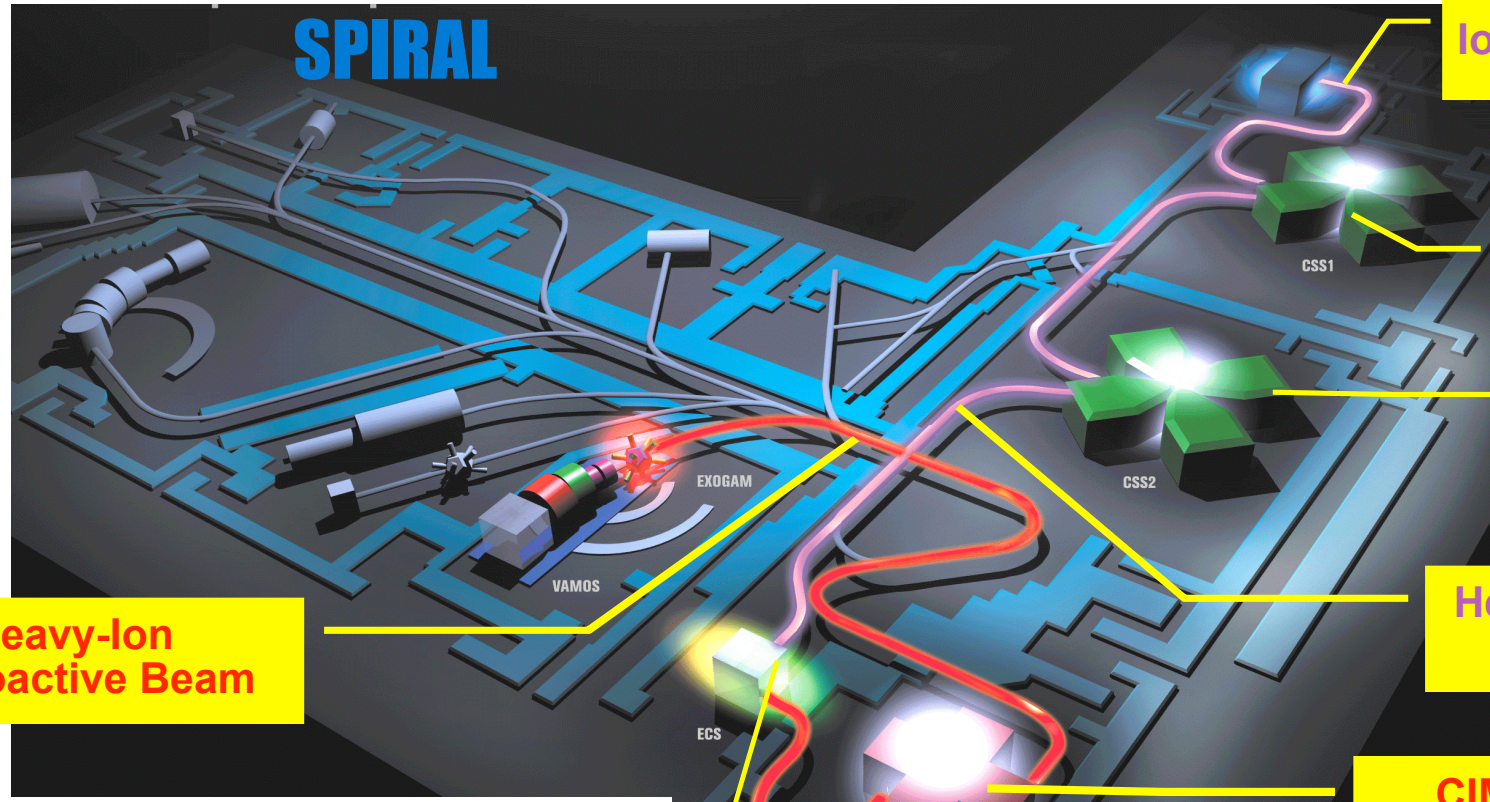
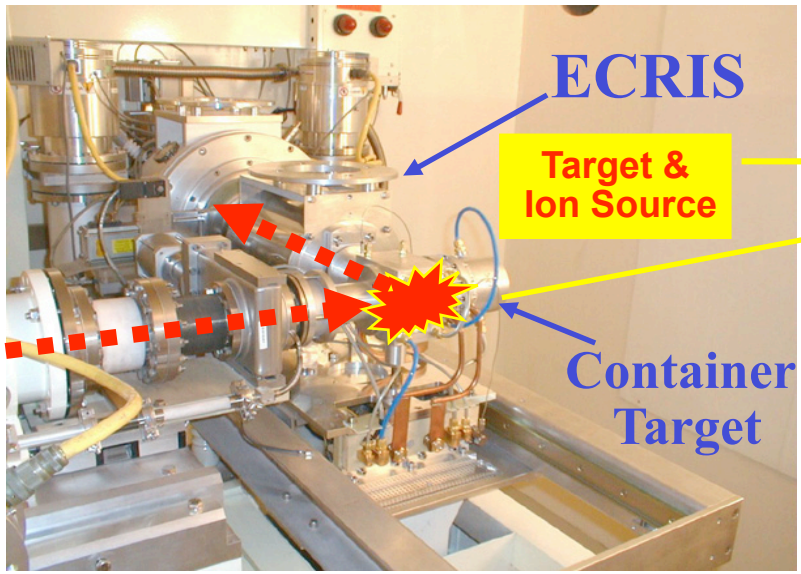
Physics opportunities with SPIRAL and SPIRAL 2

Marek Lewitowicz
GANIL

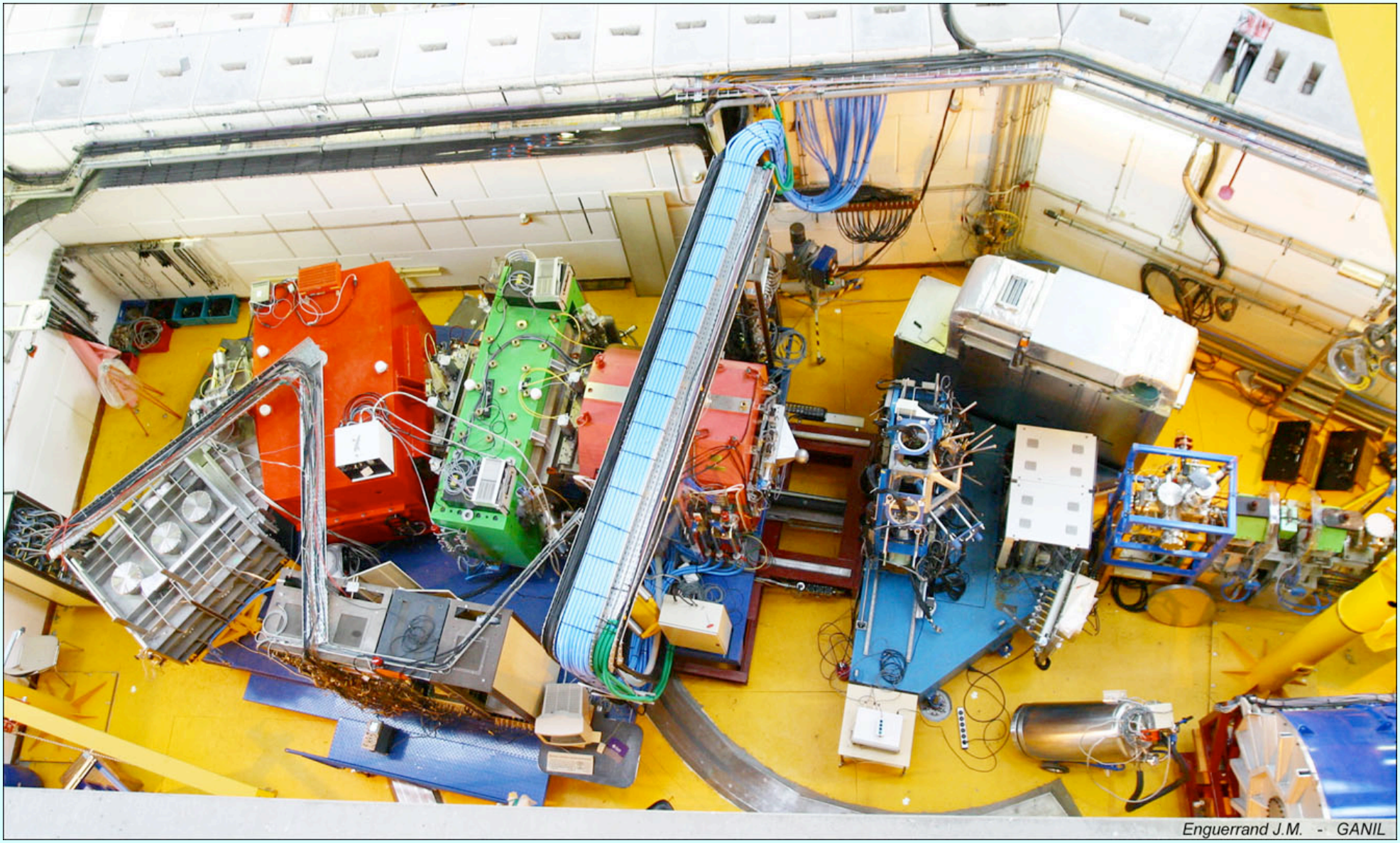




Carbon Target

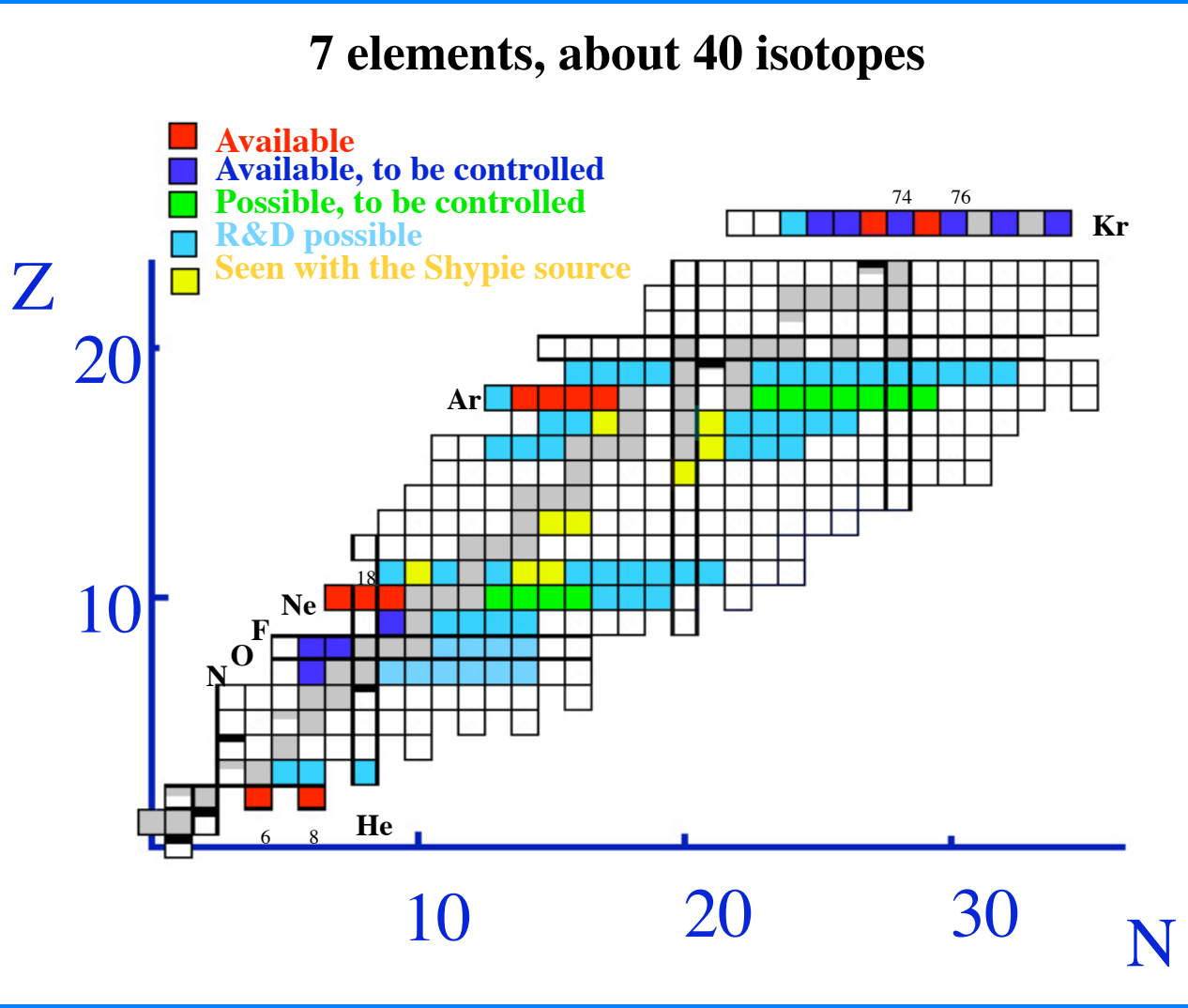
VAMOS
VARIABLE MODE SPECTROMETER

EXOGAM
- GANIL -



VAMOS and EXOGAM spectrometers constructed by European Collaborations

Available and possible RIBs at SPIRAL

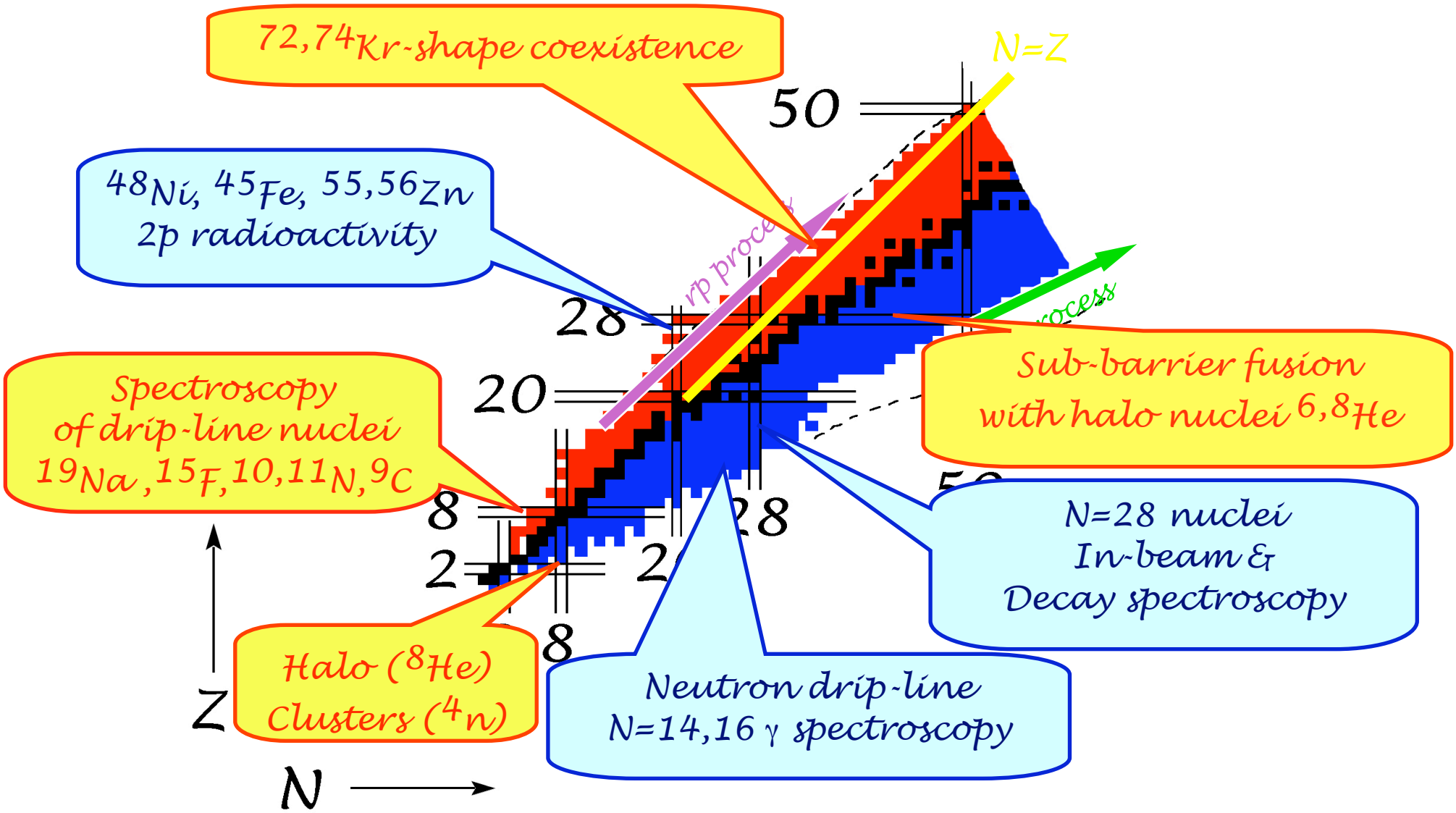


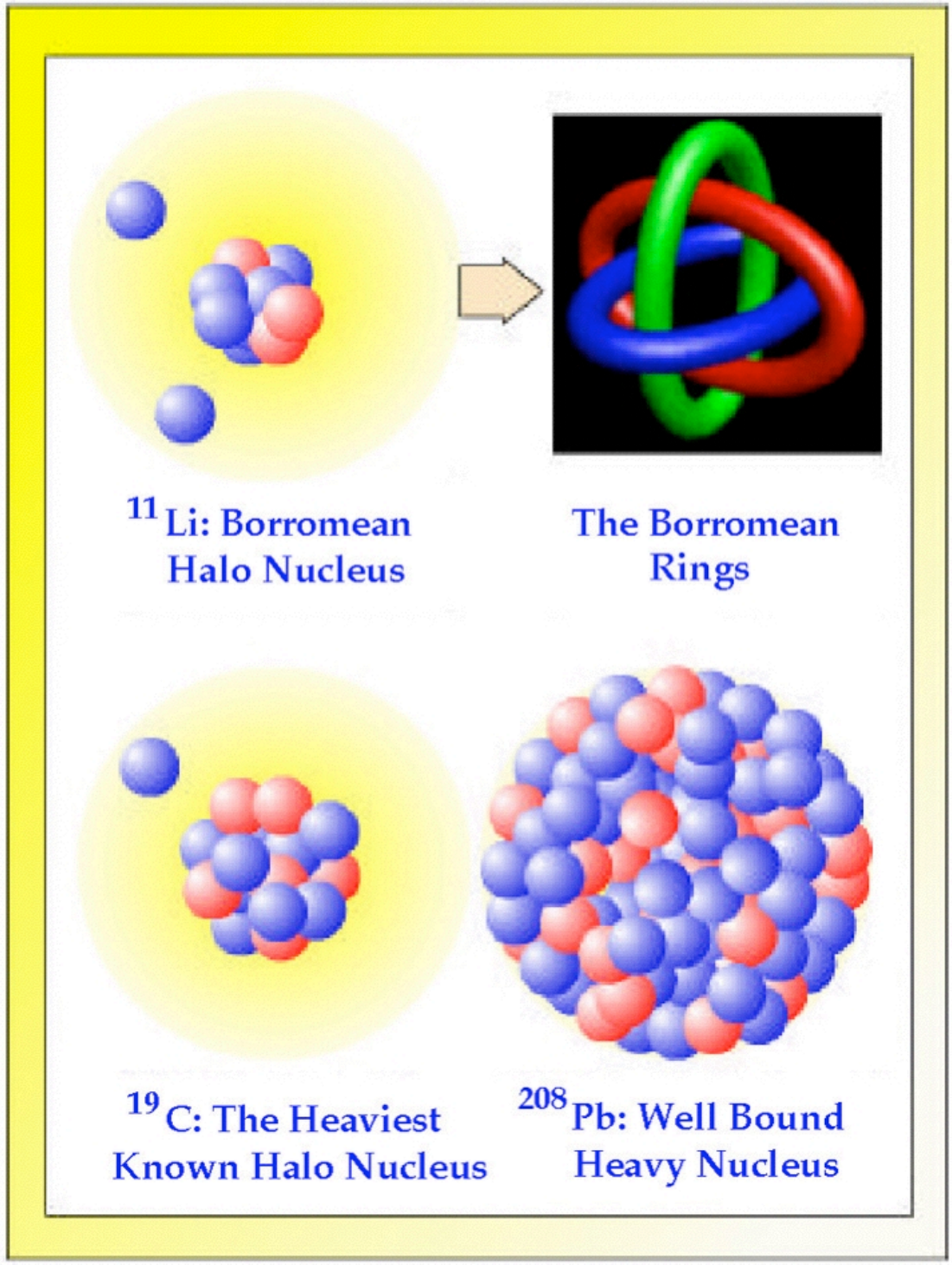
Used for experiments

Ion	I (pps) and E
$^{6}He^{1+}$	$3x10^{7}$ 5 AMeV
$^{8}He^{1+}$, $^{8}He^{2+}$	$5x10^{4}$, $1.3x10^{4}$ 3.4, 15.4 AMeV
$^{18}Ne^{4+}$	$2x10^{6}$ 7 AMeV
$^{76}Kr^{11+}$, $^{74}Kr^{11+}$	$5x10^{5}$, $1x10^{4}$ 4.3 AMeV

PURE RI BEAMS !

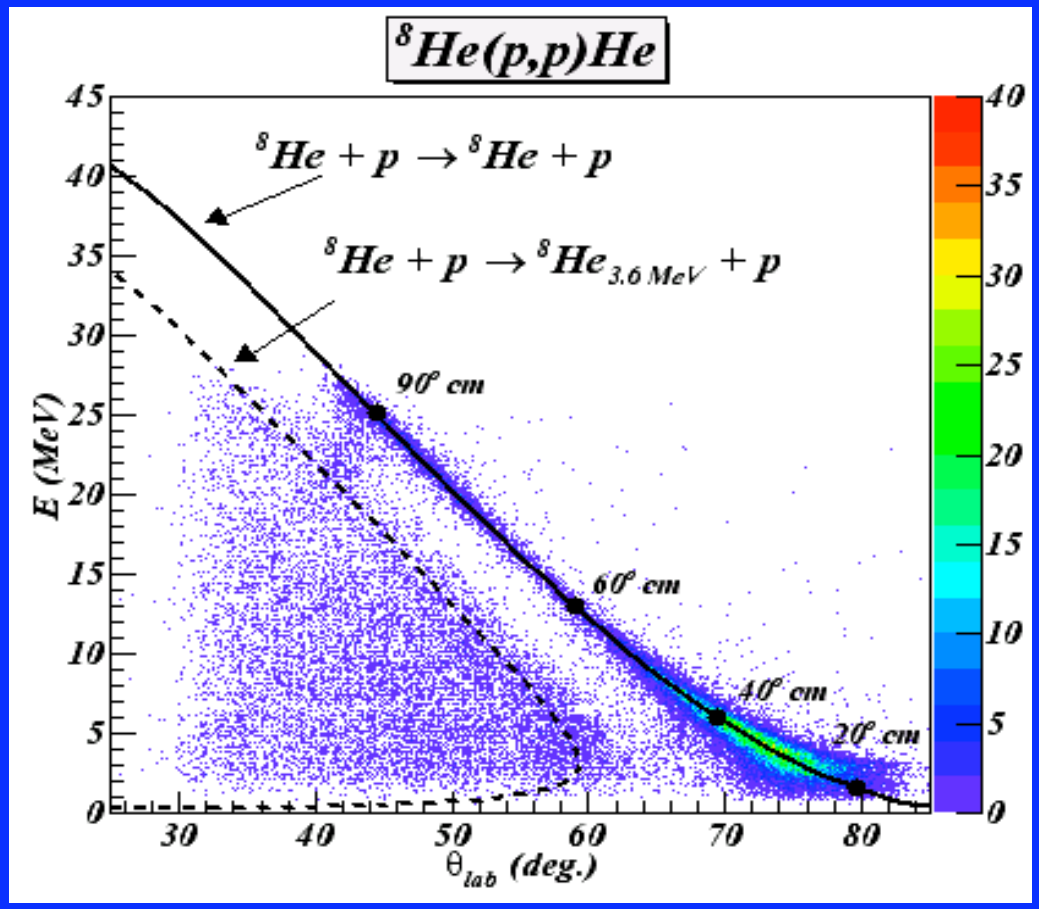
Highlights of GANIL/SPIRAL Physics

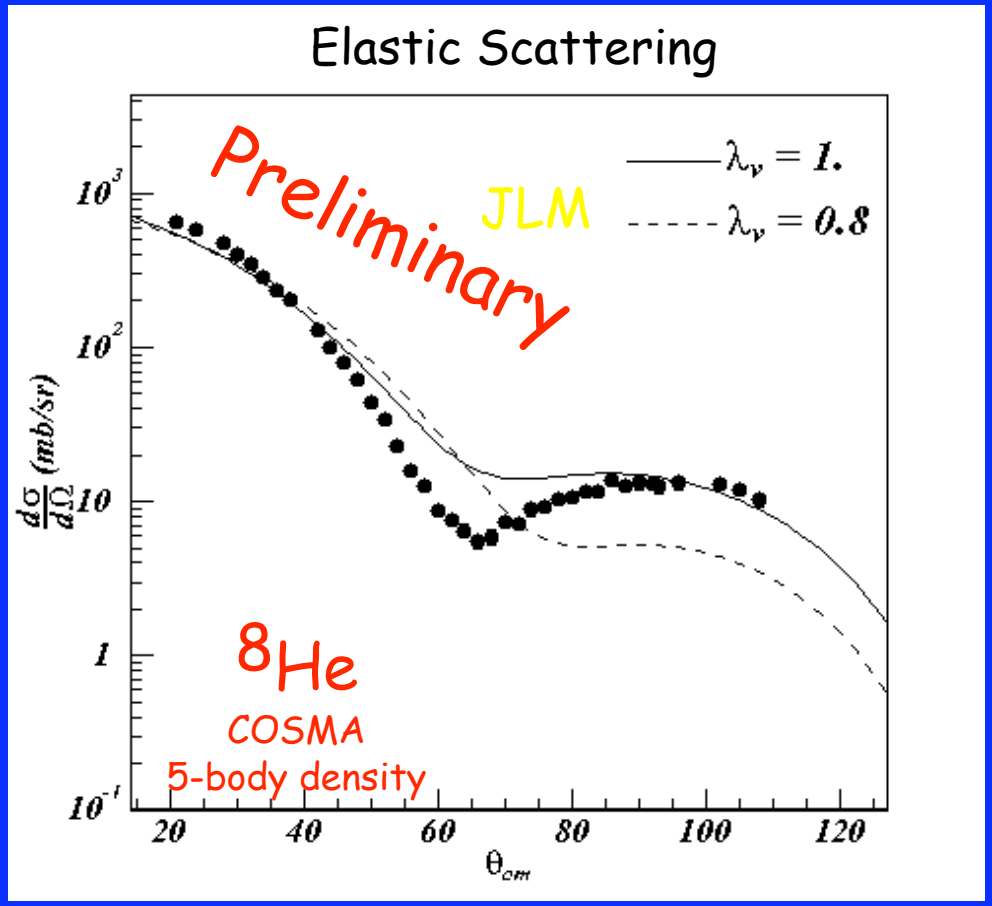



^{11}Li: Borromean Halo Nucleus
The Borromean Rings
^{19}C: The Heaviest Known Halo Nucleus
^{208}Pb: Well Bound Heavy Nucleus

Elastic & Inelastic Scattering of ^{8}He @ 15.6 AMeV

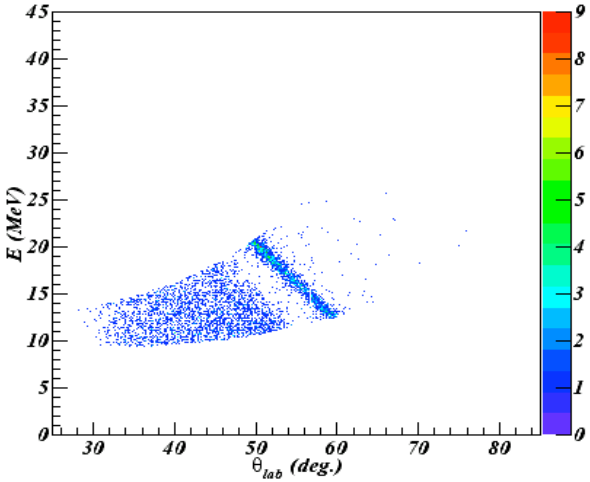
F. Skaza, MUST Collaboration

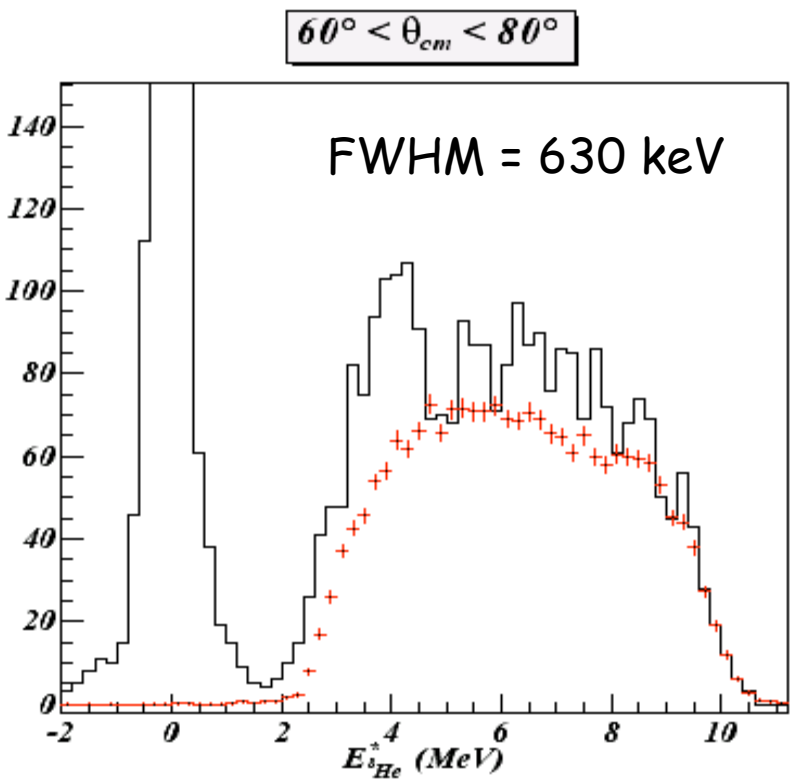


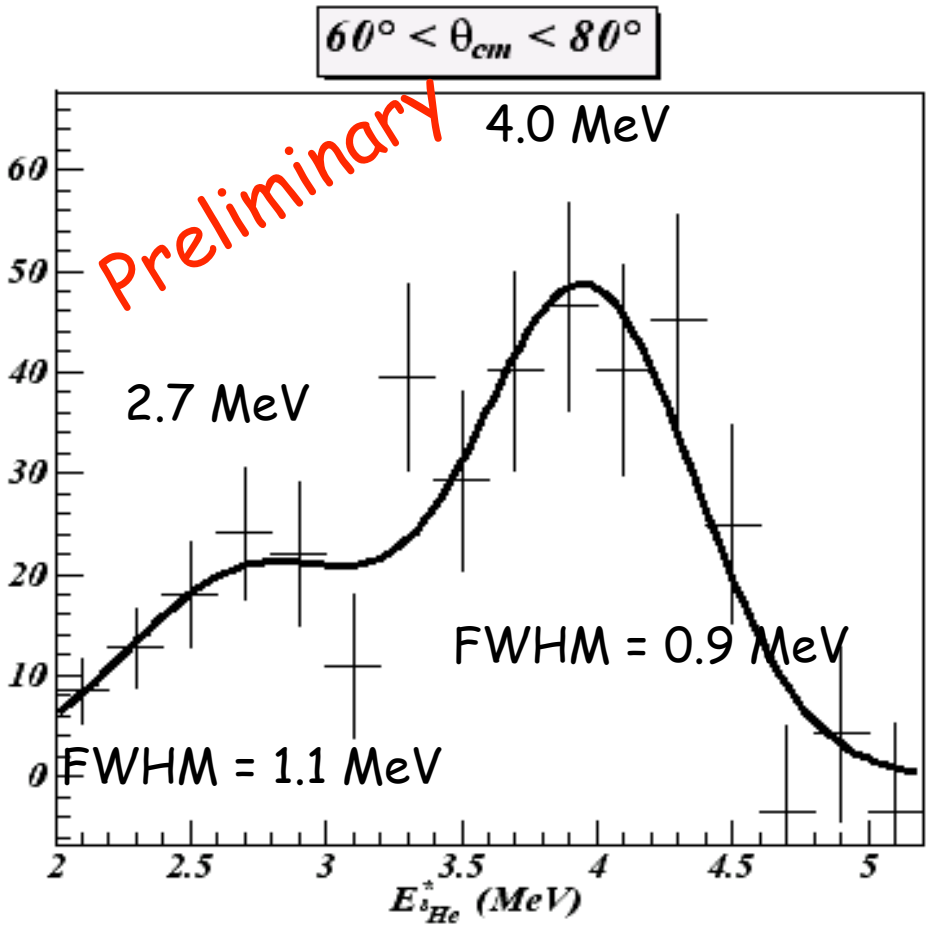


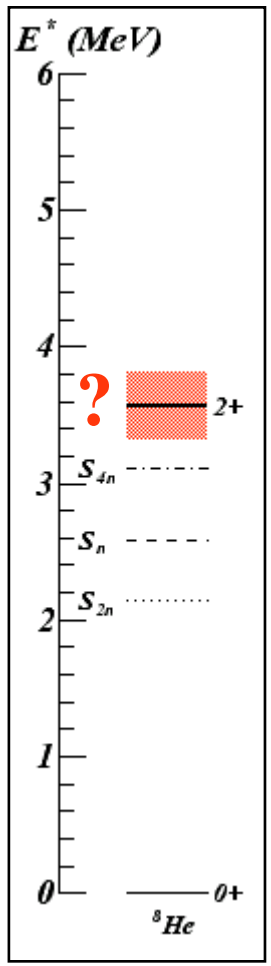
COSMA : M.V. Zhukov et al. PRC 50 (1994) R1

^{8}He excitation energy spectrum from inelastic scattering



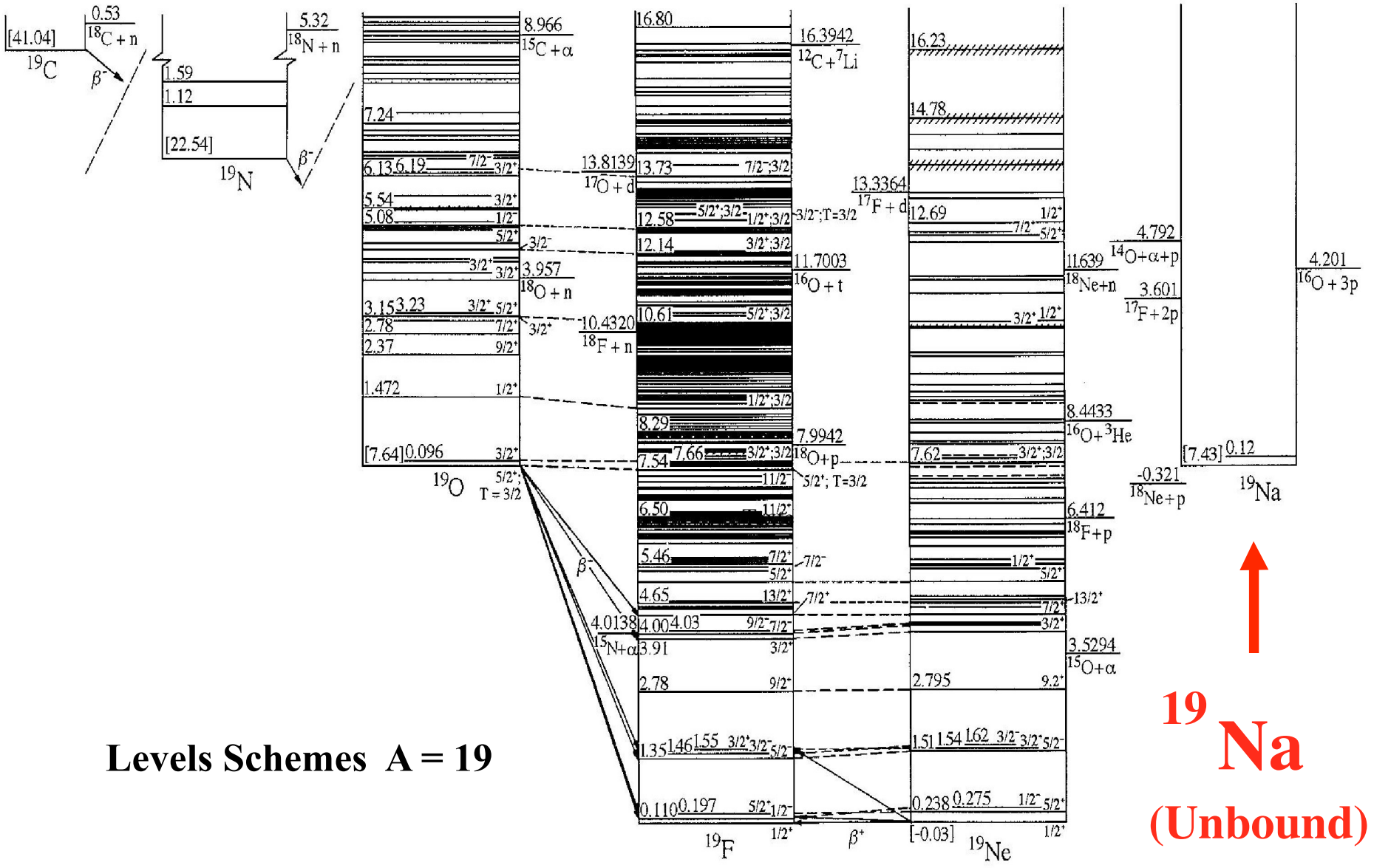




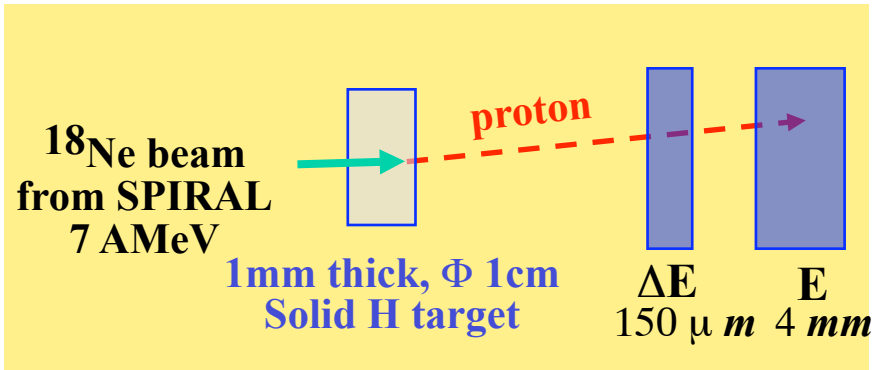


Two excited states observed ?

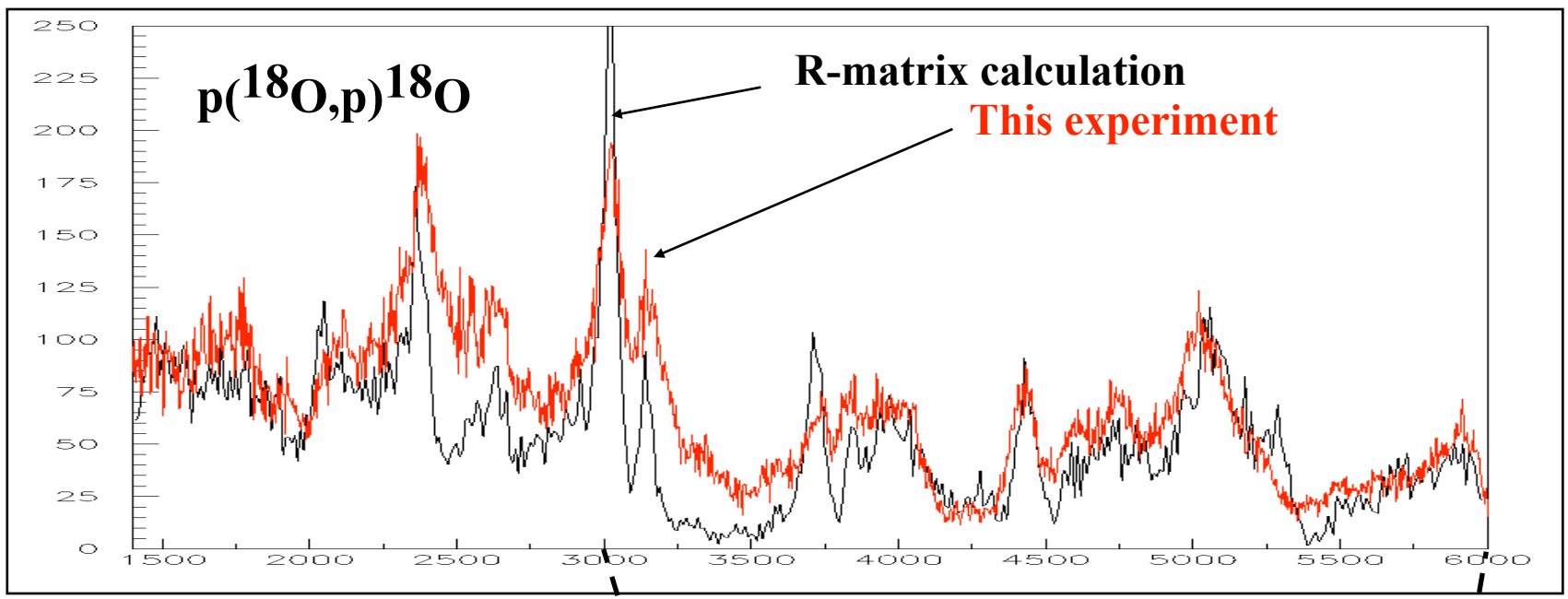
F. Skaza, MUST Collaboration


[41.04]
19C
0.53
18C + n
β-
1.59
1.12
[22.54]
19N
5.32
18N + n
β-
19O
8.966
15C + α
13.8139
17O + d
3.957
18O + n
10.4320
18F + n
7.9942
18O + p
5/2+; T = 3/2
19F
16.80
16.3942
12C + 7Li
11.7003
16O + t
3/2-;T=3/2
β-
4.0138
15N+α
β+
19Ne
16.23
14.78
13.3364
17F + d
11.639
18Ne+n
8.4433
16O+3He
6.412
18F+p
3.5294
15O+α
-0.321
18Ne+p
4.792
14O+α+p
3.601
17F+2p
4.201
16O + 3p
[7.43]
19Na
19 Na
(Unbound)
Levels Schemes A = 19

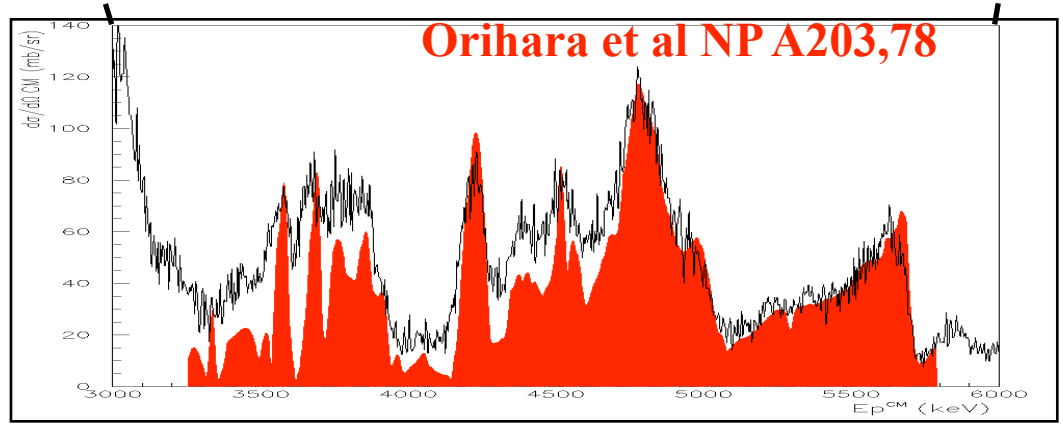
Elastic resonant scattering



Calibration

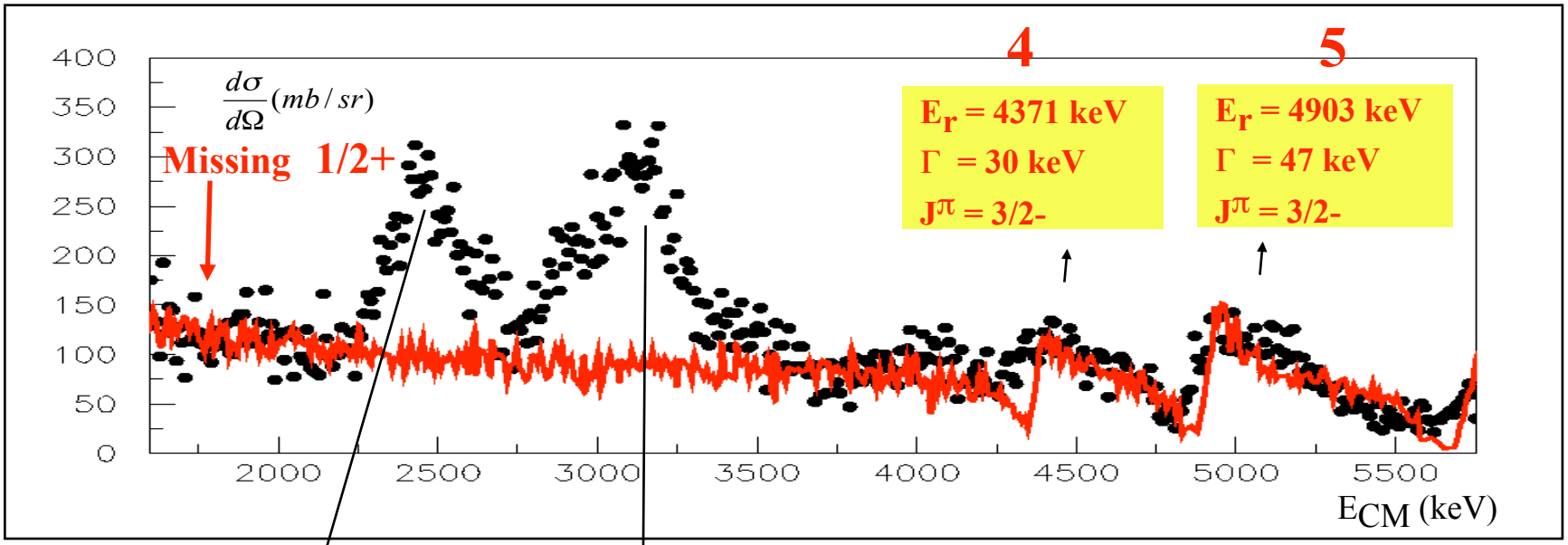


- Comparison with R-Matrix Calculation
- Comparison with Orihara et al
- Target Thickness = 1100 μm
- Resolution 40 keV
- Good homogeneity of the target
- Energy cut



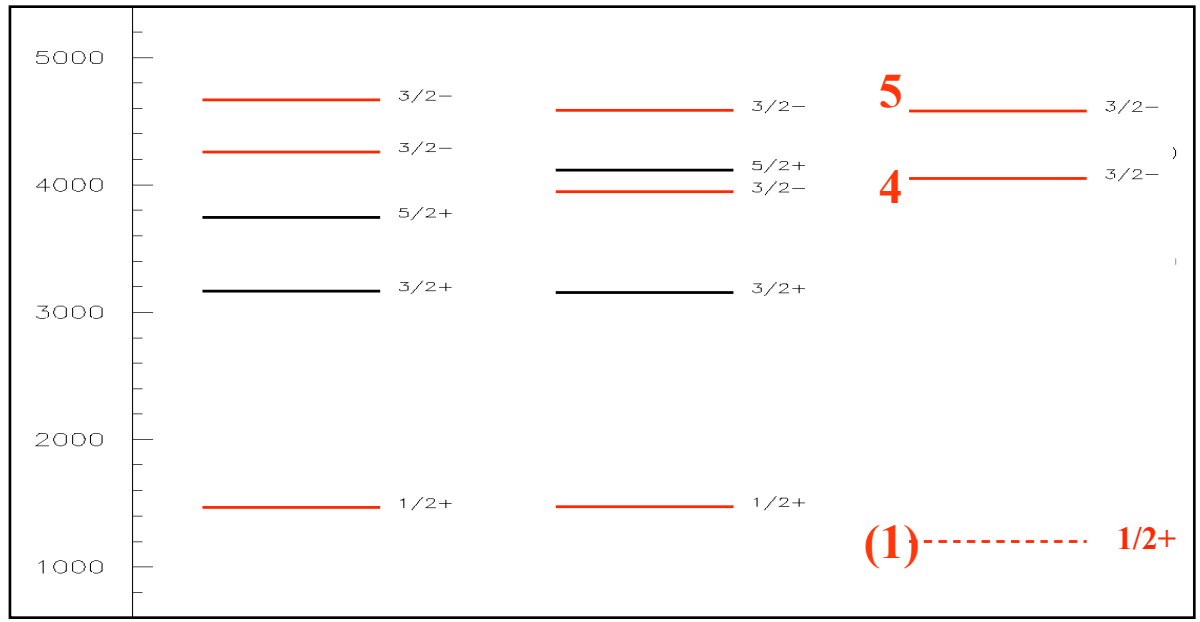
^{18}Ne+p → ^{19}Na*

Elastic scattering



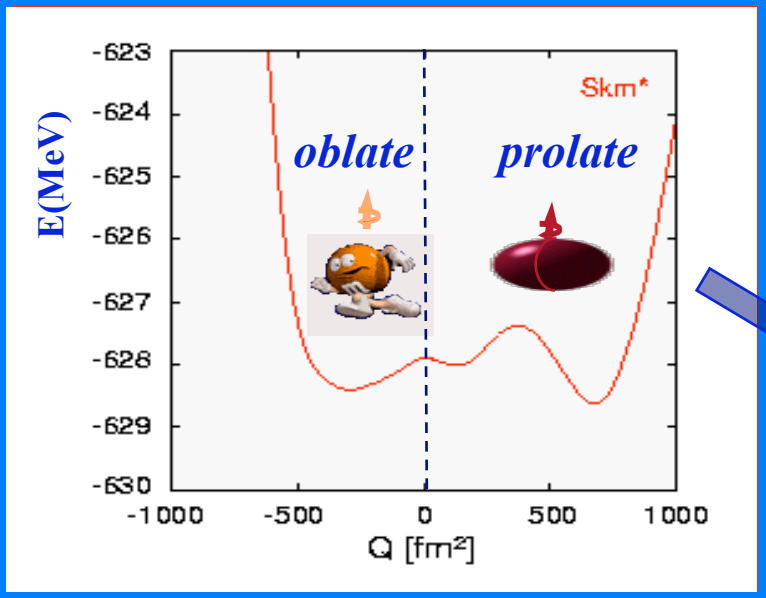
2-proton decay

F. De Oliveira et al.

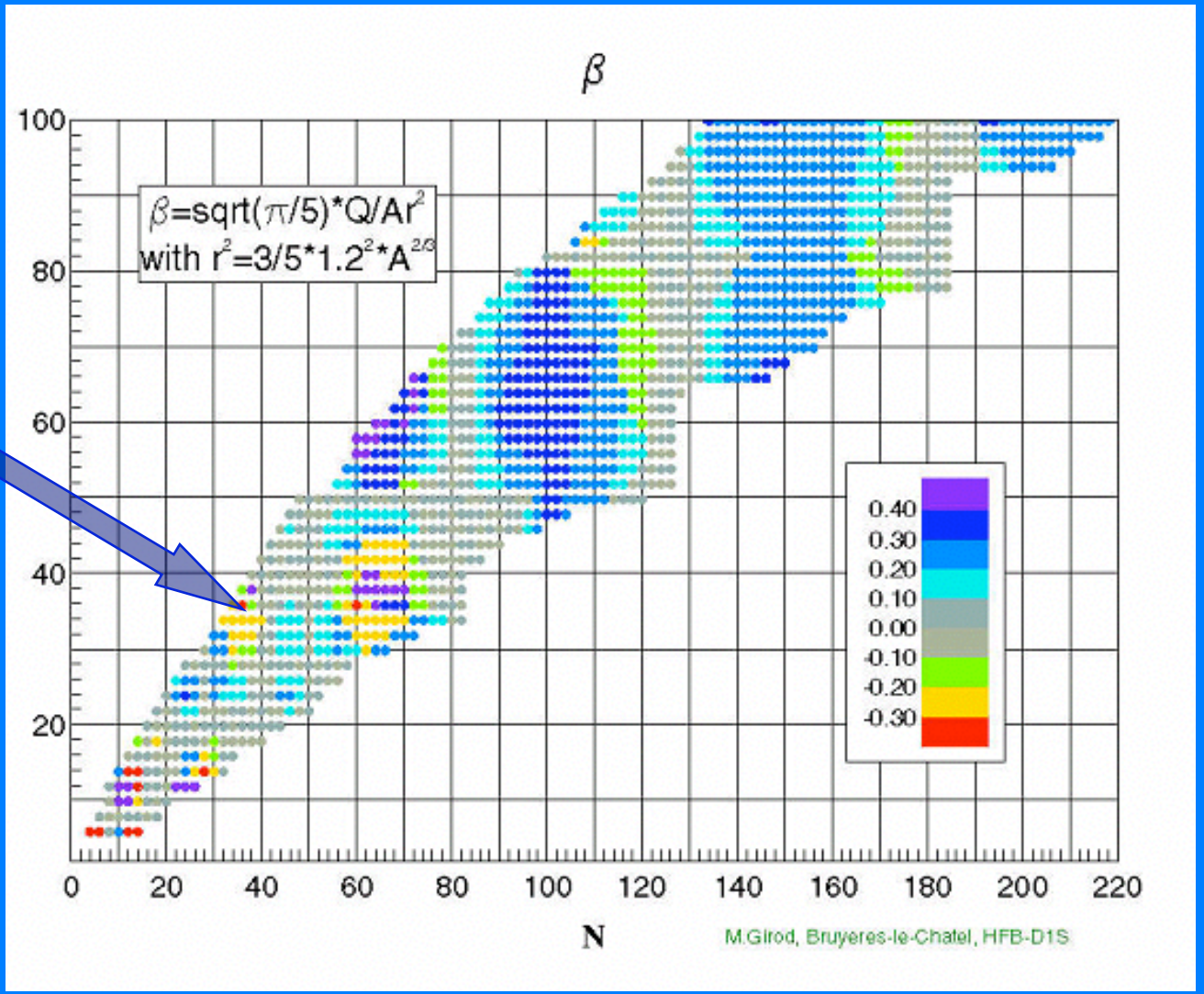


Vicinity of the N=Z line: shape coexistence

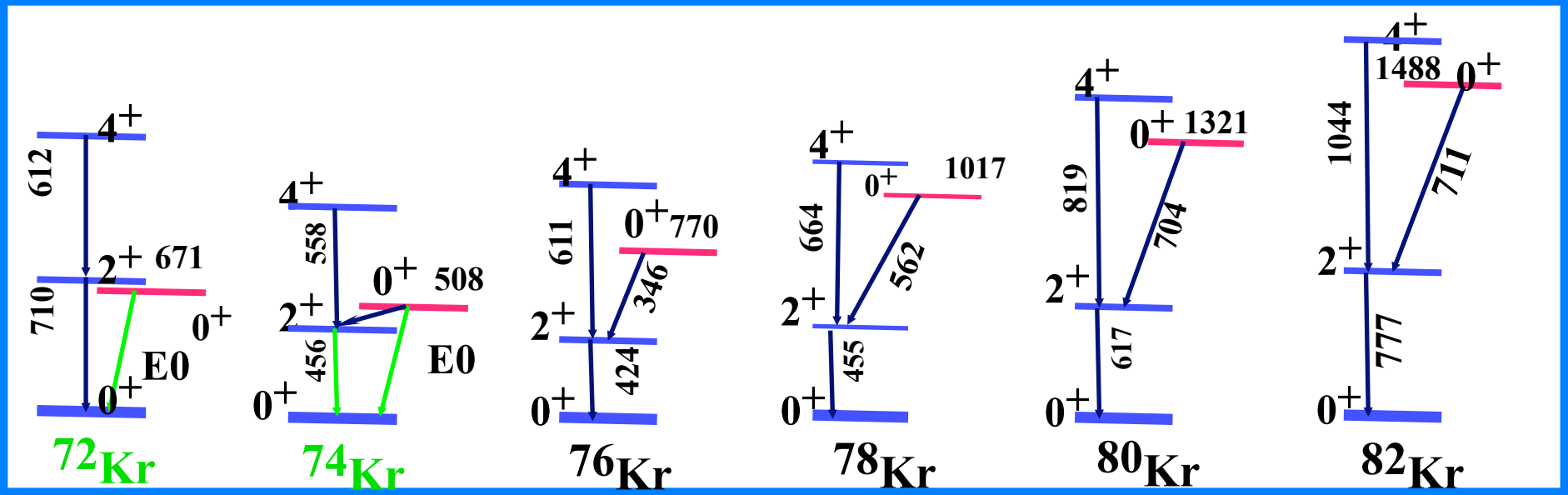
^{74}Kr

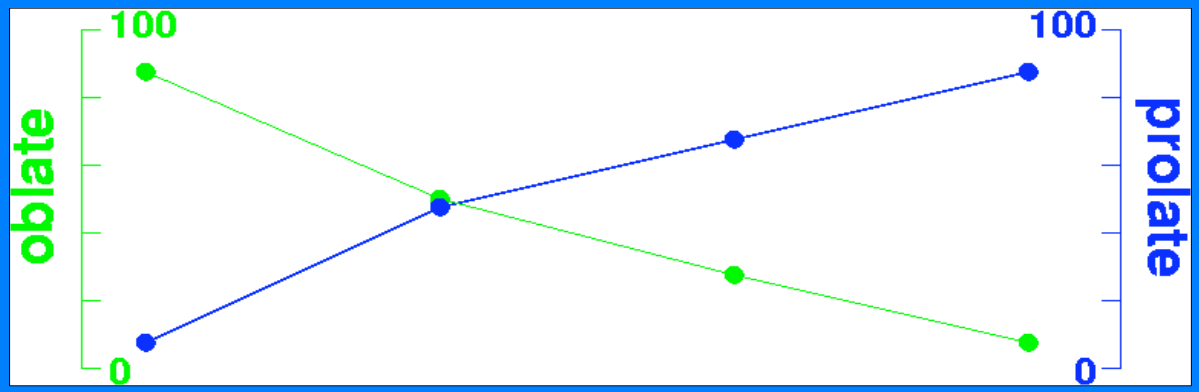


(HF+BCS calculations - F. Becker, P.Bonche, P.H. Heenen)



Shape coexistence in ^{72,74}Kr

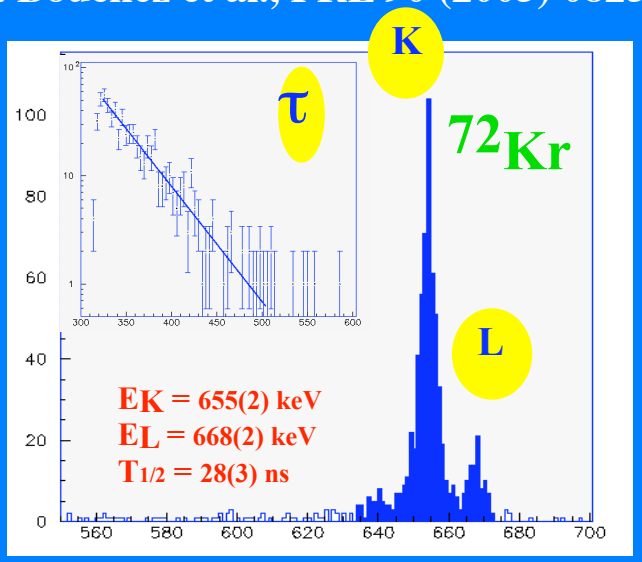




Mixing of the ground state

Oblate g.s. in N=Z nucleus

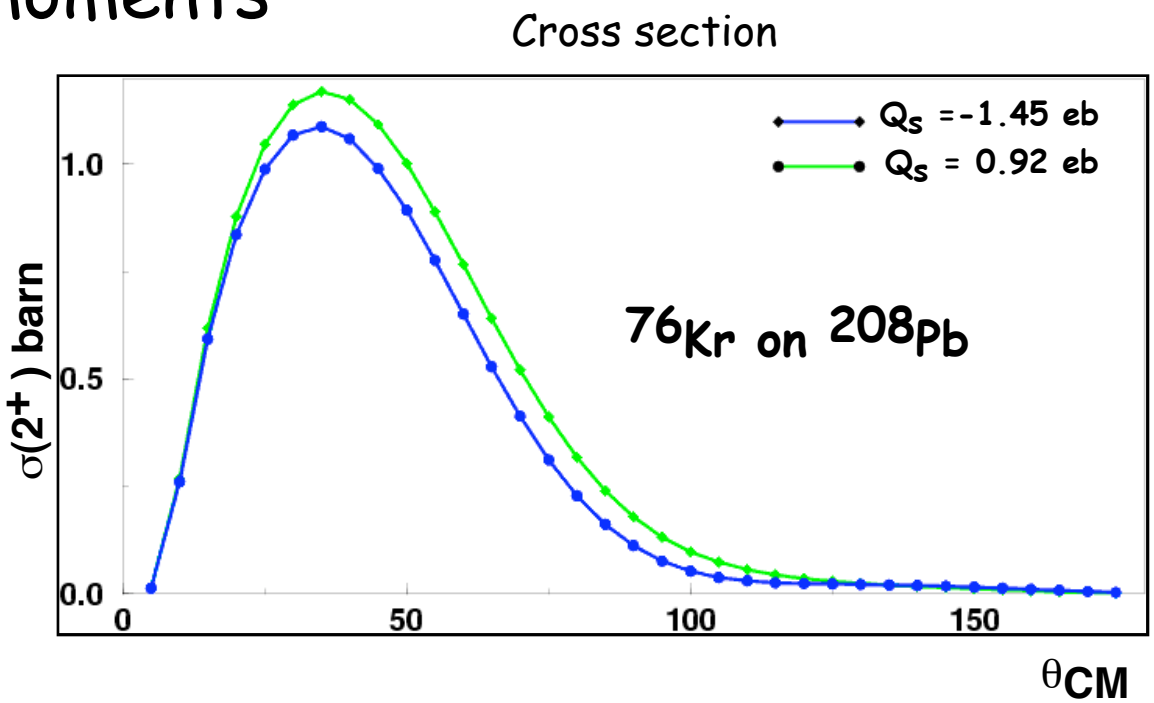
E. Bouchez et al., PRL 90 (2003) 082502



Eelectron(keV)

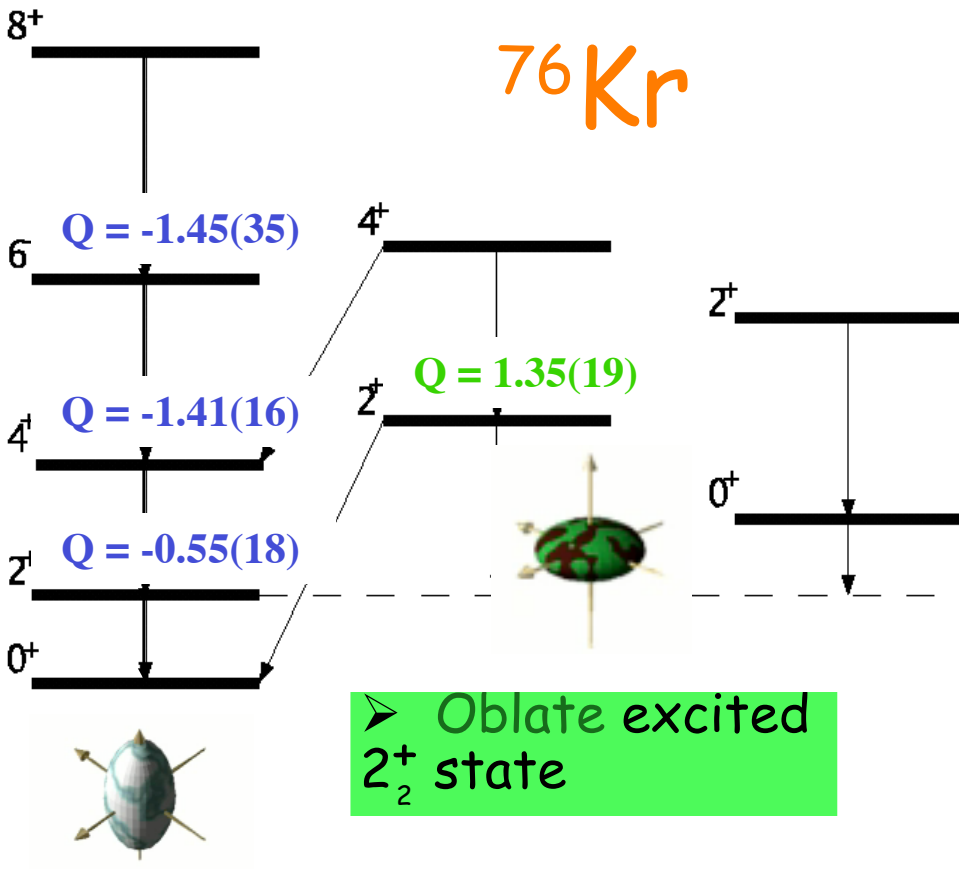
Coulomb excitation with SPIRAL Beams

- Collective states : yrast and non-yrast
- Transition probabilities B(E2)
  - Absolute value of deformation
- Static quadrupole moments
  - Oblate / Prolate ?

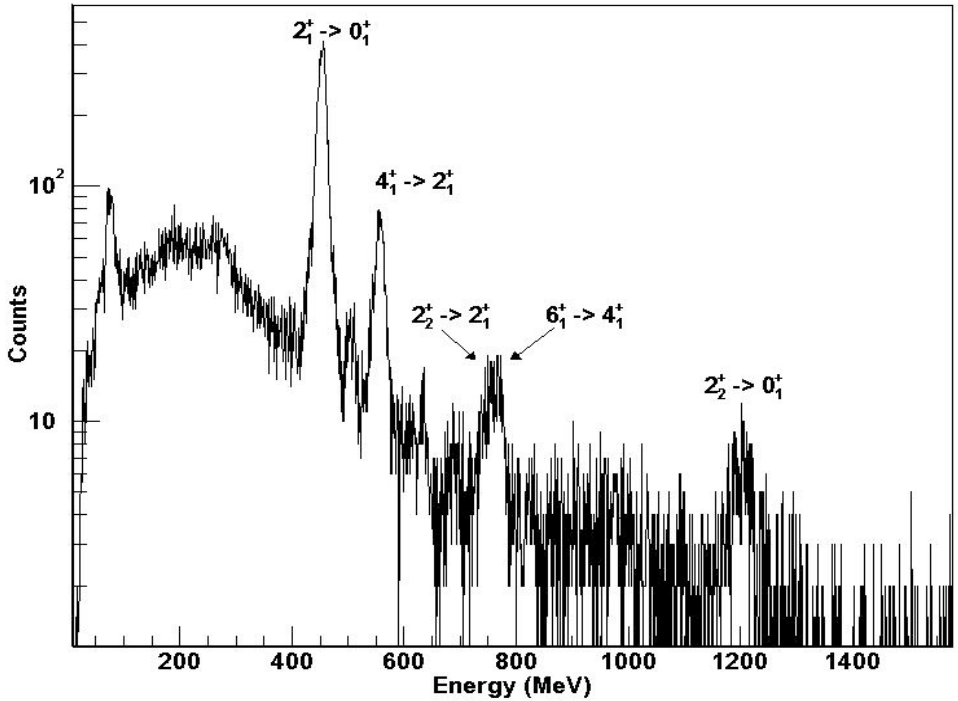


^{74}Kr(3.5 AMeV) + ^{208}Pb

^{76}Kr



➢ Oblate excited 2^+_2 state



On-line Doppler corrected spectrum

➢ gs band prolate: first measurement

E. Buchez et al.

First SPIRAL Experiments

- **Search for the ^{4}n resonances with the ^{8}He beam**
- **Structure of halo nuclei**

  Elastic, inelastic scattering and transfer reactions with ^{8}He
- **Sub-barrier fusion with halo nuclei**

  γ spectroscopy with the ^{6}He beam
- **Structure of proton unbound nuclei**

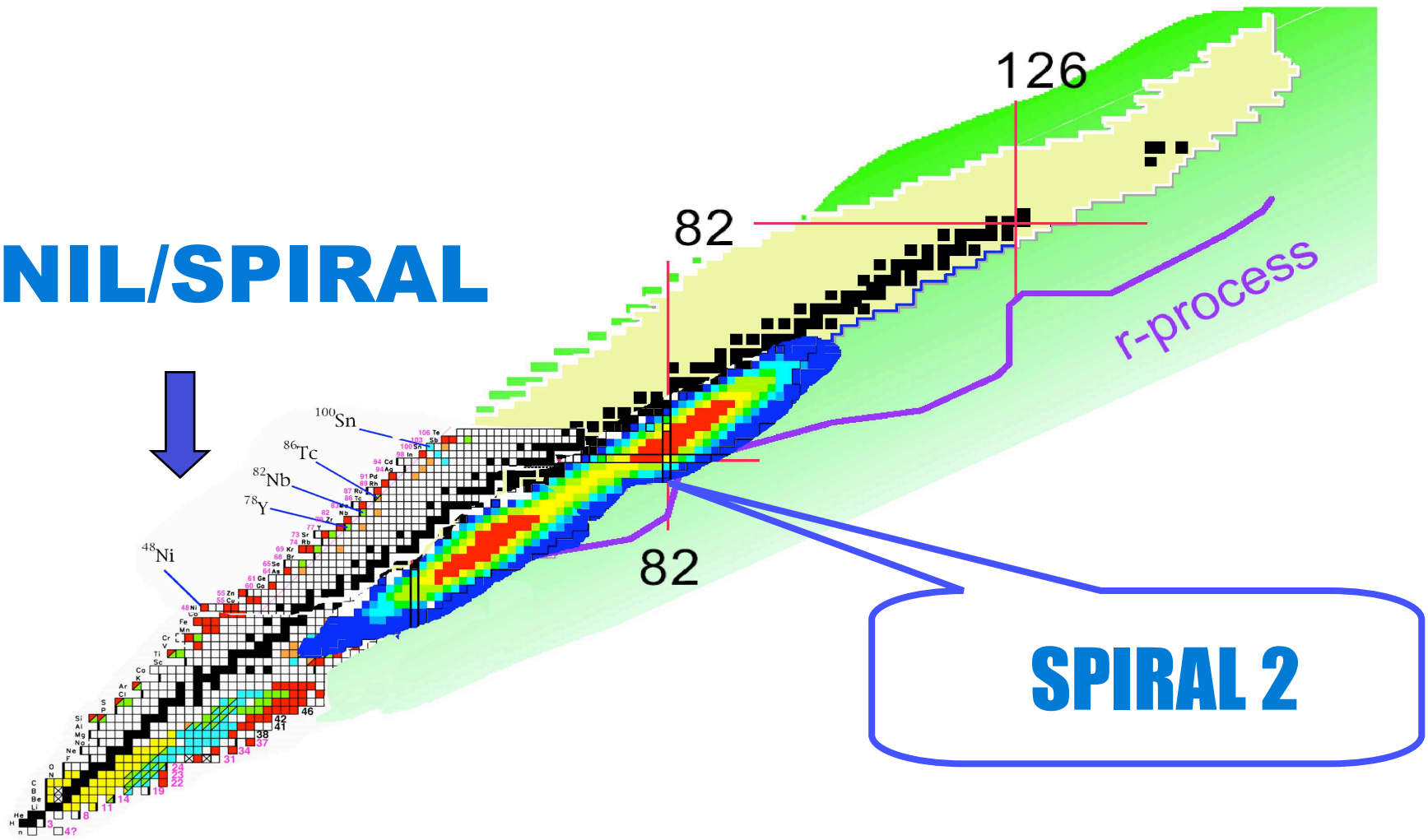
  ^{19}Na excited states from ^{18}Ne+p resonant elastic scattering
- **Study of K-isomers in the Po isotopes**

  Fusion- evaporation + in-beam γ spectroscopy with the ^{8}He beam
- **Structure of very neutron deficient A=130 nuclei**

  Fusion-evaporation + in-beam γ spectroscopy with the ^{76}Kr beam
- ***Low-energy Coulomb excitation of light Kr isotopes.***

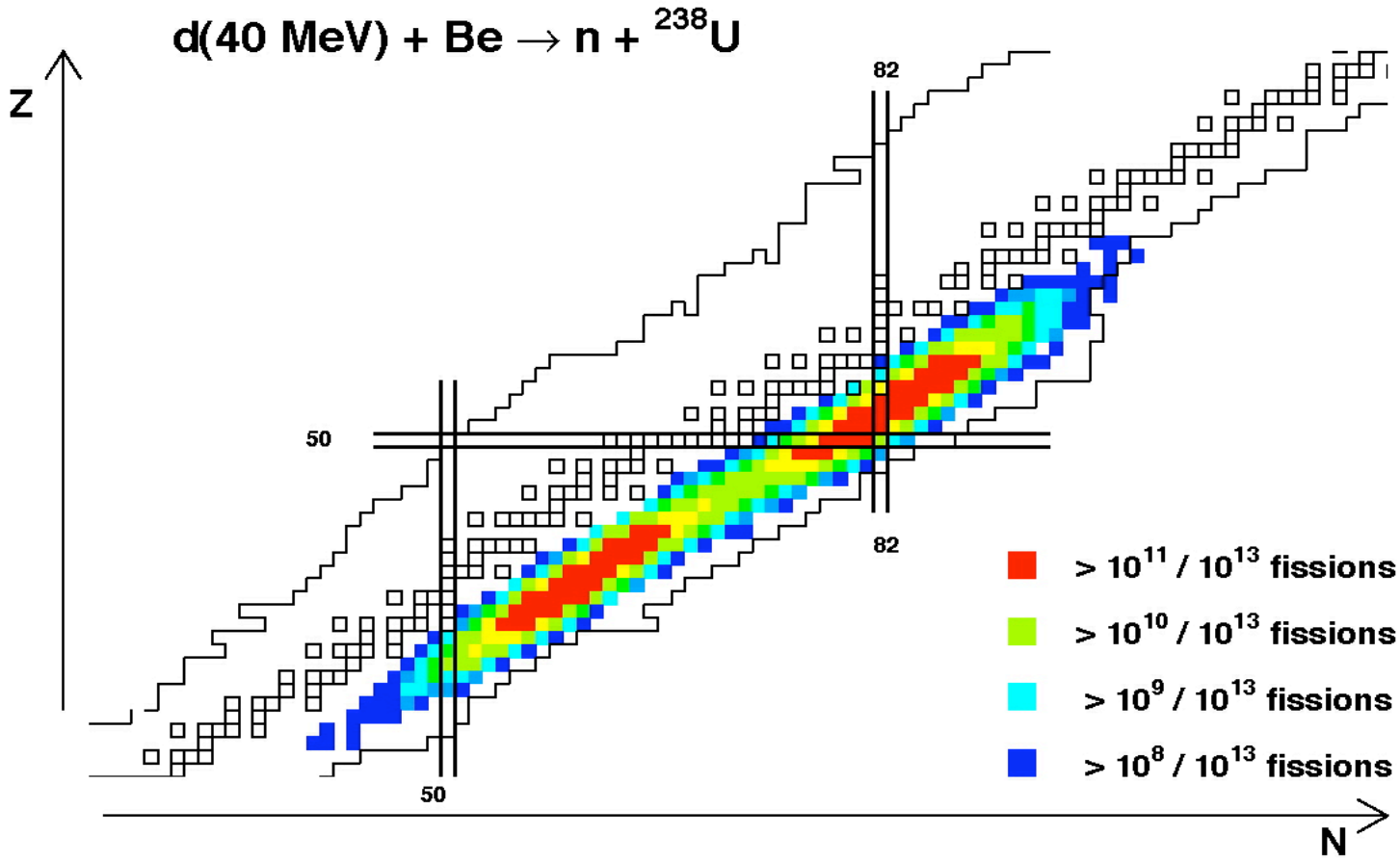
Motivation for the SPIRAL 2 project

GANIL/SPIRAL



SPIRAL 2 - Performences

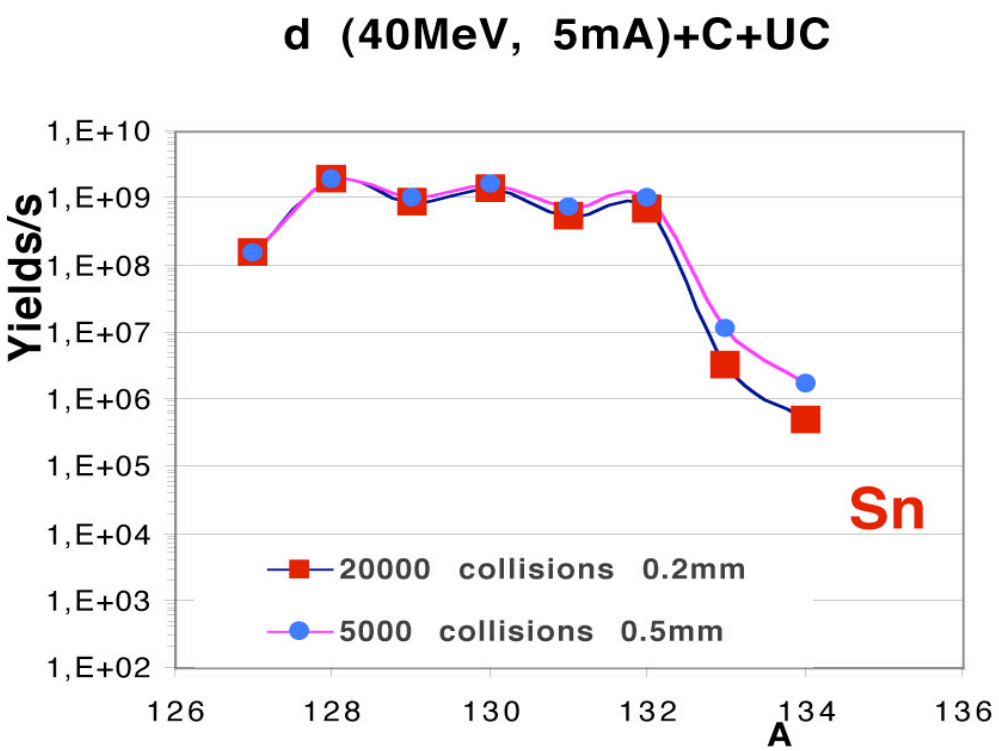
Production yields in the UC_2 target

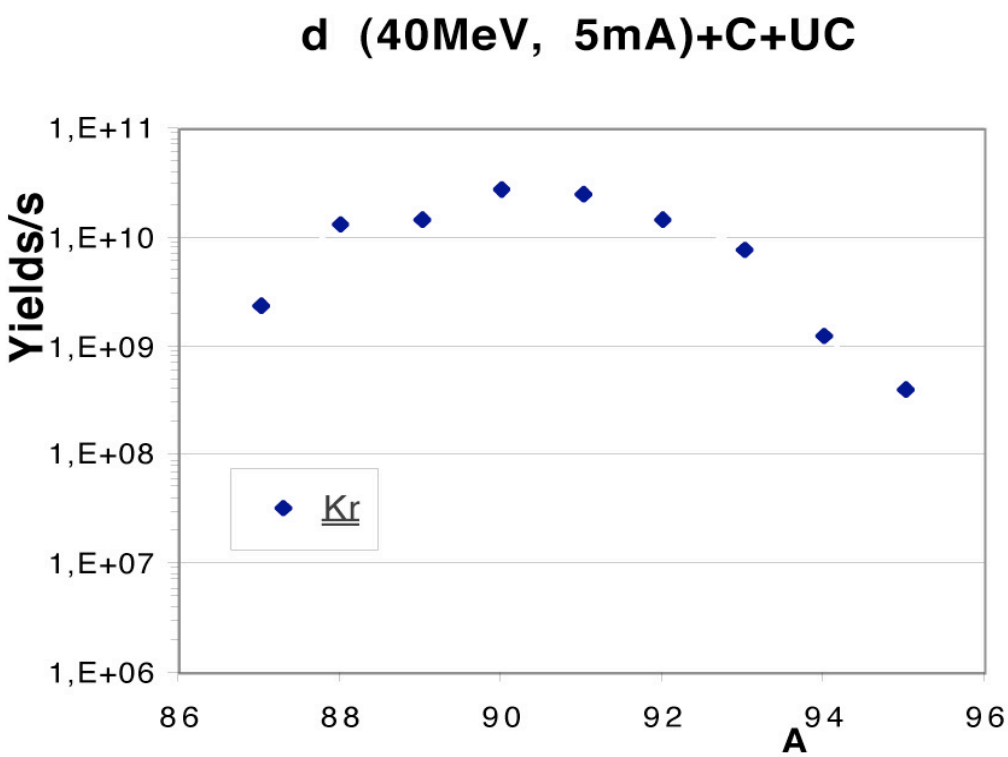


J. Benlliure et al.

SPIRAL 2 - Performences

Expected yields after diffusion, effusion, ionisation and acceleration





Possible (relatively easy) beams:

Cu, Zn, As, Se, Br, Kr, Rb, Ag, Cd, In, Sb, I, Xe, Cs

SPIRAL II - Performences

Production of N=Z, light and heavy nuclei

p,d,HI → Thick target

Fusion-evaporation and transfer reactions
Residues produced by thick target method
(like at GSI mass separator)

Example: $^{100}Sn^{1+}$ 1/s

HI → Recoil Separator

Fusion-evaporation residues produced
by thin target method (In-flight)

Ex: $^{24}Mg(25p\mu A)+^{58}Ni->^{80}Zr^{1+}$ $3x10^4$/s

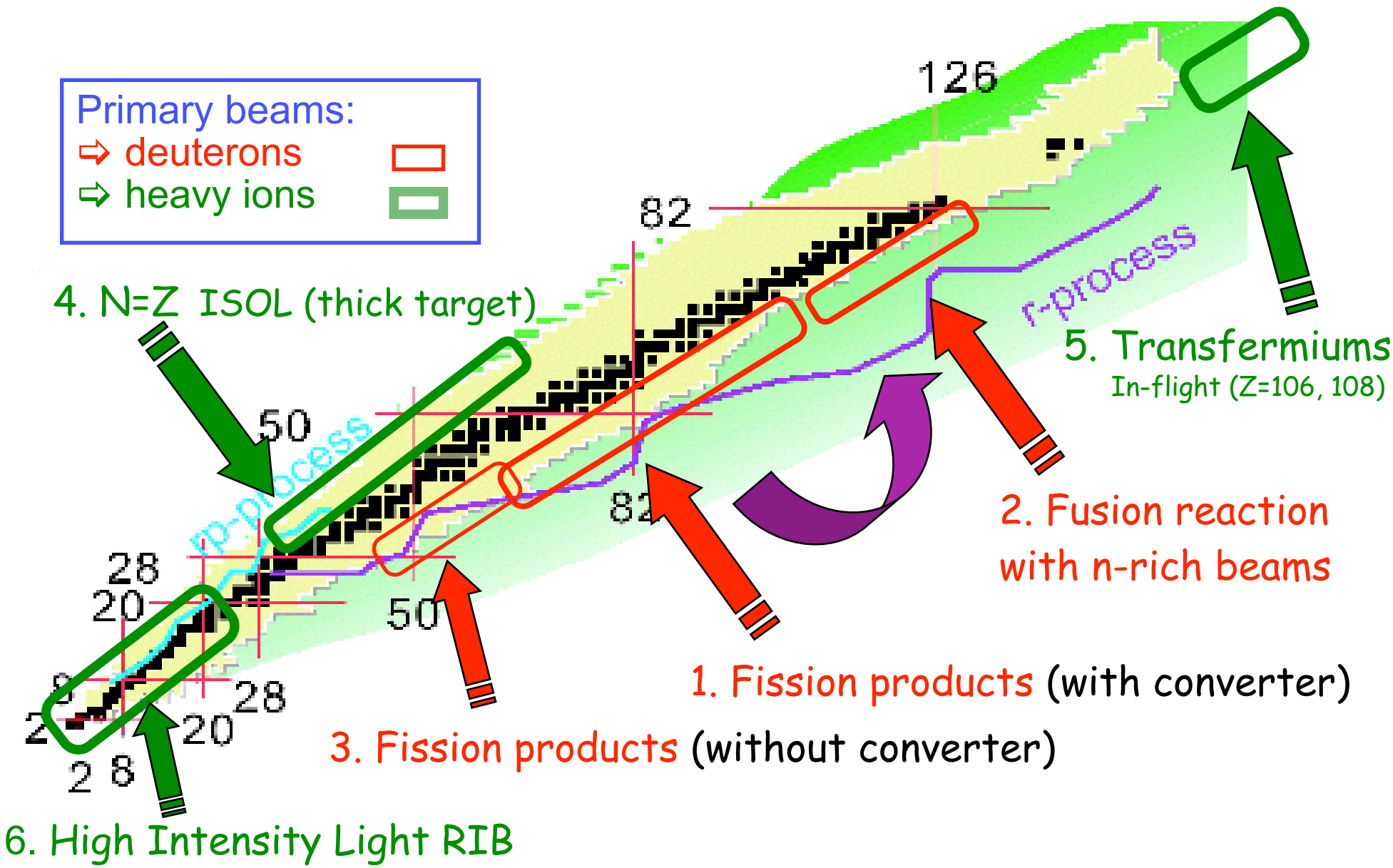
But also:

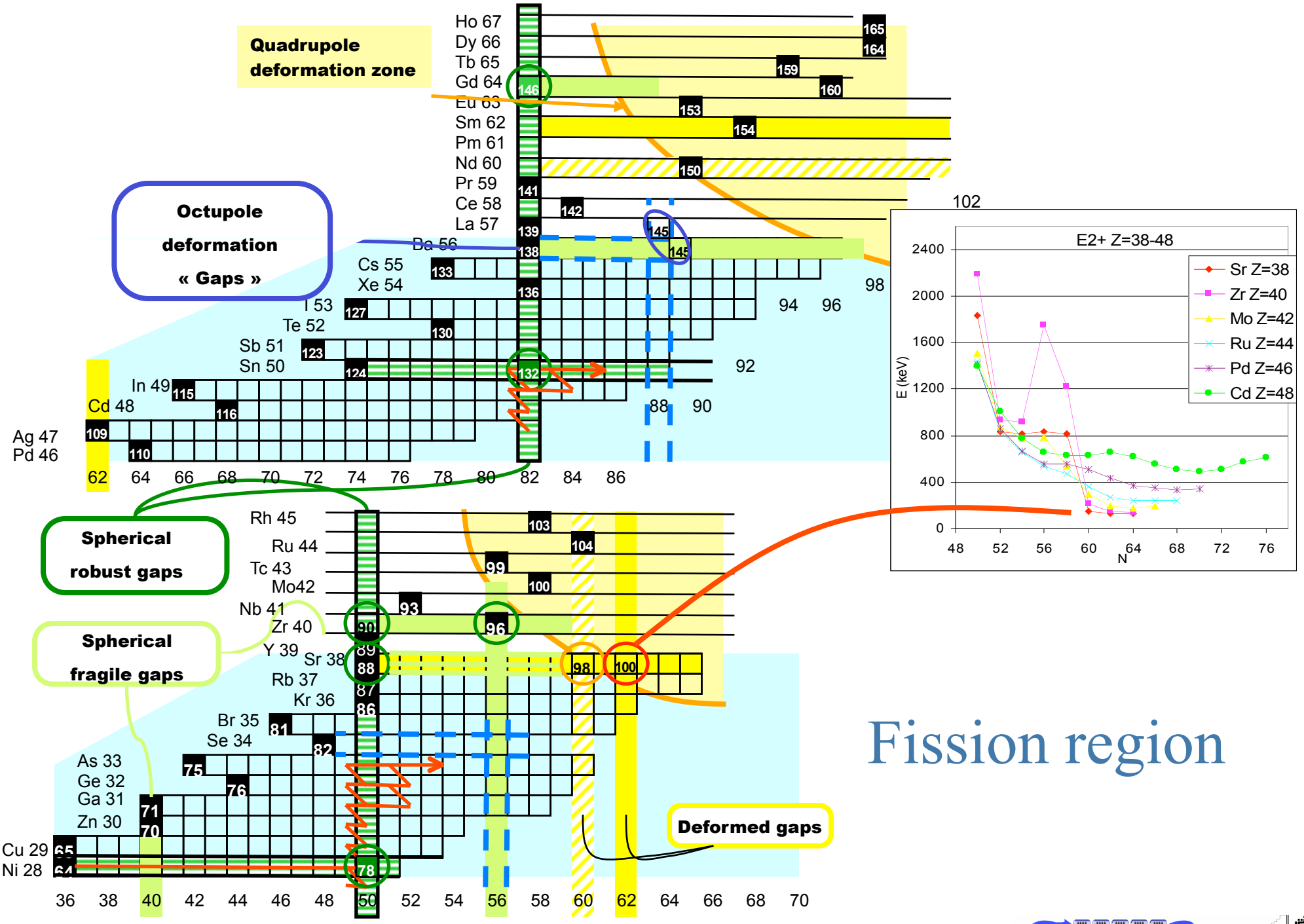
$^{9}Be(n,\alpha)^{6}He$ - 10^{13} pps
$^{14}N(d,n)^{15}O$ - 10^{12} pps

Detailed study being done presently…

GANIL

Regions of the Chart of Nuclei Accesible with SPIRAL 2 beams



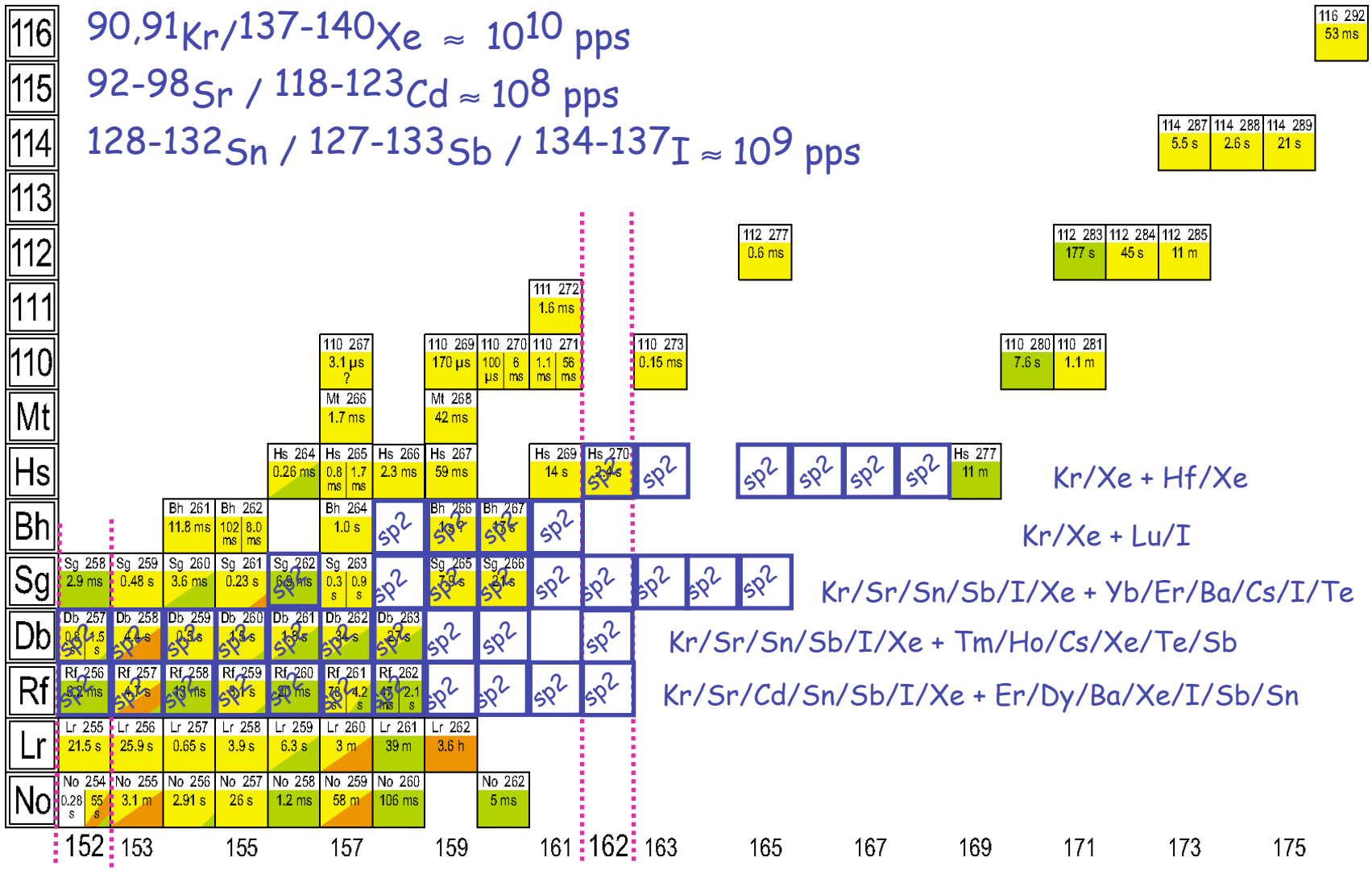


Fission region

D. Verney

Spiral2

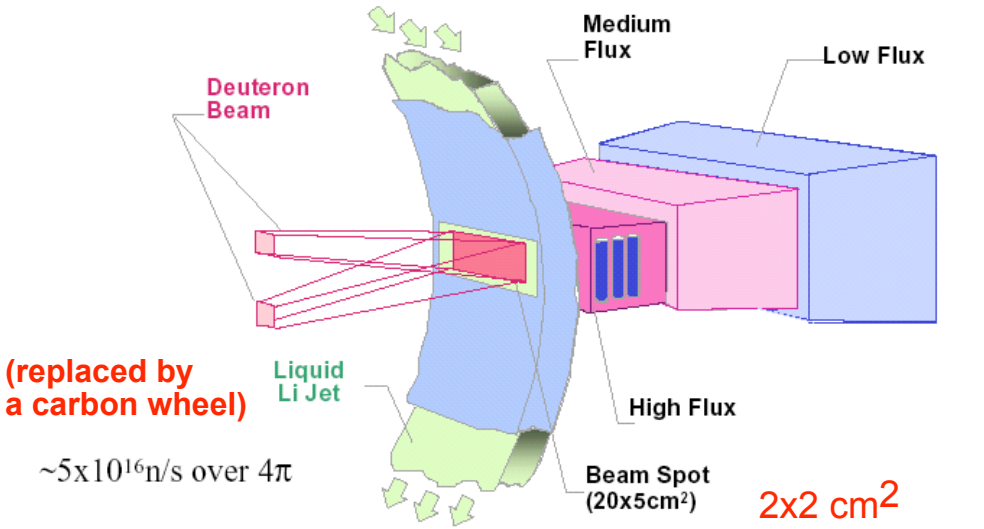
Study of Heavy Nuclei with SPIRAL 2

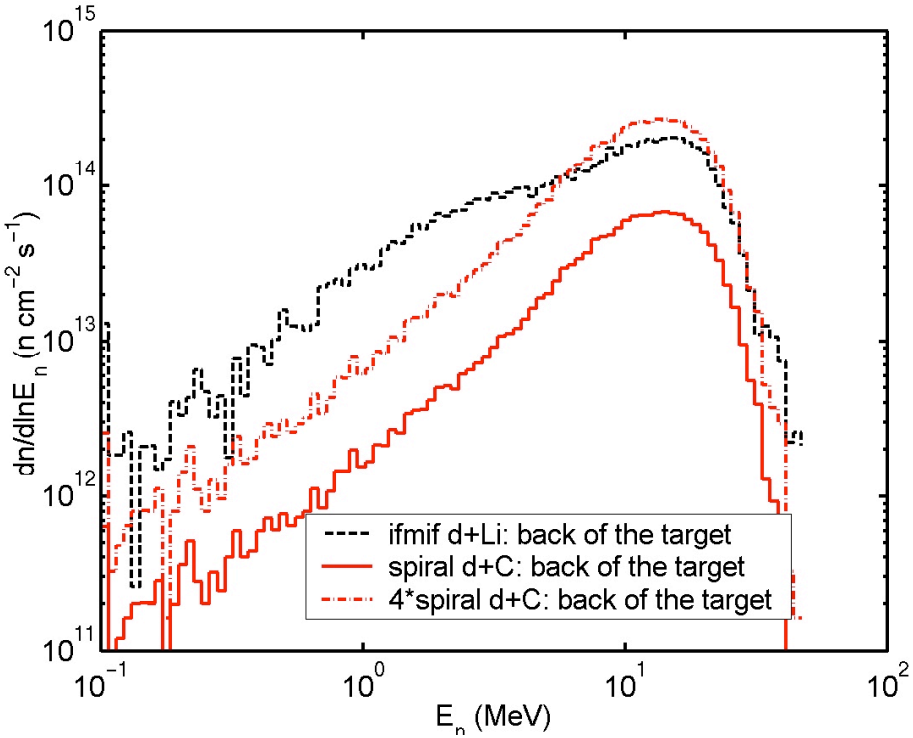


Ch. Stodel, GANIL, Caen, France

Neutrons for science - NFS

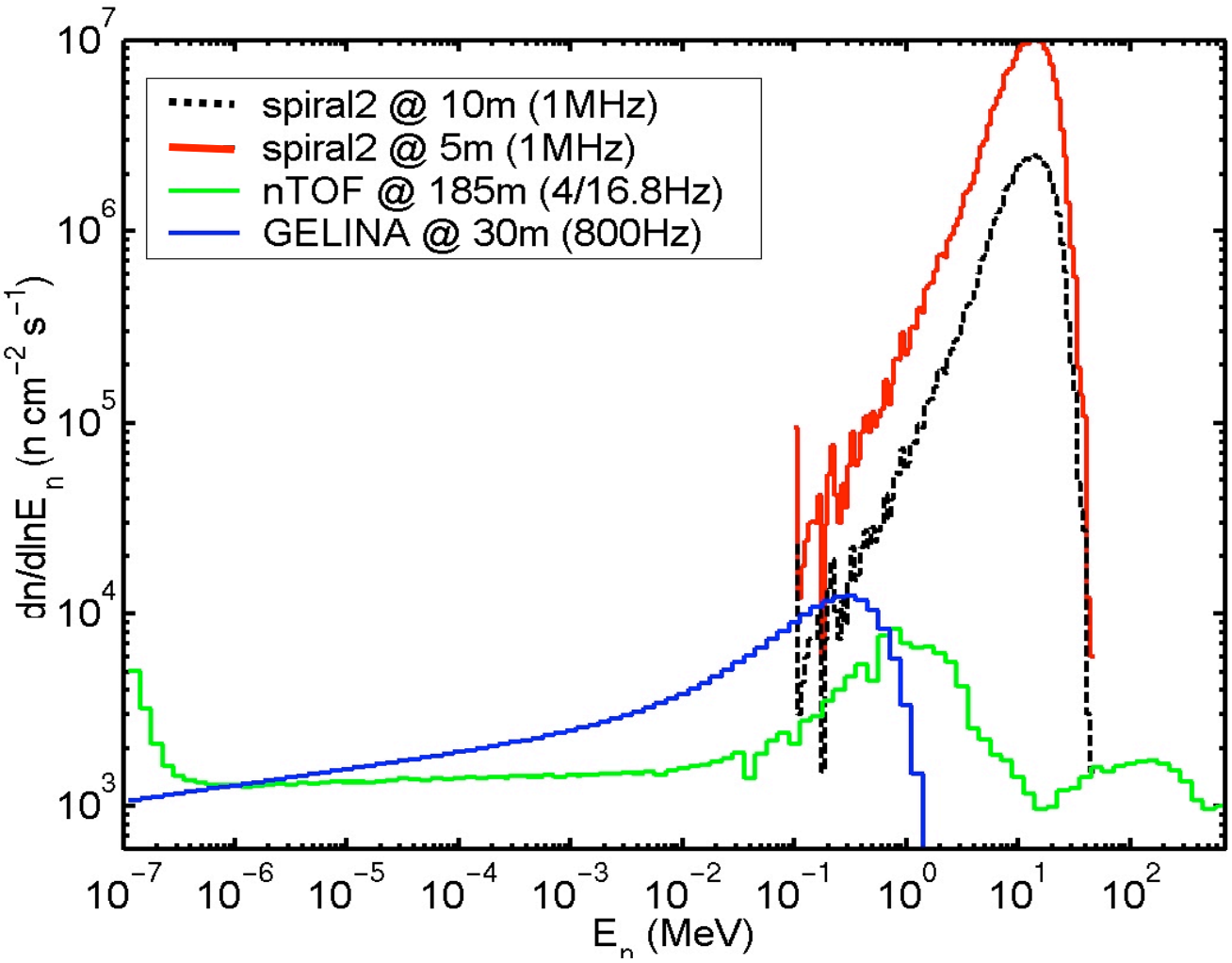
« IFMIF like » neutron source: High intensity neutron source for material science (for fusion reactors like ITER).





Spiral 2 should be able to provide comparable flux densities (~ 5 lower) and similar neutron energy spectrum.

NFS - "NTOF - like"



The time structure of the LINAG accelerator gives a neutron energy resolution of 1% for only 10 m ToF

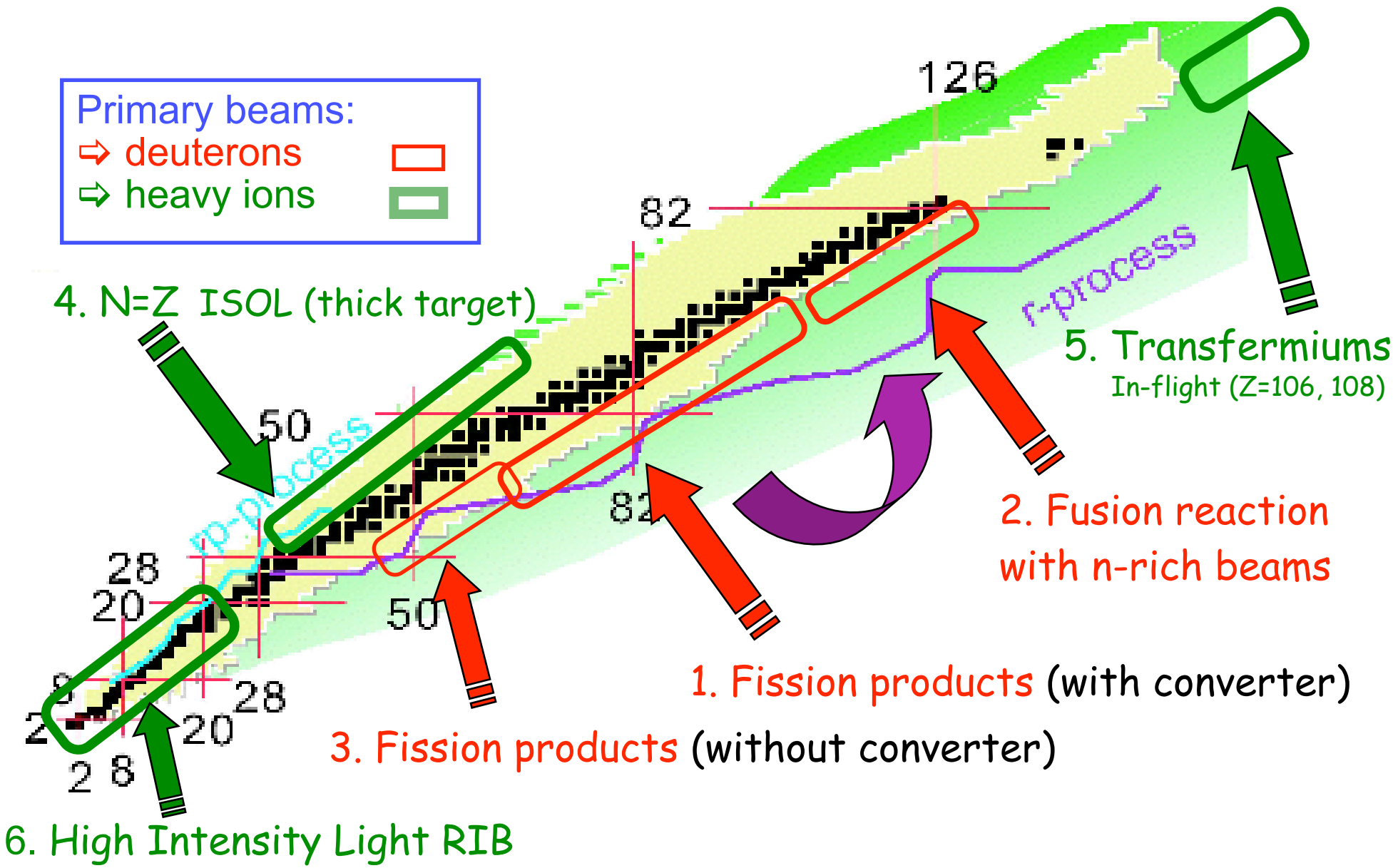
1 MHz and 50μA

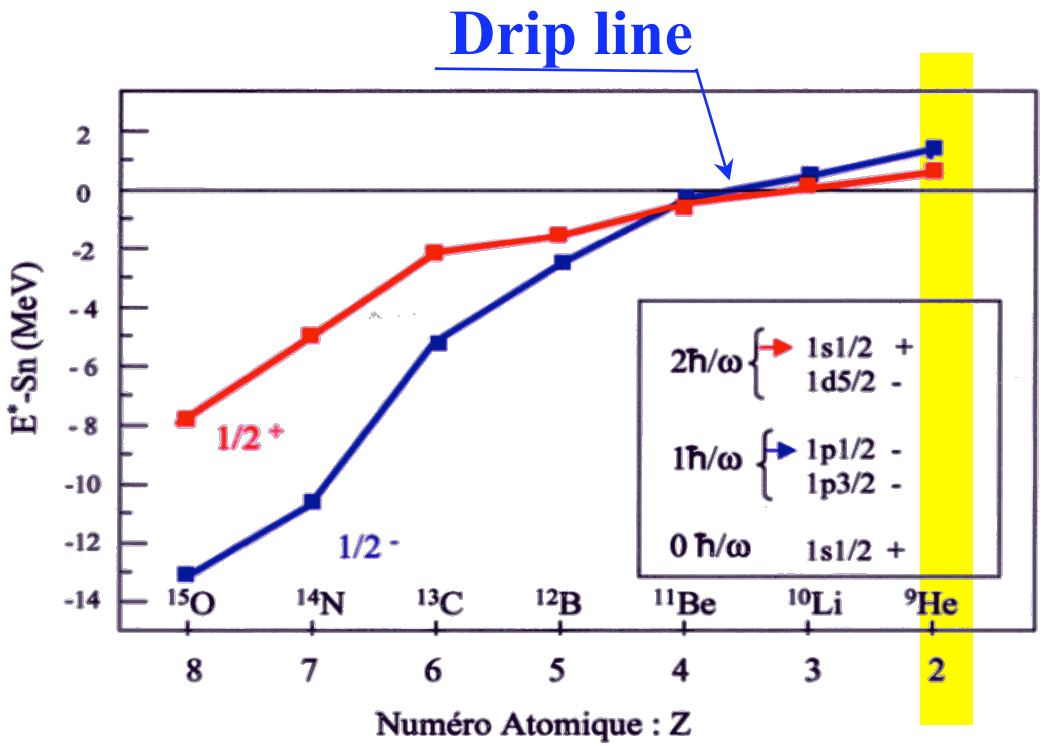
Spiral2

Conclusions

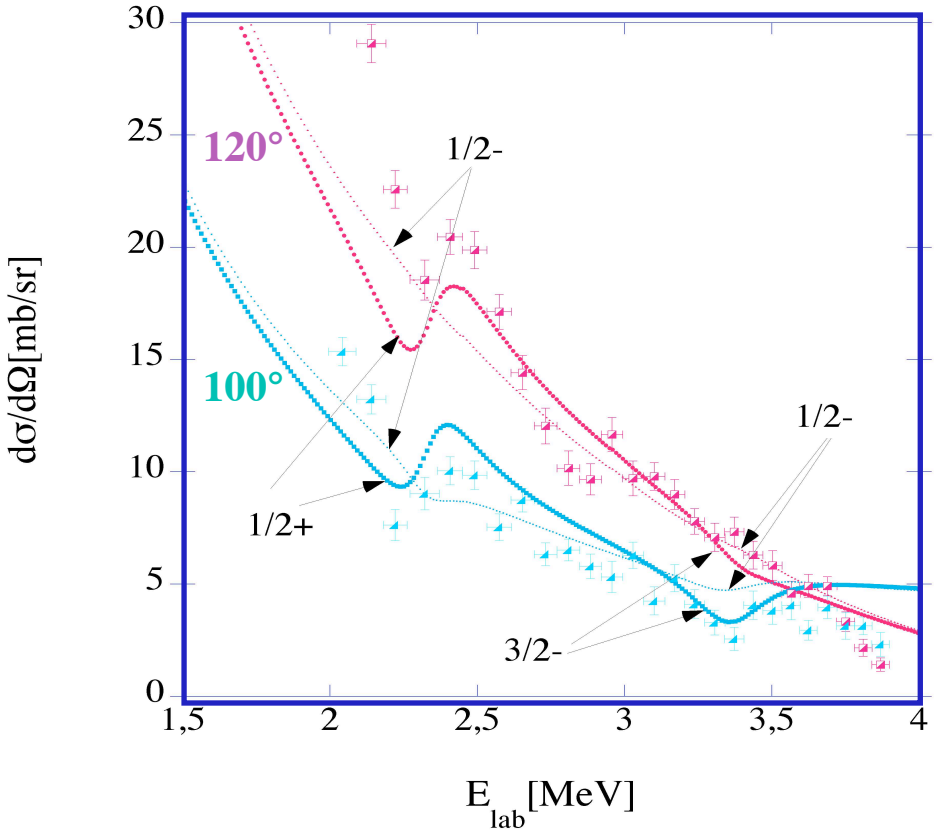
- GANIL today offers unique possibilities to study nuclei far from stability using:
  - fragmentation-like RNBs(A<100, E<100 AMeV)
  - ISOL/SPIRAL RNBs (A<80, E<25 AMeV)
  - EXOGAM,VAMOS,LISE,SPEG,MUST,TIARA… spectrometers
- Short range plans: SPIRAL 2
  - High intensity ISOL beams of fission fragments (>10^{13}fiss./s)
  - High intensity heavy-ion beams (E<14.5 AMeV, I < mA)
  - High intensity neutron flux for physics and applications
  - Up to 5 simultaneous stable/radioactive beams
  - International collaborations under construction

Regions of the Chart of Nuclei Accesible with SPIRAL 2 beams

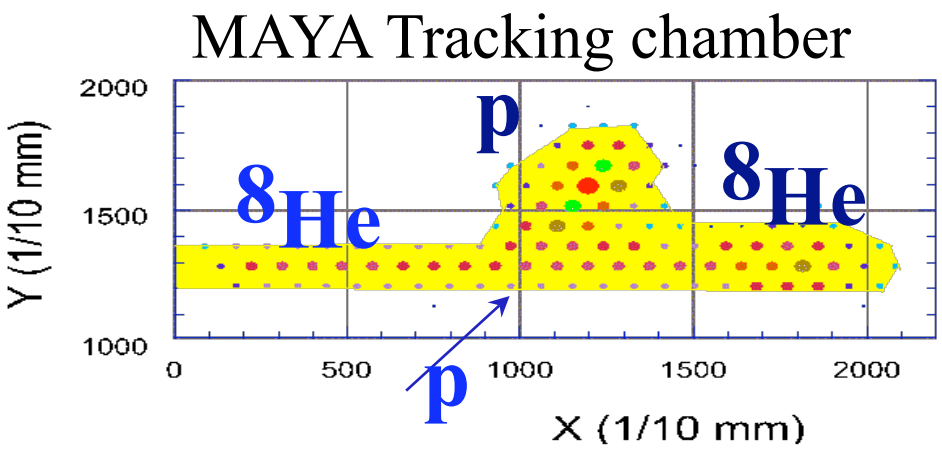




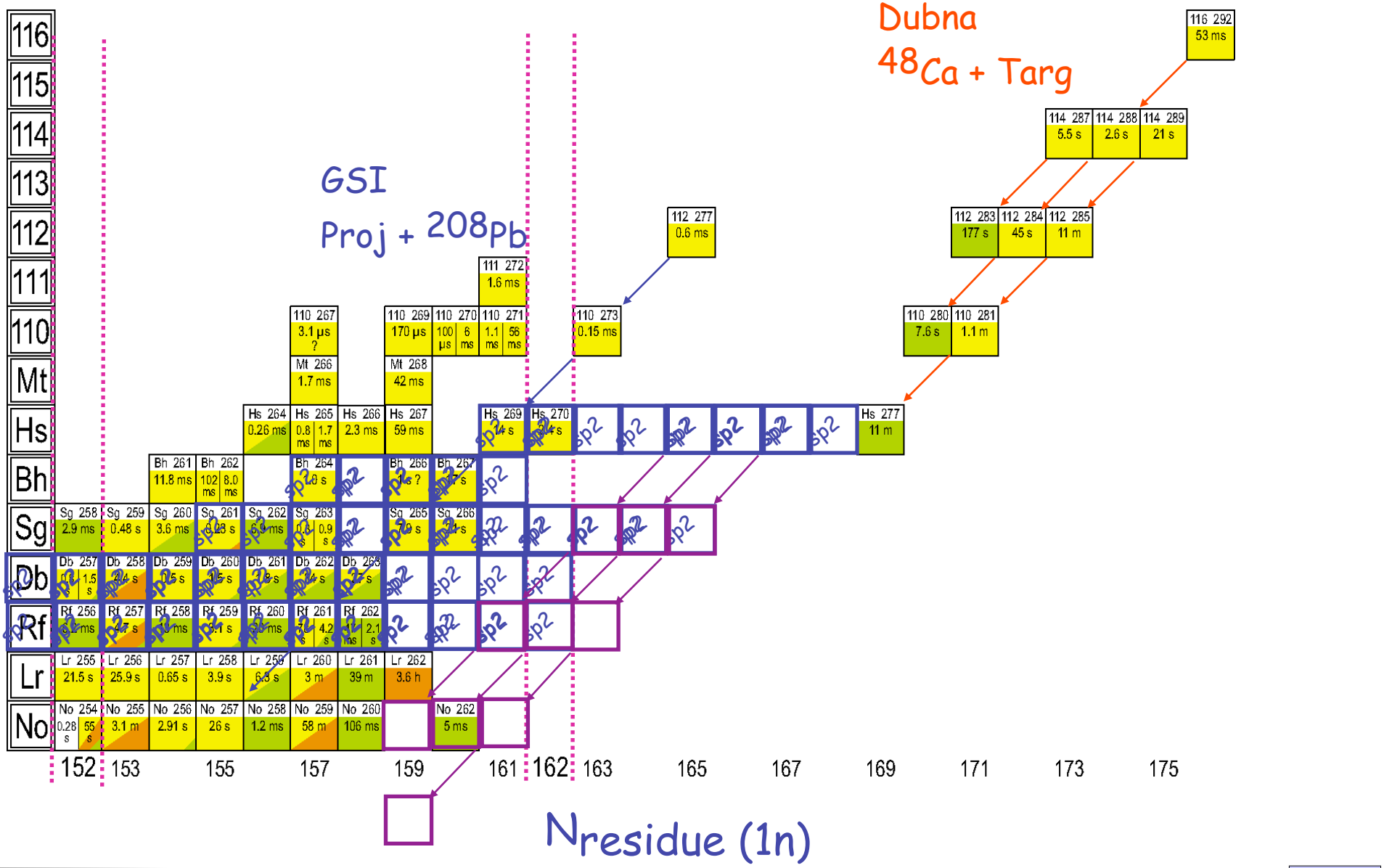
IAS of ^{9}Li -> ^{9}He ground-state



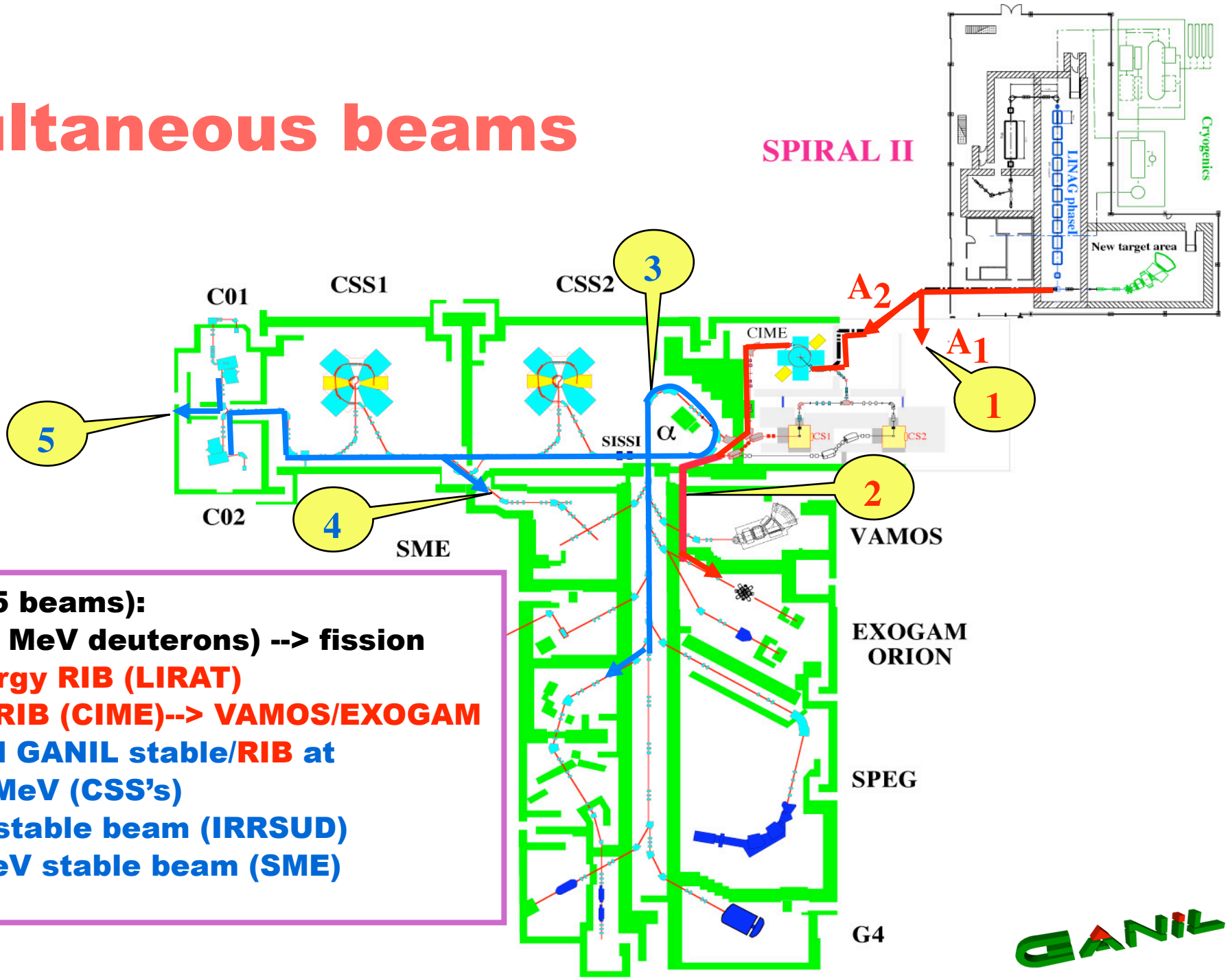
Resonant scattering



C.-E. Demonchy et al.


Dubna
48Ca + Targ
GSI
Proj + 208Pb
Nresidue (1n)
116
115
114
113
112
111
110
Mt
Hs
Bh
Sg
Db
Rf
Lr
No
152
153
155
157
159
161
162
163
165
167
169
171
173
175

Simultaneous beams



Example (5 beams):

***LINAG (40 MeV deuterons) --> fission**

1) Low energy RIB (LIRAT)

2) 6 AMeV RIB (CIME)--> VAMOS/EXOGAM

3) Standard GANIL stable/RIB at 50-100AMeV (CSS's)

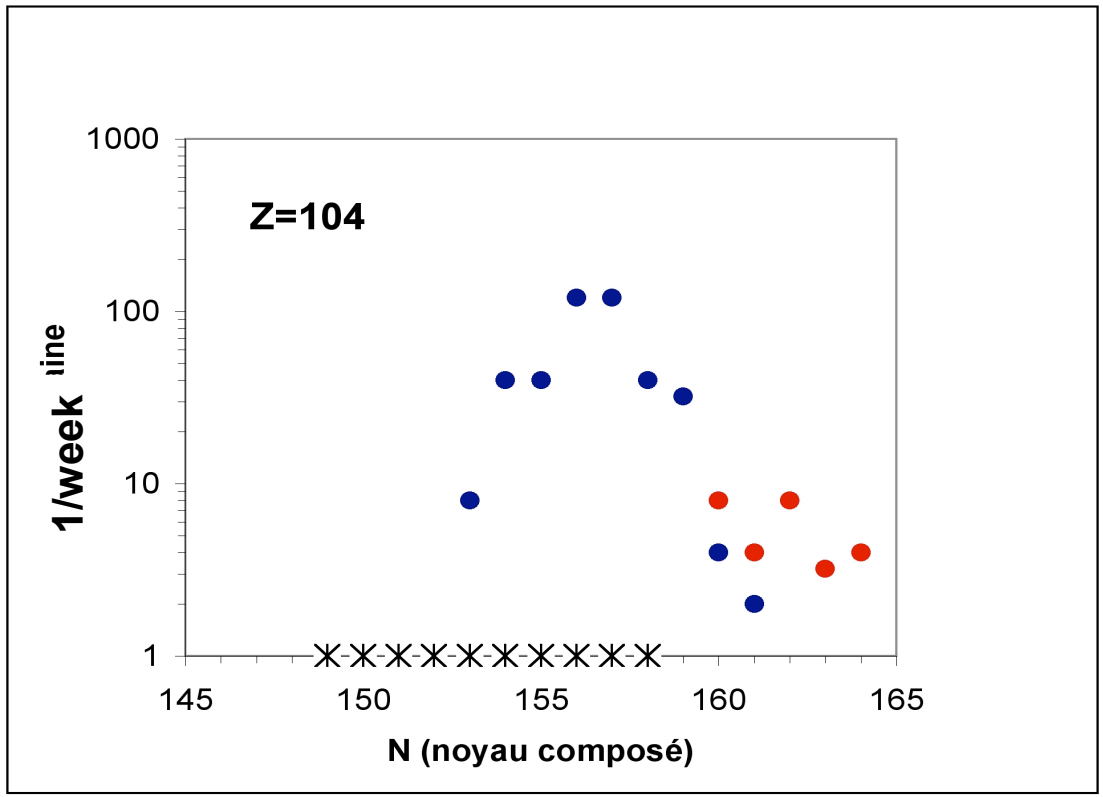
4) 1 AMeV stable beam (IRRSUD)

5) 8-10 AMeV stable beam (SME)

Transfermiums

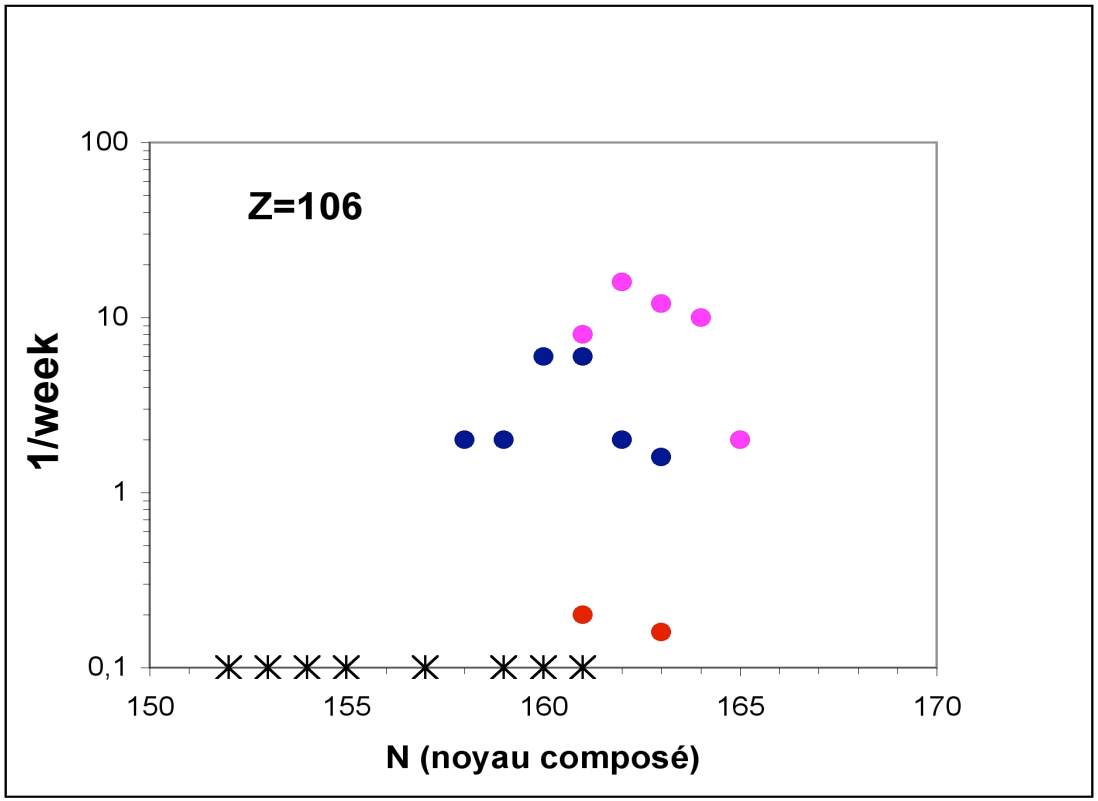
1- Considering SPIRAL2 RIB intensities and appropriate targets.

2- Considering a « reasonable » cross section evolution.



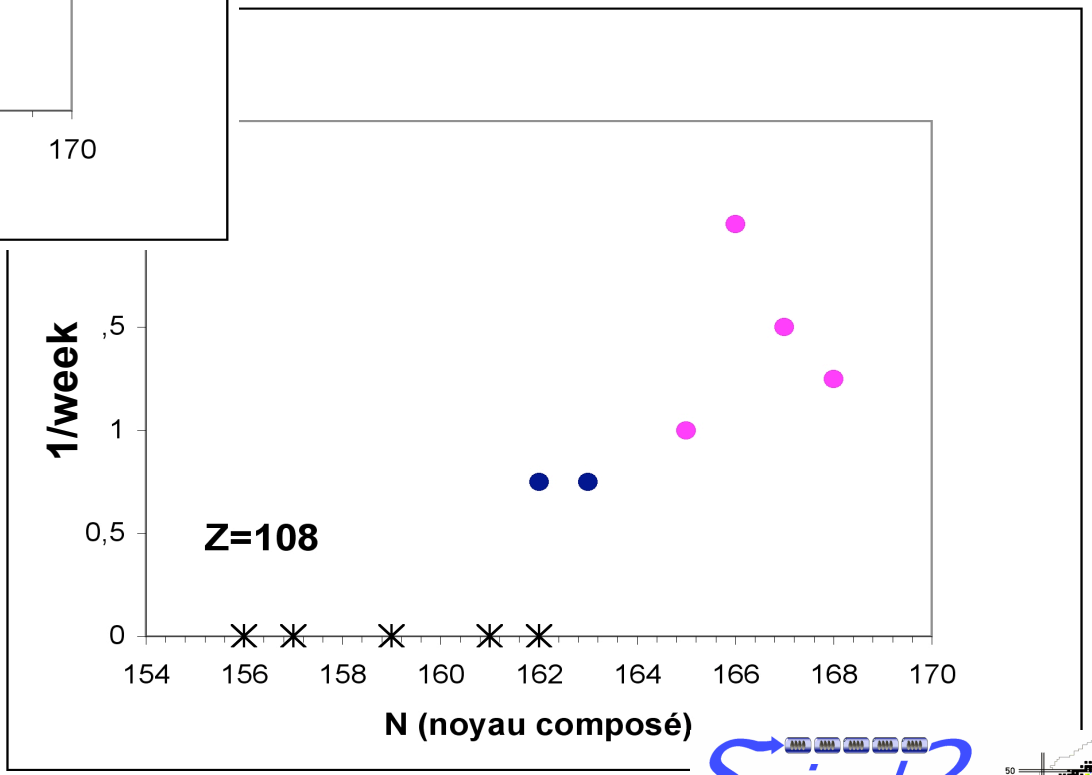
- $^{87\text{-}95}Kr + {}^{170}Er$
- $^{128\text{-}132}Sn + {}^{136}Xe$
- * known isotopes

Spiral2



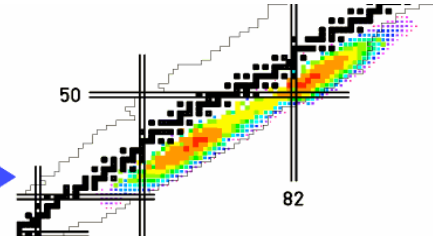
- $^{88\text{-}93}Kr + {}^{176}Yb$
- $^{129,131}Sn + {}^{138}Ba$
- $^{137\text{-}141}Xe + {}^{130}Te$

- $^{90\text{-}91}Kr + {}^{270}Hf$
- $^{137\text{-}140}Xe + {}^{136}Xe$



Spiral2

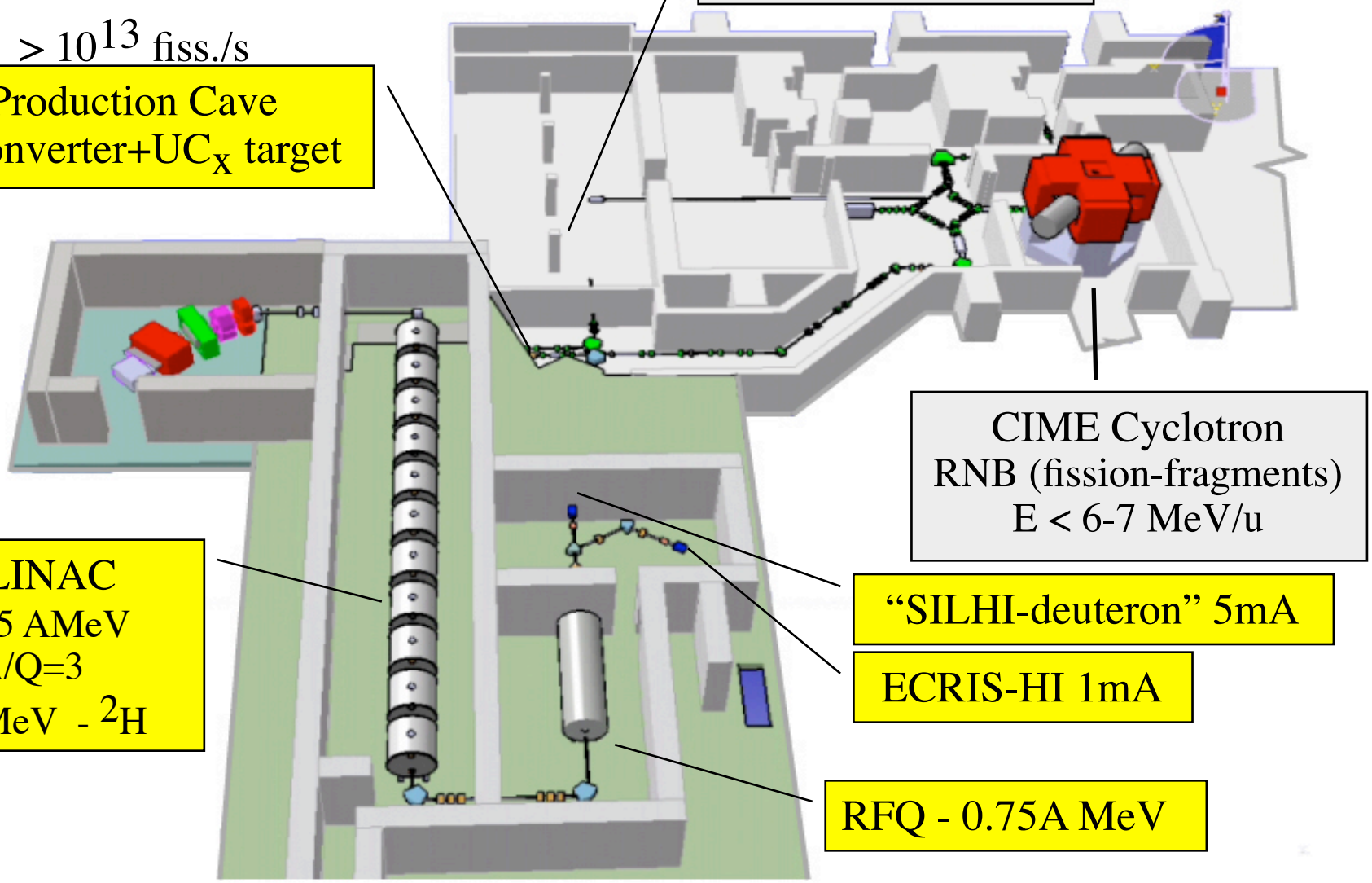
Spiral2



Low energy RNB

$> 10^{13}$ fiss./s

Production Cave
C converter+UC_X target



CIME Cyclotron
RNB (fission-fragments)
E < 6-7 MeV/u

SC - LINAC
E = 14.5 AMeV
HI A/Q=3
E = 40 MeV - ^2H

"SILHI-deuteron" 5mA

ECRIS-HI 1mA

RFQ - 0.75A MeV