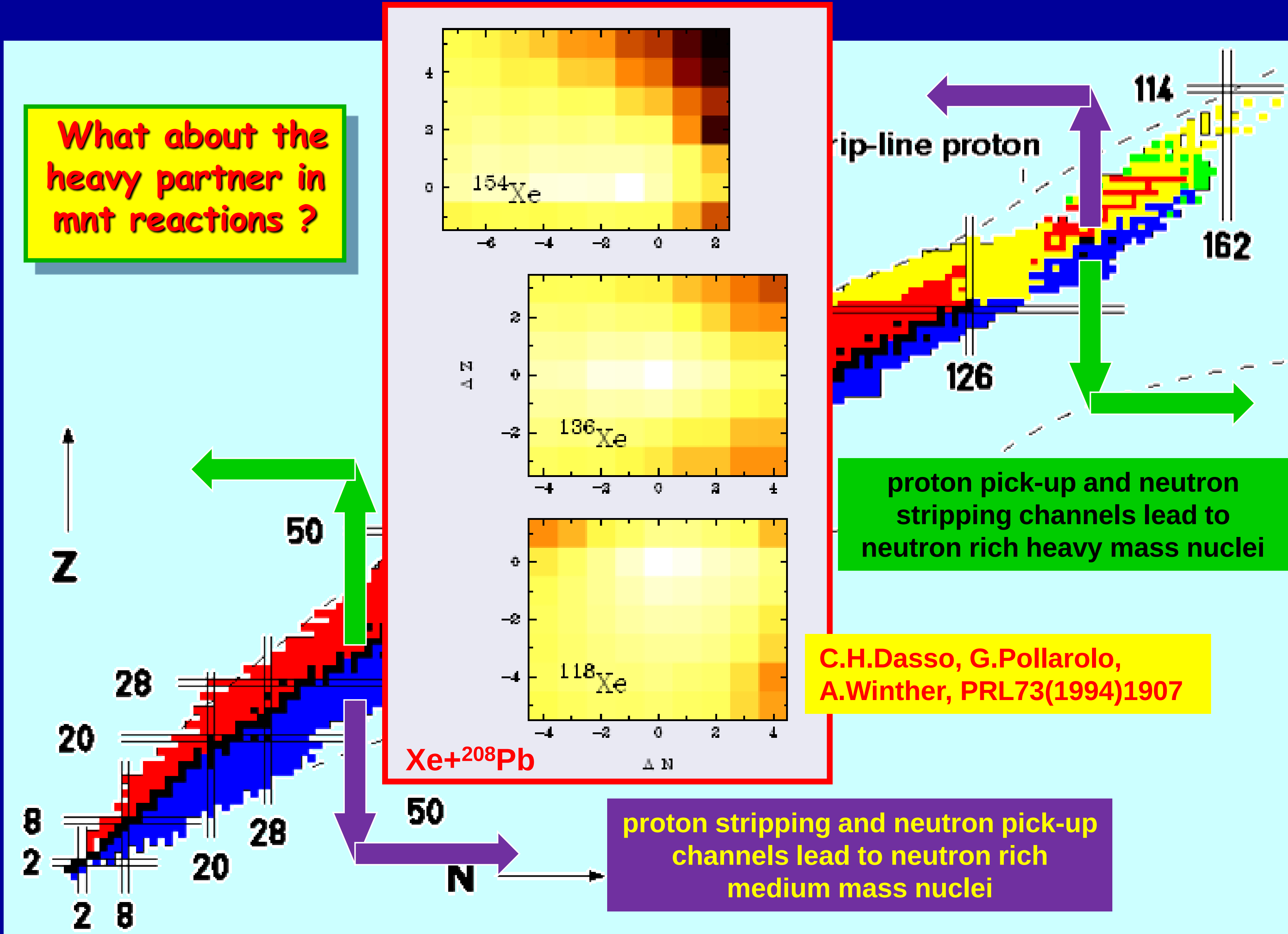


positive parity states obtained within the particle-vibration model employing the SkX Skyrme interaction

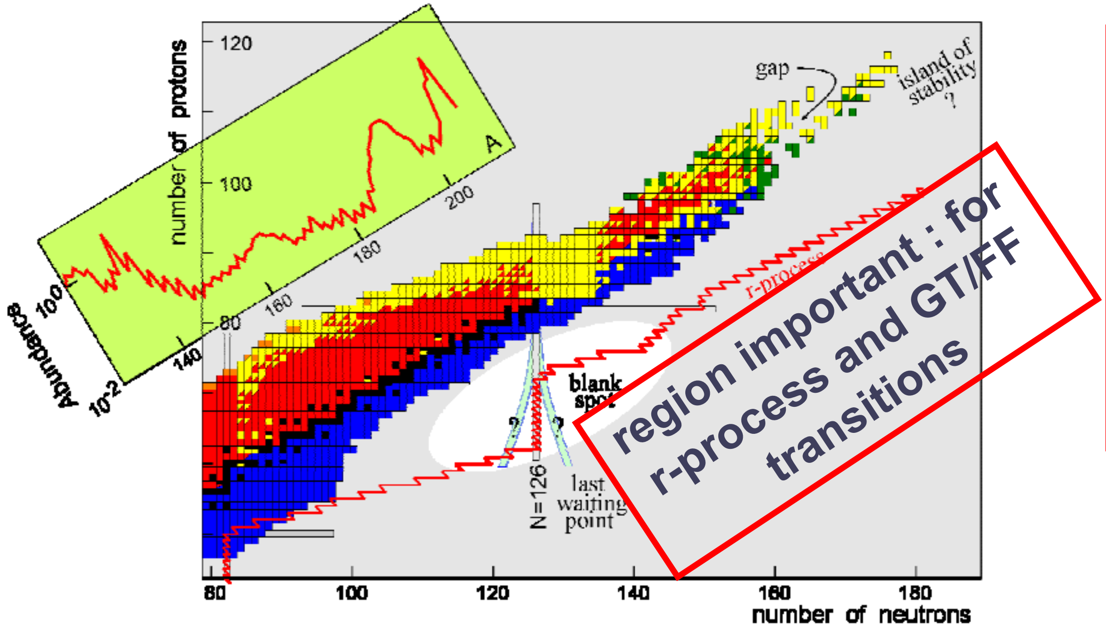


D.Montanari et al, PLB697(2011)288 and PRC85(2012)044301

What about the heavy partner products ?


What about the heavy partner in mnt reactions ?
Z
N
2
8
20
28
50
2
8
20
28
50
126
114
162
rip-line proton
154Xe
136Xe
118Xe
ΔZ
ΔN
Xe+208Pb
proton pick-up and neutron stripping channels lead to neutron rich heavy mass nuclei
proton stripping and neutron pick-up channels lead to neutron rich medium mass nuclei
C.H.Dasso, G.Pollarolo, A.Winther, PRL73(1994)1907

Exploring the north-east part of the nuclear chart via multinucleon transfer



high primary cross sections of mnt channels (mb-µb range)

processes lowering final yield : evaporation and transfer induced fission

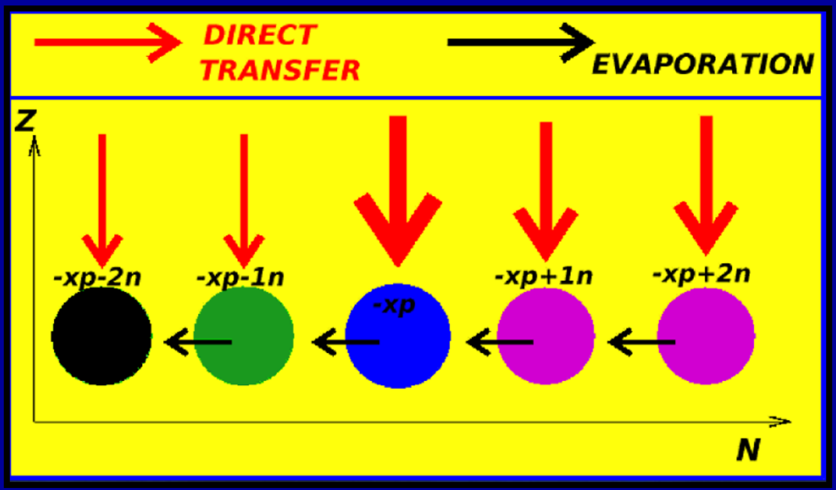
ONGOING EXPERIMENTS

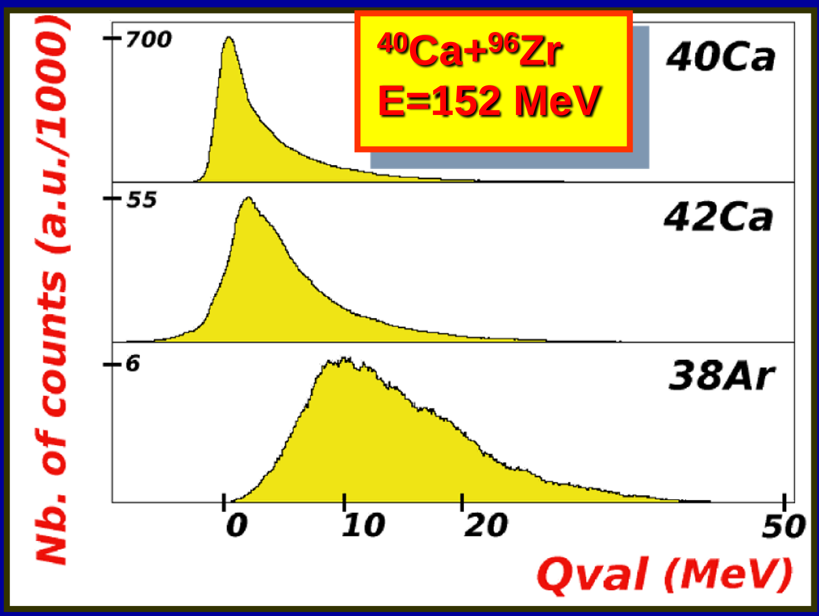
tagging of “light” partner with high resolution spectrometers and detection of coincident gamma rays of the heavy partner

high resolution kinematic coincidences between binary partners, and detection of secondary events (both mechanism and spectroscopy)

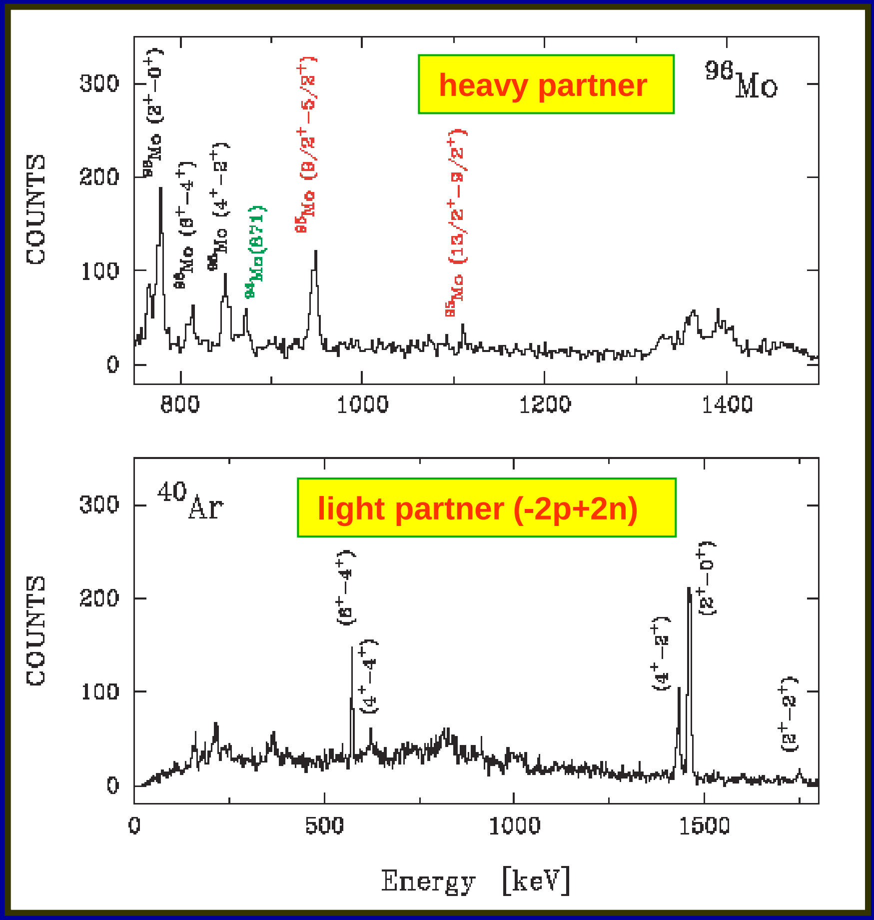
“off beam” measurements of integrated yields

Evaporation processes in multinucleon transfer reactions : an example of gamma-particle coincidences





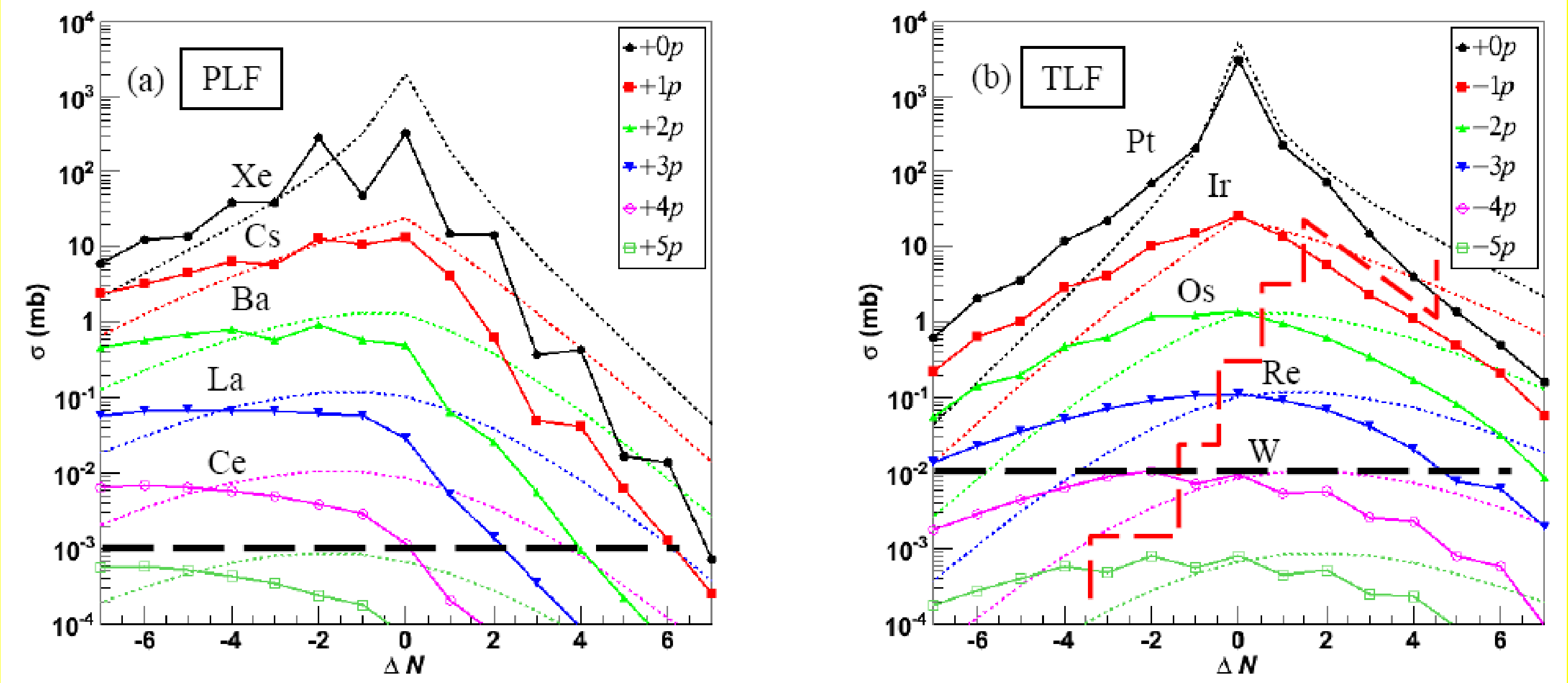
Direct identification with PRISMA+CLARA

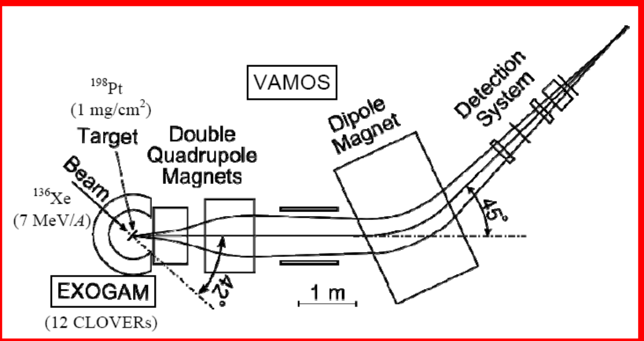


S.Szilner et al, Phys.Rev.C76(2007)024604

Production of heavy neutron rich nuclei by multinucleon transfer reactions of $^{136}Xe+^{198}Pt$ at 7 MeV/A

GRAZING code calculations



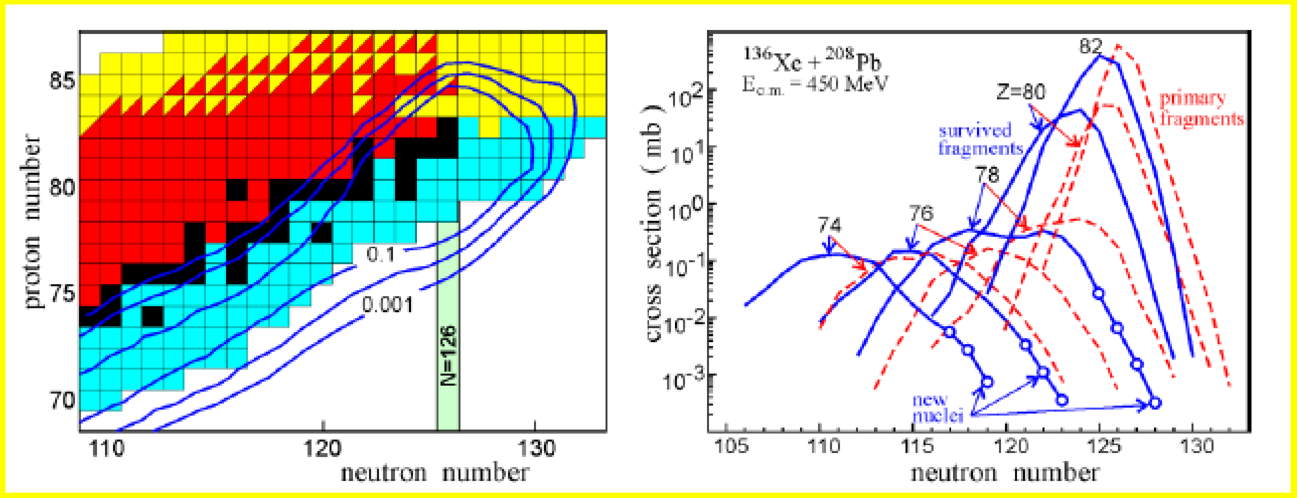


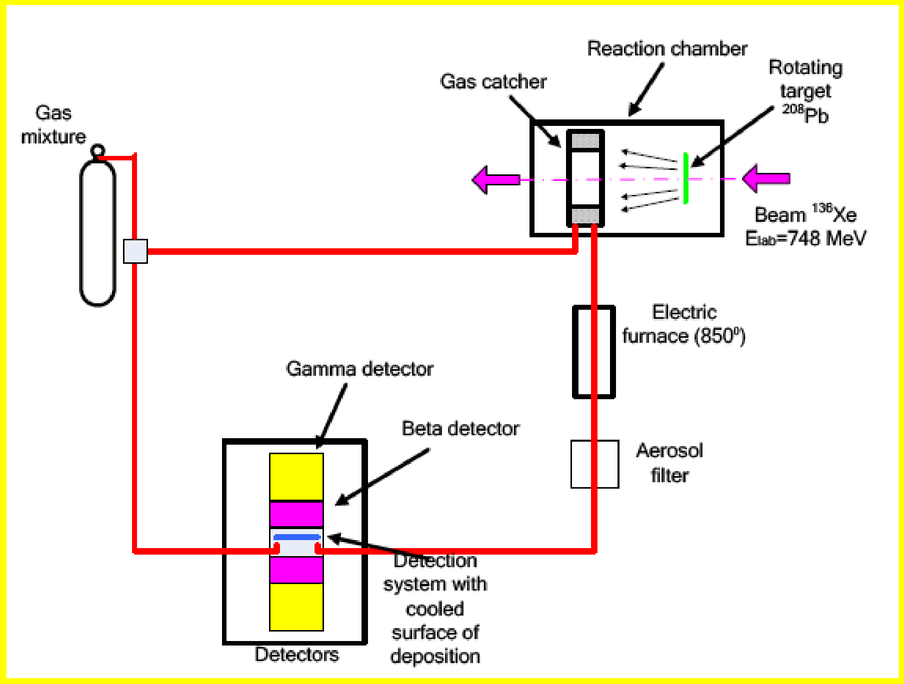
PLF nuclei detected with VAMOS, coincident gamma-rays (both PLF and TLF) detected with EXOGAM

GANIL exp 2012

Y.Watanabe et al, contribution to this conference

Heavy neutron rich nuclei in the region of neutron closed shell N=126 populated via $^{136}Xe+^{208}Pb$ multinucleon transfer reaction





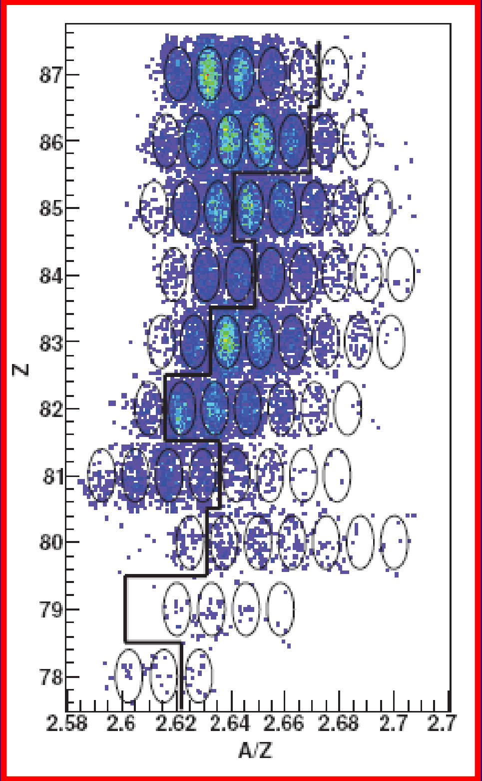
Integral measurement to detect heavy transfer reaction products below the Pb region

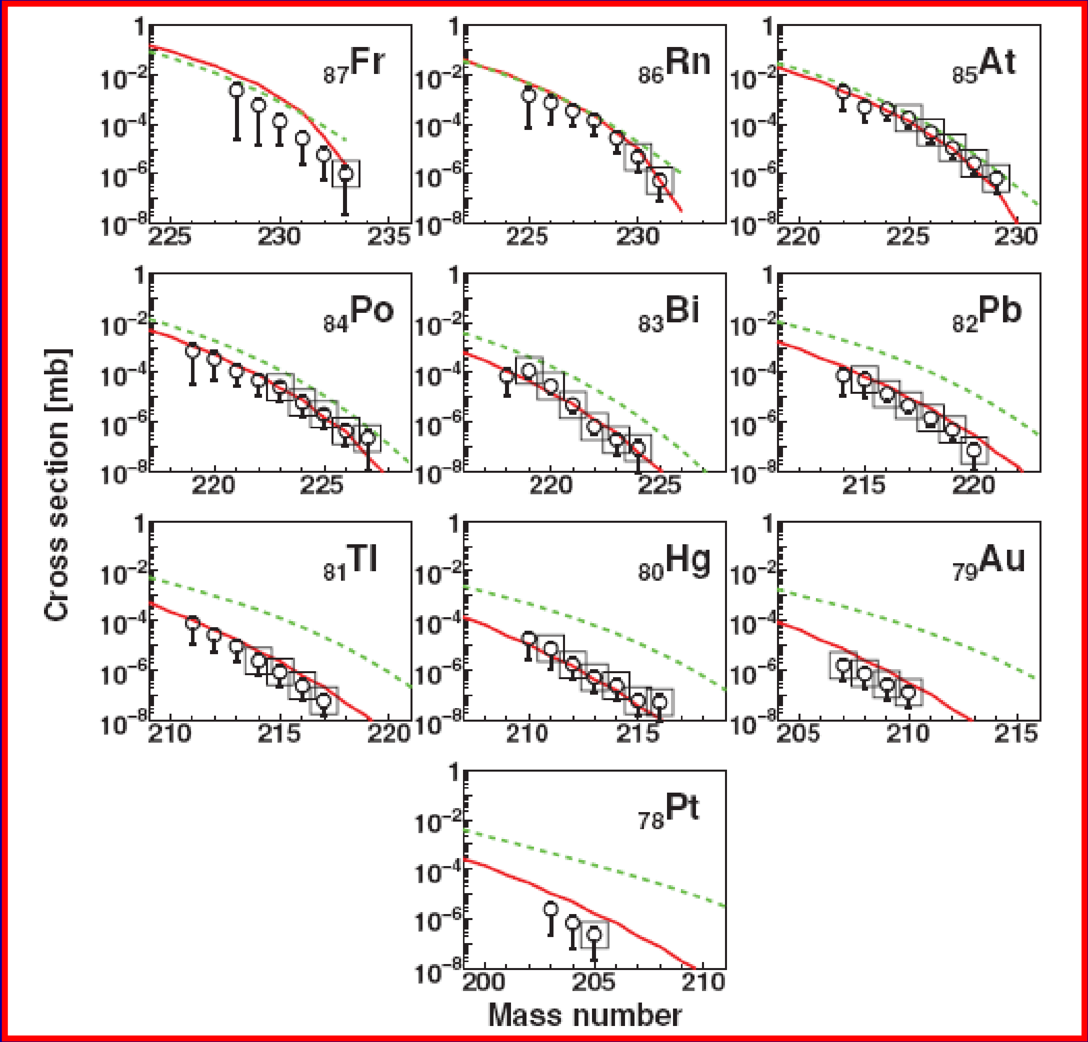
Possibility to study beta-gamma decays properties

Jyväskylä exp 2012

E.Kozulin, V.Zagrebaev et al

Fragmentation reactions of ^{238}U at 1 A GeV on Be targets

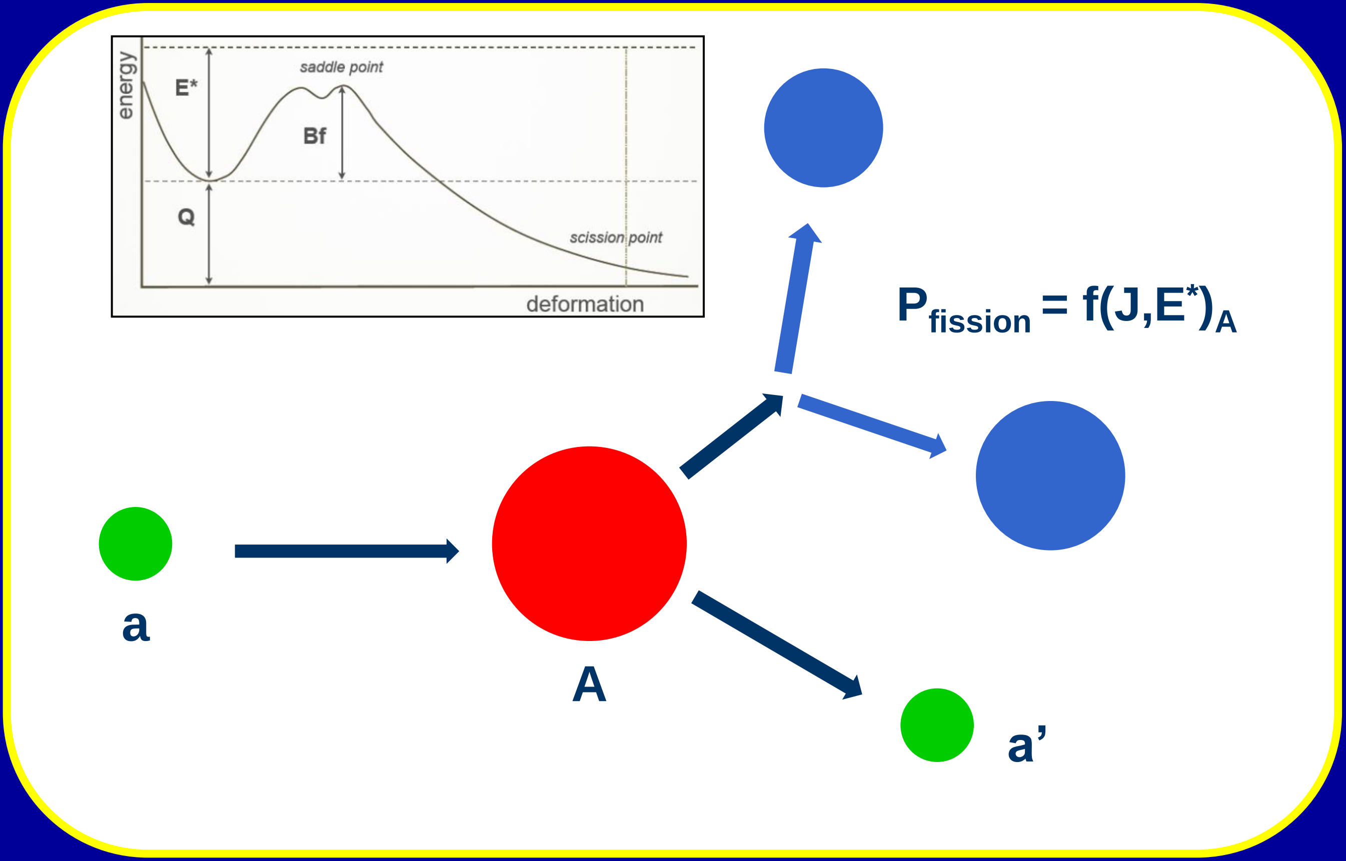




In fragmentation reactions on light targets one could produce very neutron rich nuclei in the “northeast” region, with cross sections down to 100 pb

H.Alvarez-Pol t al, Phys.Rev.C82(2010)041602R

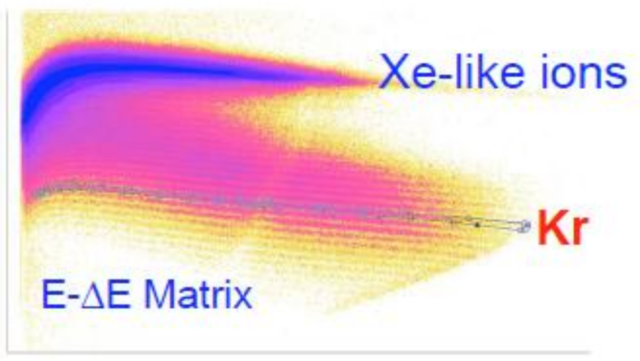
Transfer induced fission : an interesting mechanism to study the population of very neutron rich heavy nuclei

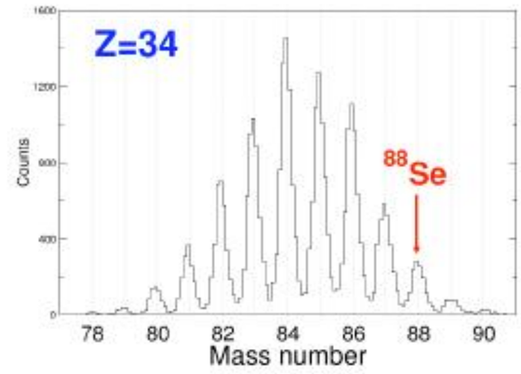


When fission is wanted…

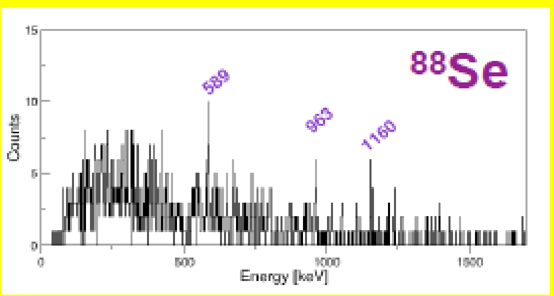
Neutron rich nuclei produced in the fission of ^{238}U in $^{136}Xe+^{238}U$ at E_{lab}=990 MeV

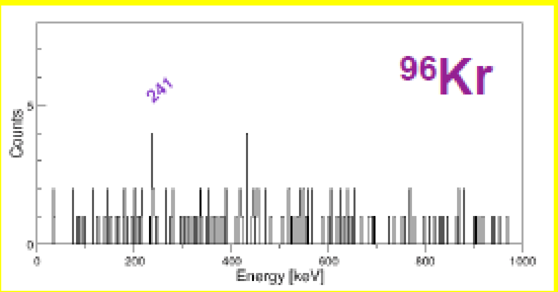
Part of the detected yield should correspond to transfer induced fission, a mechanism suitable to produce more neutron rich nuclei



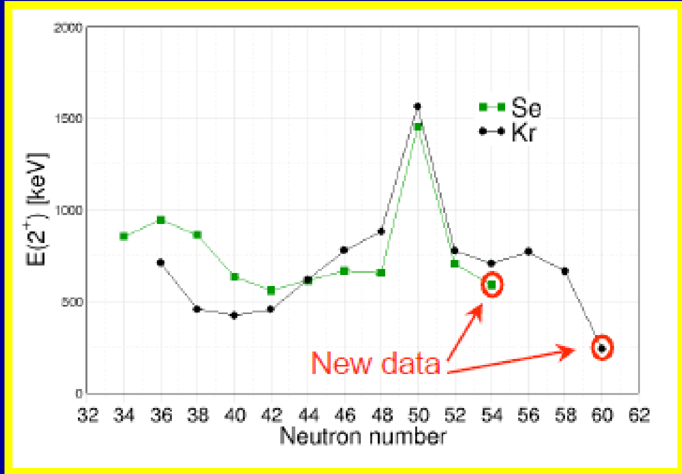


PRISMA setted in order to detect (lighter) fission fragments



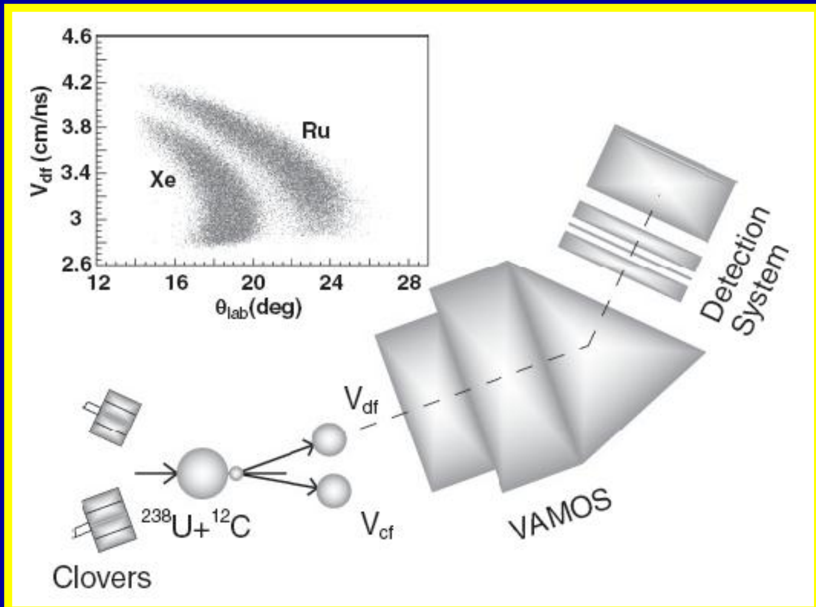


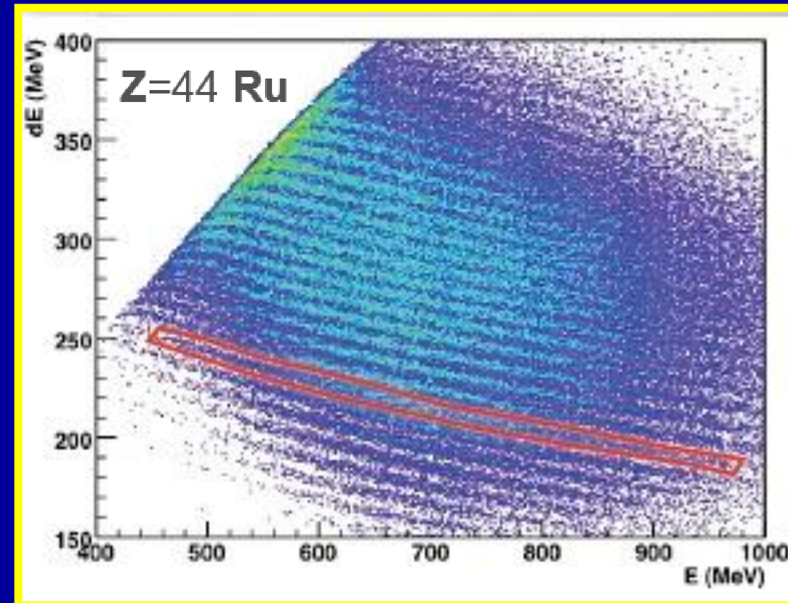
Extended the studies of the evolution of collectivity in n-rich Kr isotopes

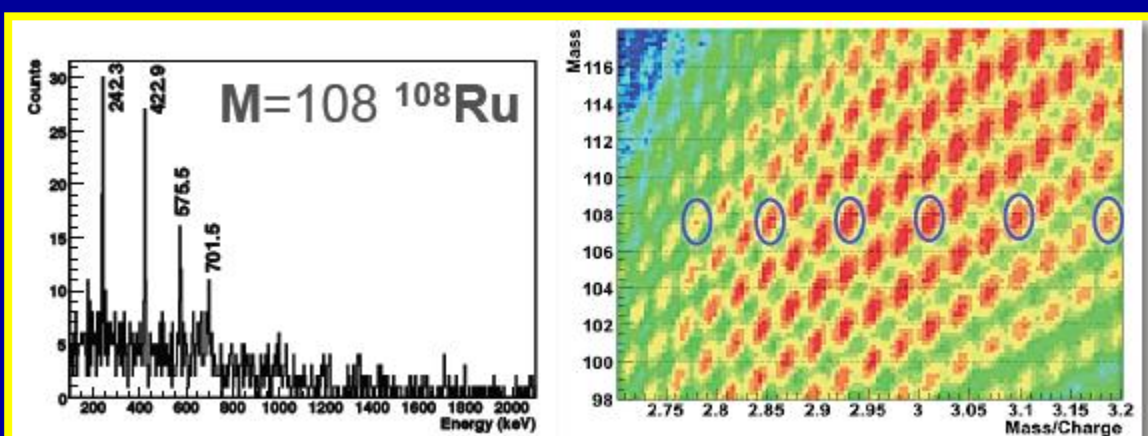


N.Marginean et al., Phys. Rev. C80(2009)021301(R)

Neutron rich nuclei produced in the fission of ^{238}U in $^{238}U+^{12}C$ at E = 6 MeV/A





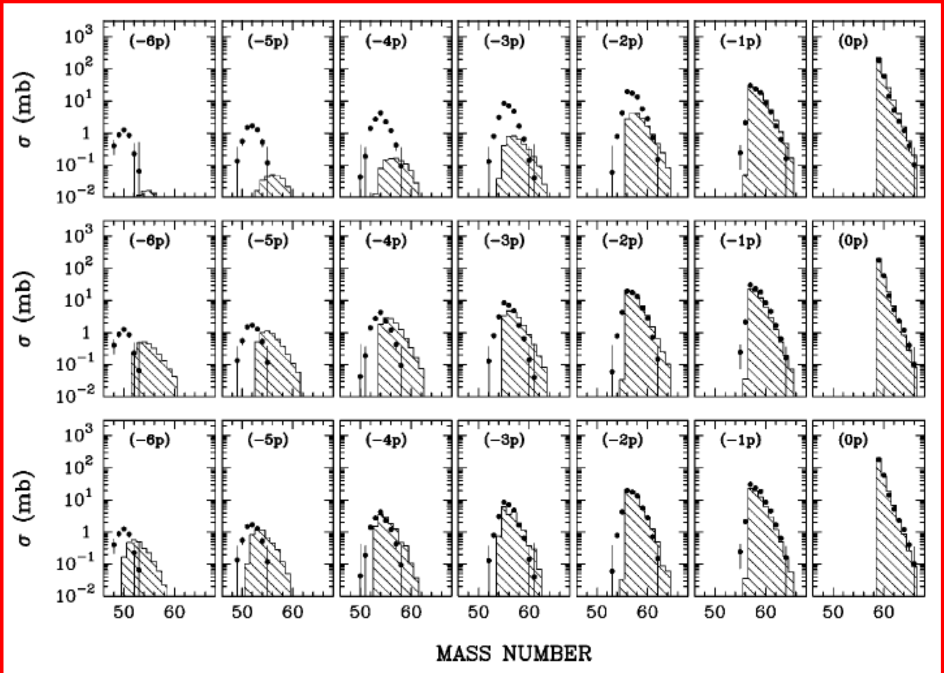


Fission fragment identification with VAMOS+EXOGAM (GANIL)

A.Shrivastava et al, Phys.Rev.C80(2009)051305R

When fission is unwanted…

An example of simultaneous detection light and heavy transfer products for transfer induced fission studies



ind. part. tr. only

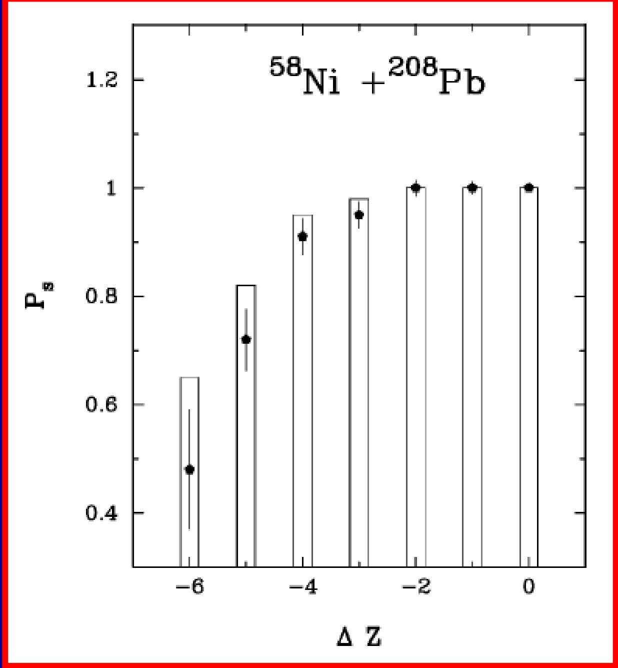
+ pair mode

+ evap

light reaction products fully identified via a time of flight system in $^{58}Ni+^{208}Pb$

points : exp. data

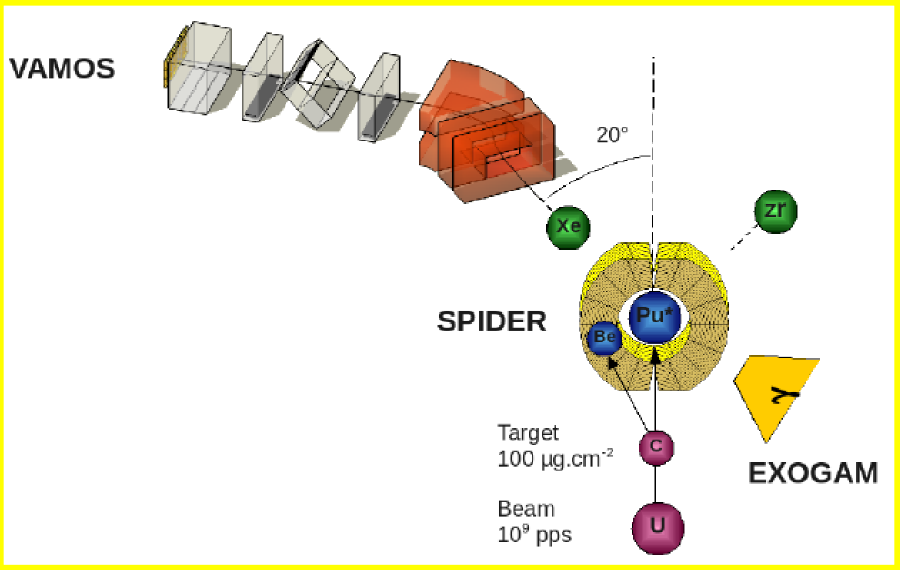
histograms : GRAZING calculations



fission probability of associated heavy partners determined as function of Z,A (light partner) and Q-value of the reaction via a high resolution kinematic coincidence

L.Corradi et al, Phys.Rev.C66(2002)024606

Transfer induced fission in inverse kinematics : $^{238}U+^{12}C$ at E = 6 MeV/A

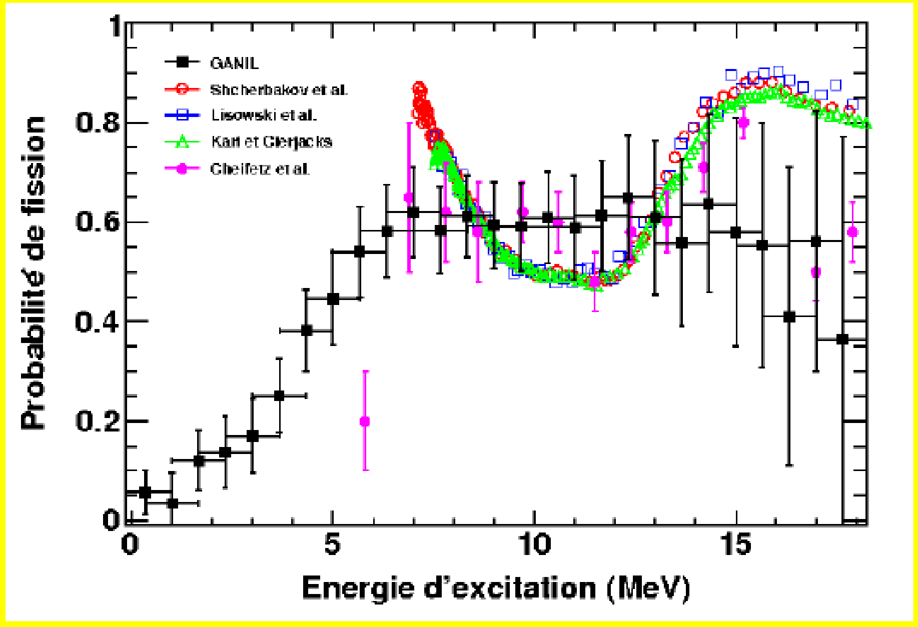


Set-up

- Actinide identification ⇒ **SPIDER**
- Fission fragment identification ⇒ **VAMOS**
- Fission fragment spectroscopy ⇒ **EXOGAM**

Fission probability for ^{240}Pu

Discrepancies with data from neutron-induced fission

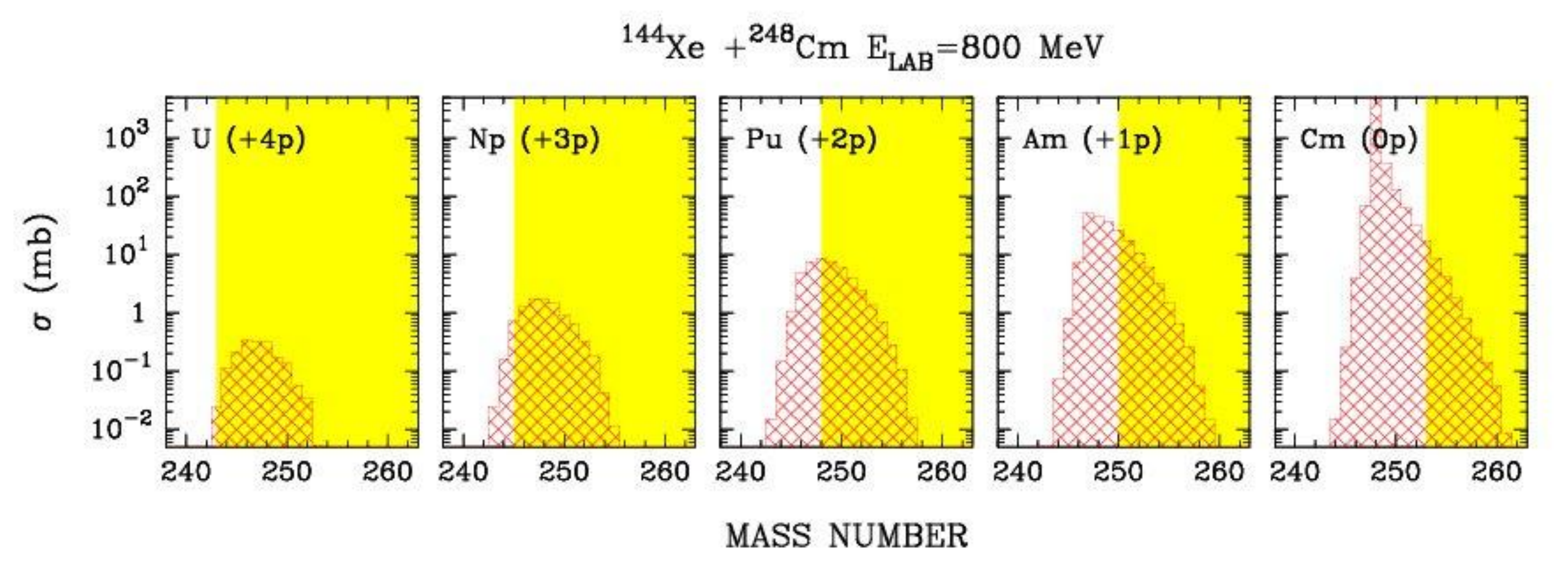


X.Derkx et al, Perspectives in nuclear fission

Tokai 2012

Exploiting the multinucleon transfer mechanism to get acces to yet unknown transactinides

GRAZING code calculations

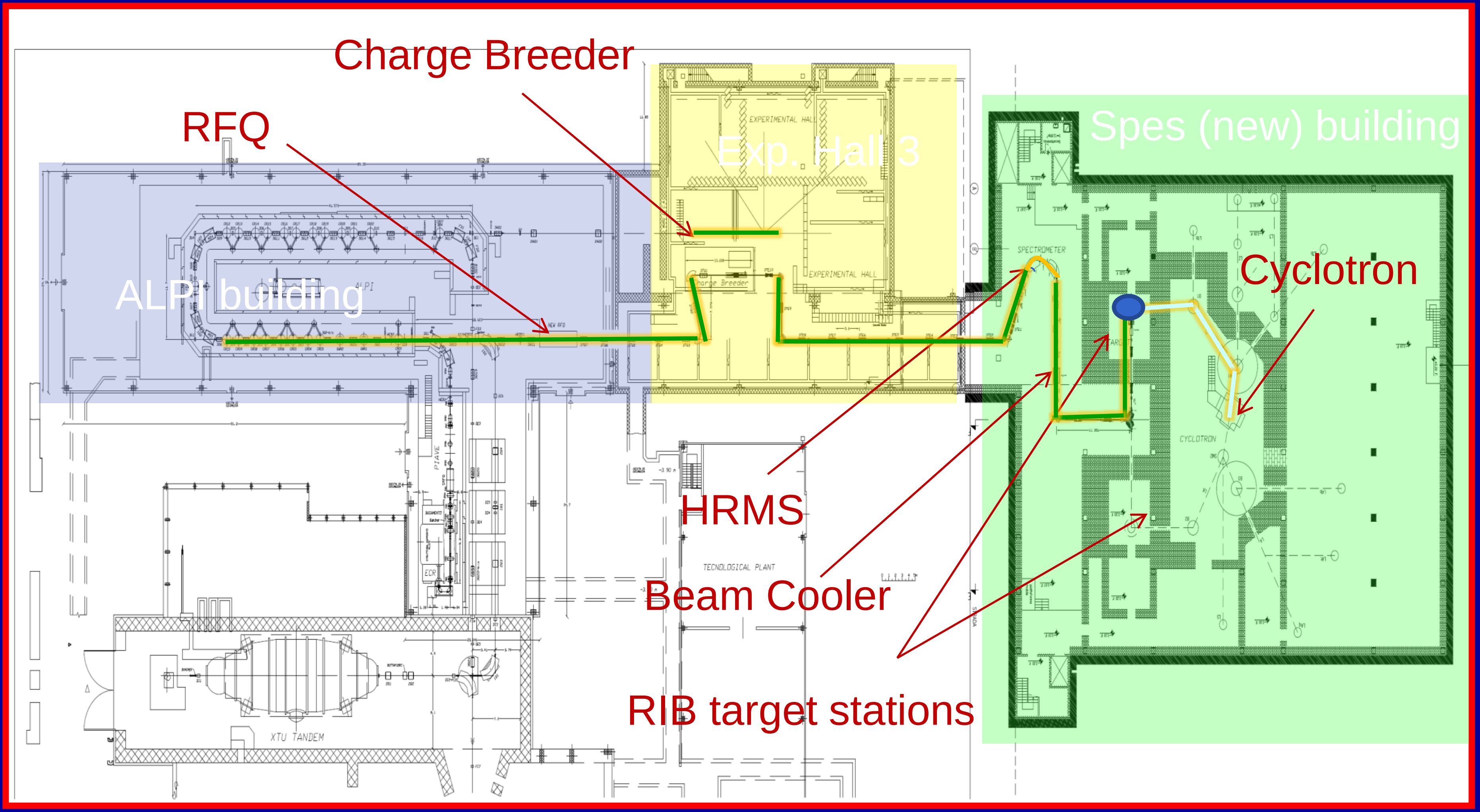


using very neutron rich projectiles, via proton pick-up and neutron stripping channels, one predicts very high primary cross sections for yet unknown transactinides. Therefore, it is important to study the fission probability of the heavy partner

Eurisol Project (key experiments) http://www.ganil.fr/eurisol/

More challenging experiments to be planned for RIB facilities

SPES ISOL facility at LNL : building design and beam transport to ALPI



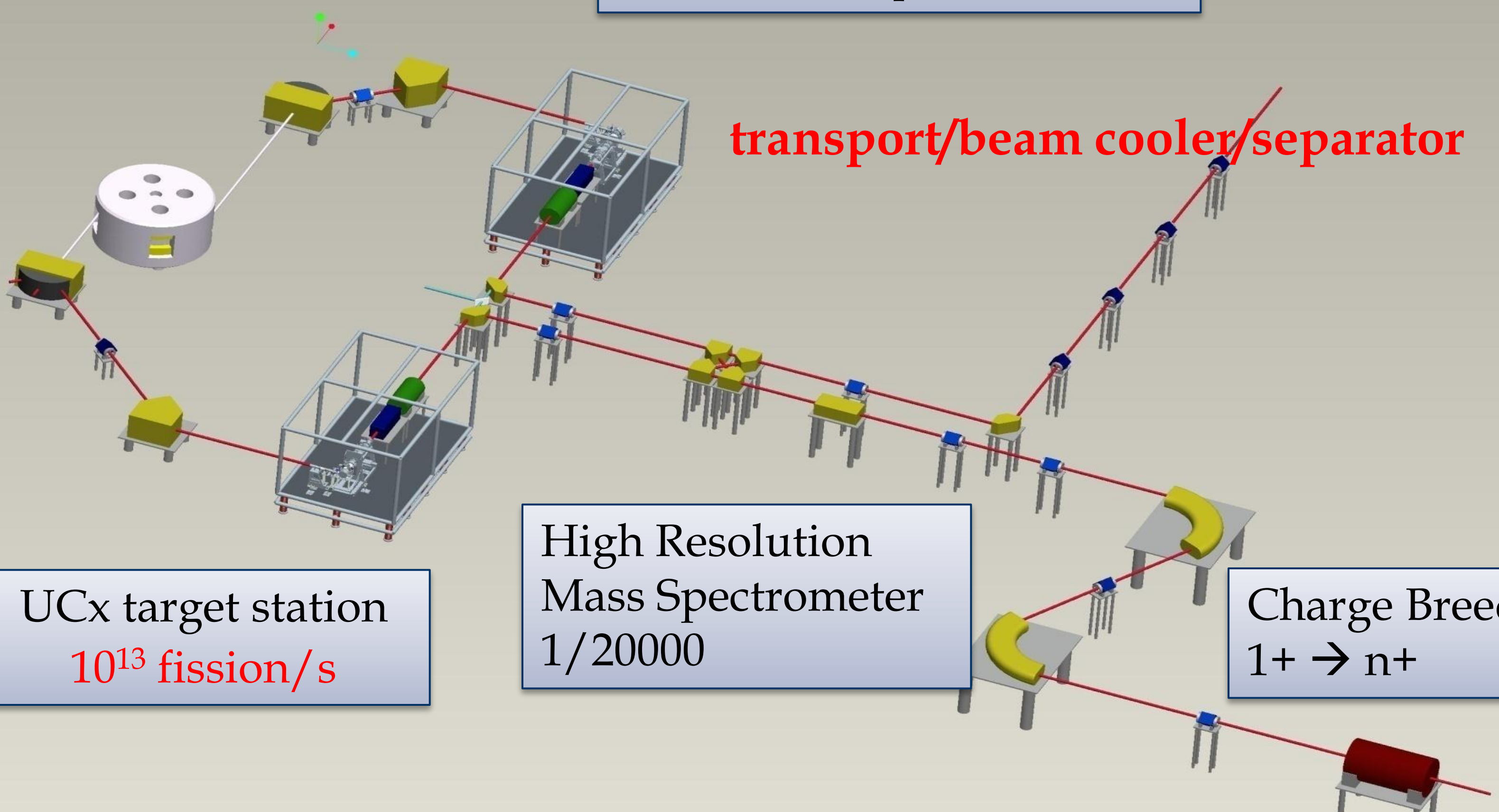
G. Prete

SPES ISOL facility at LNL

Cyclotron 750 μA, 70 MeV (max) for protons in two exit ports:

- RIB - up to 300 μA p on UCx
- Application - up to 500 μA

Additional target station
(special plants second priority)
RIB or neutron production

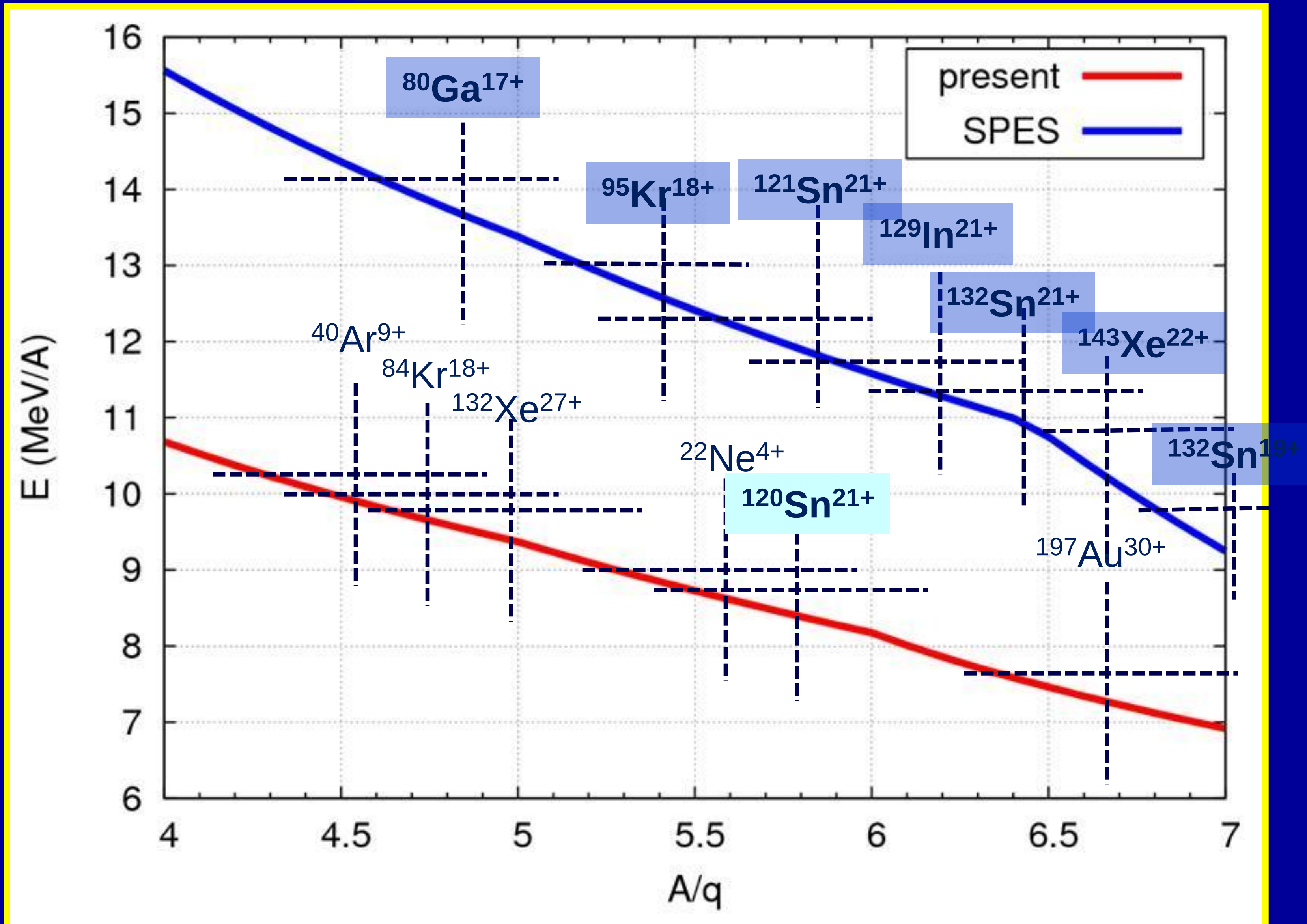


UCx target station
10^{13} fission/s

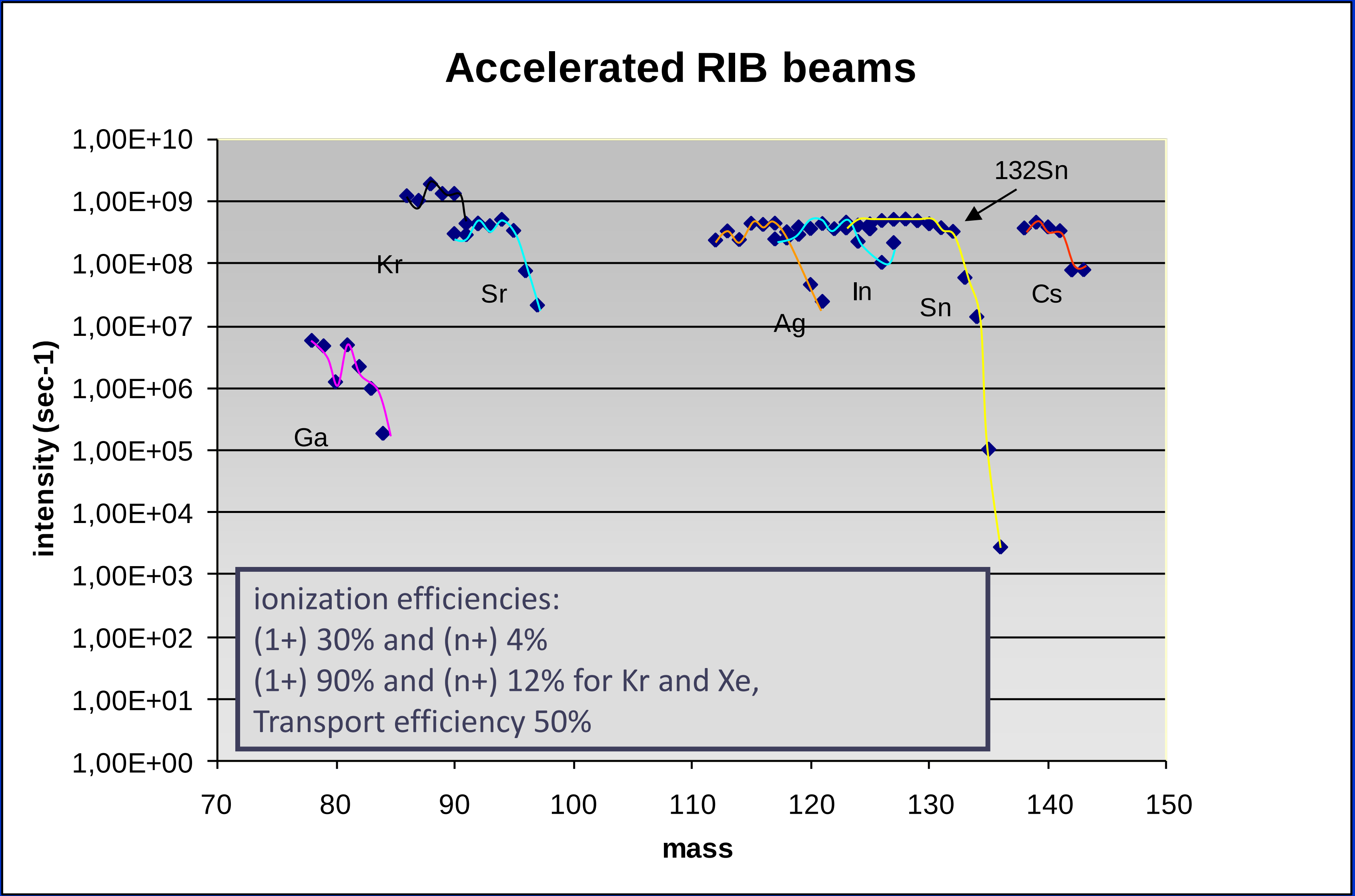
High Resolution
Mass Spectrometer
1/20000

Charge Breeder
1+ → n+

SPES : beam energy



Representative expected beams at SPES



Second generation ISOL facilities in Europe (Ucx target)

	Primary beam	Power on target	UCx target	Fission s-1	Reaccelerator	Nominal energy AMeV A=130
HIE ISOLDE upgrade	p 1-1.4 GeV - 2 μA	2 kW	Direct (150g)	**$4 \cdot 10^{12}$**	SC Linac	5-10
SPIRAL2	d 40 MeV 5mA	200 kW	Converter (4000g)	**10^{13}** 10^{14}	CIME Cyclotron	5
SPES	p 40 MeV 200 μA	8 kW	Direct (30g)	**10^{13}**	ALPI SC Linac	10

Summary

- mnt reactions have proven to be a suitable tool for the study of nuclear structure and reaction mechanisms of nuclei moderately far from stability

- the field benefited from exploiting the coupling of large solid angle spectrometers with large gamma-arrays

- so far, efforts concentrated mainly on the light reaction products. Ongoing experiments focus also on the heavy partner

- it is important to study secondary effects, like transfer induced fission , which will become more and more important using radioactive beams

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