GANIL Spiral 2

The 4th International Conference on the Chemistry and Physics of the Transactinide Elements

5 - 11 September 2011, Sochi, Russia

TAN 11

Super Heavy Elements Research at GANIL: Past , Present and Future

S. Galès

I) ALICE @Orsay :The Origin

II) SHE @GANIL

1995-2003 : A true attempt to enter in the race

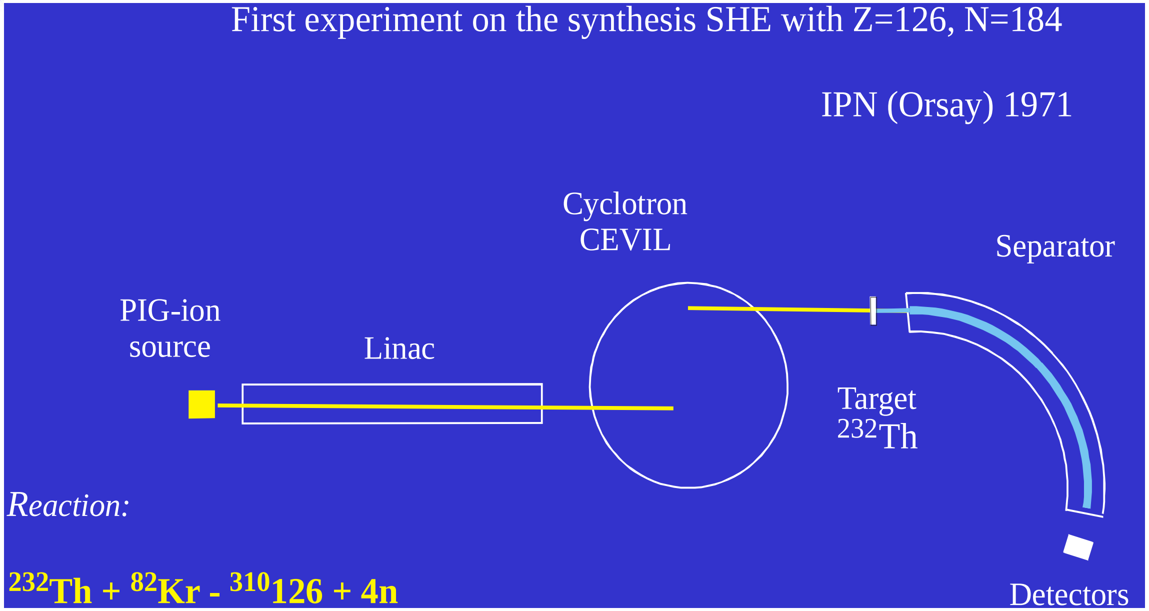
Fusion reactions with LISE

III) 2003- 2011 The Modern Era

- **Spectroscopy and reaction dynamics with symmetric systems**
- **Channeling and Recent X-ray clock for fission times**
- **U+U test experiment**
- **U beams in inverse kinematics – A new window**

IV)2012 and Beyond :GANIL-SPIRAL2 and S3

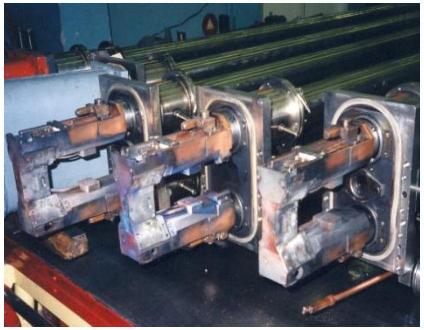
SHE research at Orsay in 1968…



1969: The World First HI Accelerator Complex

ALICE = LINAG + Cyclotron

with heavy ions up to krypton at variable energies



LINAG PIG Source

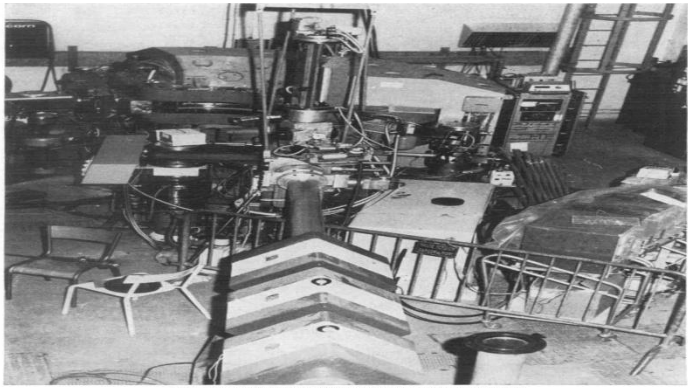


Fig. 15. Double focusing magnetic spectrometer.

Electrostatic separator + Double Focusing spectro- Magnetic analyser Detection with E_{TKE} and TOF →Mass

March 1970,
Search For SHE
M. Riou and Marc Lefort & Y.Oganessian
Fusion reaction :
Kr + Th → SHE(126) +xn

Expected cross section was very optimistic:

σ_{4n} about 0.5 mb!

Super Heavy Elements at Orsay

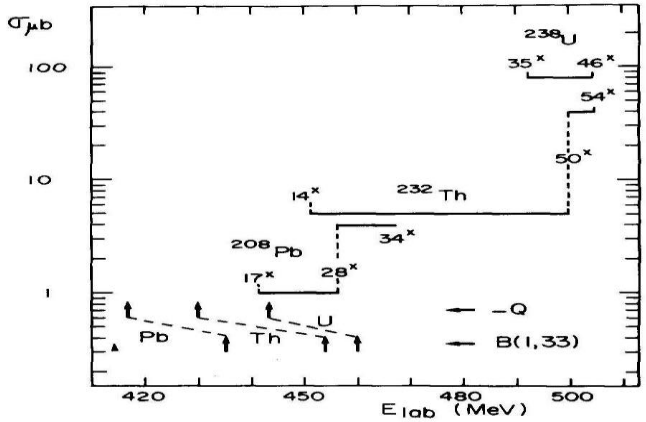


Fig. 1. Upper limits of the cross section for compound nucleus formation as a function of the bombarding energy of $^{84}_{36}$Kr on targets of ^{208}Pb, ^{232}Th and ^{238}U. The Q values have been calculated from the masses given by Nix [1]. Numbers with stars indicate the excitation energies of the compound nucleus for the corresponding incident energies. The symbol B (1, 33) has been used for $B = Z_1Z_2e^2/r_e(A_1^{1/3}\ A_2^{1/3})$ (expressed in MeV) with r_e = 1:33 fm observed to correspond to the transfer reaction threshold on Th [7] and to elastic scattering measurements [8].

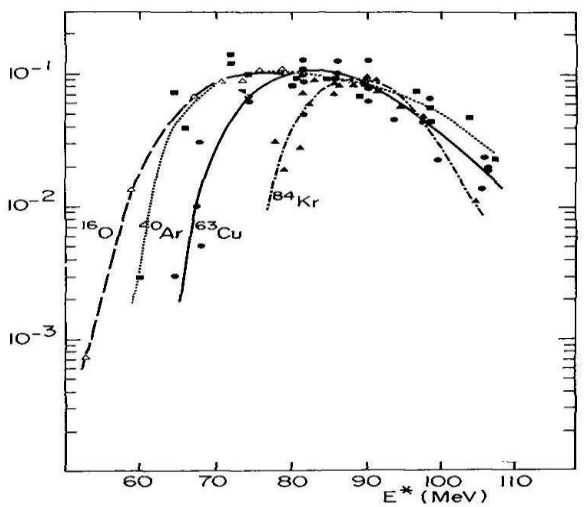


Fig. 22 – Excitation functions for (HI,5n) reactions passing through the same compound nucleus ^{158}Er (^{159}Tm for ^{63}Cu projectiles). The shift between ^{16}O and ^{84}Kr is clearly seen [75–76].

1972 Results no M>300 observed

- Stability island does not exist
  - *Or failed method ?* *σ_{lim}(^{84}Kr+^{208}Pb@460-500MeV)=1μb so σ_{fus} deduced to be very negligeable*

But….

1972-1982

The studies of fusion with Krypton beams with lighter targets

- *Discovery of viscosity and new reaction process :Quasi Fission and/or Deep inelastic*

M. Lefort Journal de physique Colloque C5 Tome 37 1976,

Since then Dubna-Orsay Collaboration was very active

Chemistry of SHE with few atoms

Radiochimica Acta 37, 113 (1984)

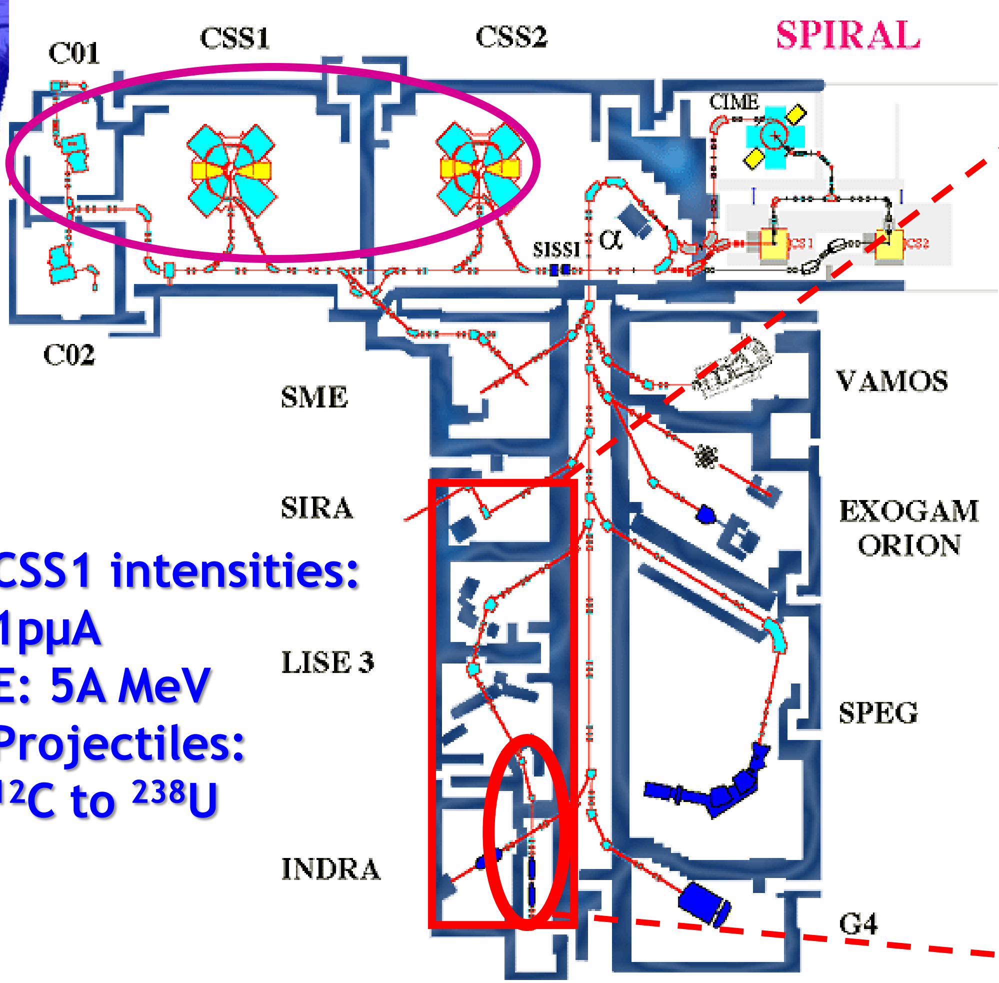
Experimental studies on the formation
and
radioactive decay of isotopes with Z =104-109

Yu. Oganessian, M. Hussonois, A. Demin, Yu. Kharitonov, H. Bruchertseifer, O. Constantinescu Yu. Korotkin, S. Tretiakova, I. Shirokovsky and I. Estevez

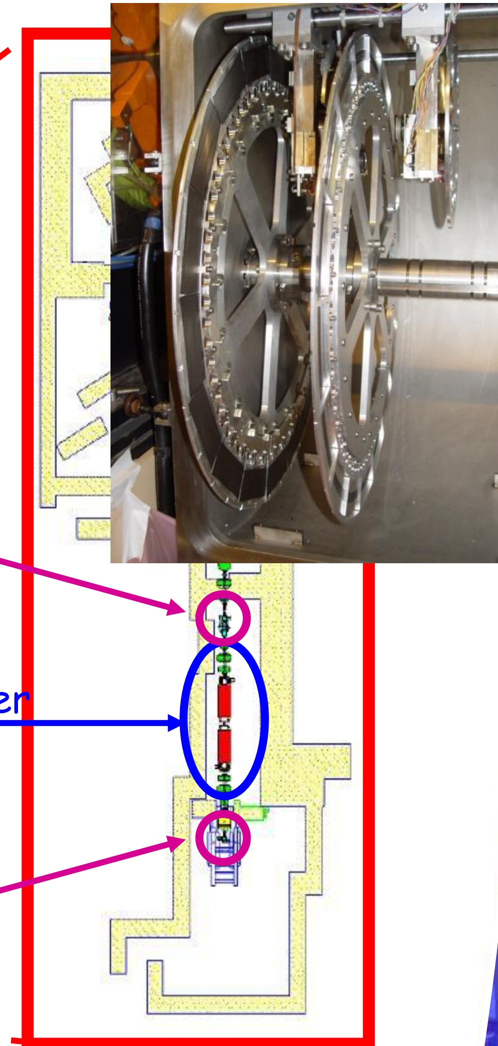
by Yuri Tumanov

Super Heavy Elements at GANIL

Started with Kr+Pb saga 1998

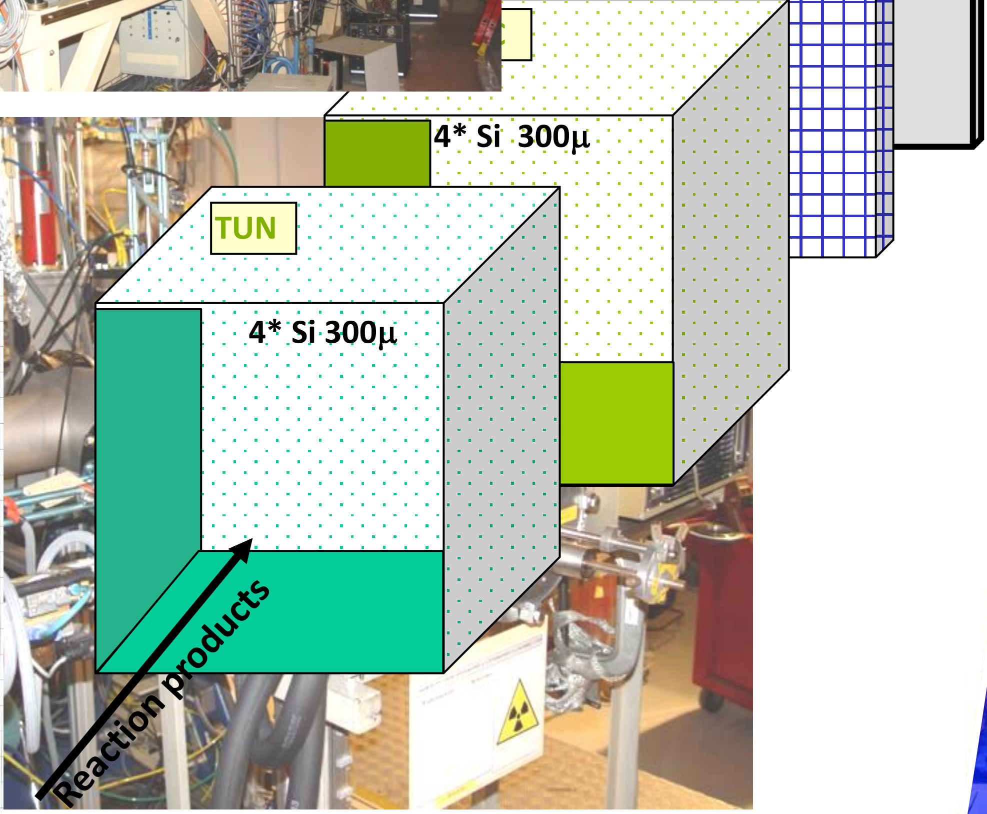


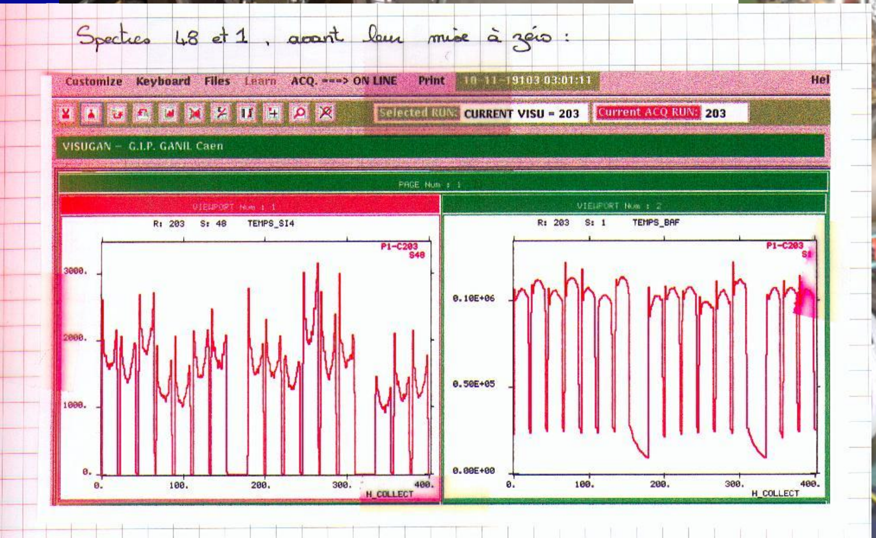
CSS1 intensities:
1pμA
E: 5A MeV
Projectiles:
^{12}C to ^{238}U



DAPNIA/SPhN, CEN Saclay; Univ. Jyvaskyla, Finland; JINR, Dubna, Russia; Univ. Liverpool, U.K.; G.S.I., Darmstadt; C.S.N.S.M., Orsay; I.R.E.S., Strasbourg; I.F.U., Krakow; GANIL, Caen; LPC, Caen

LISE: Small cross-sections measurements in cold fusion reactions





Target control and evolution…

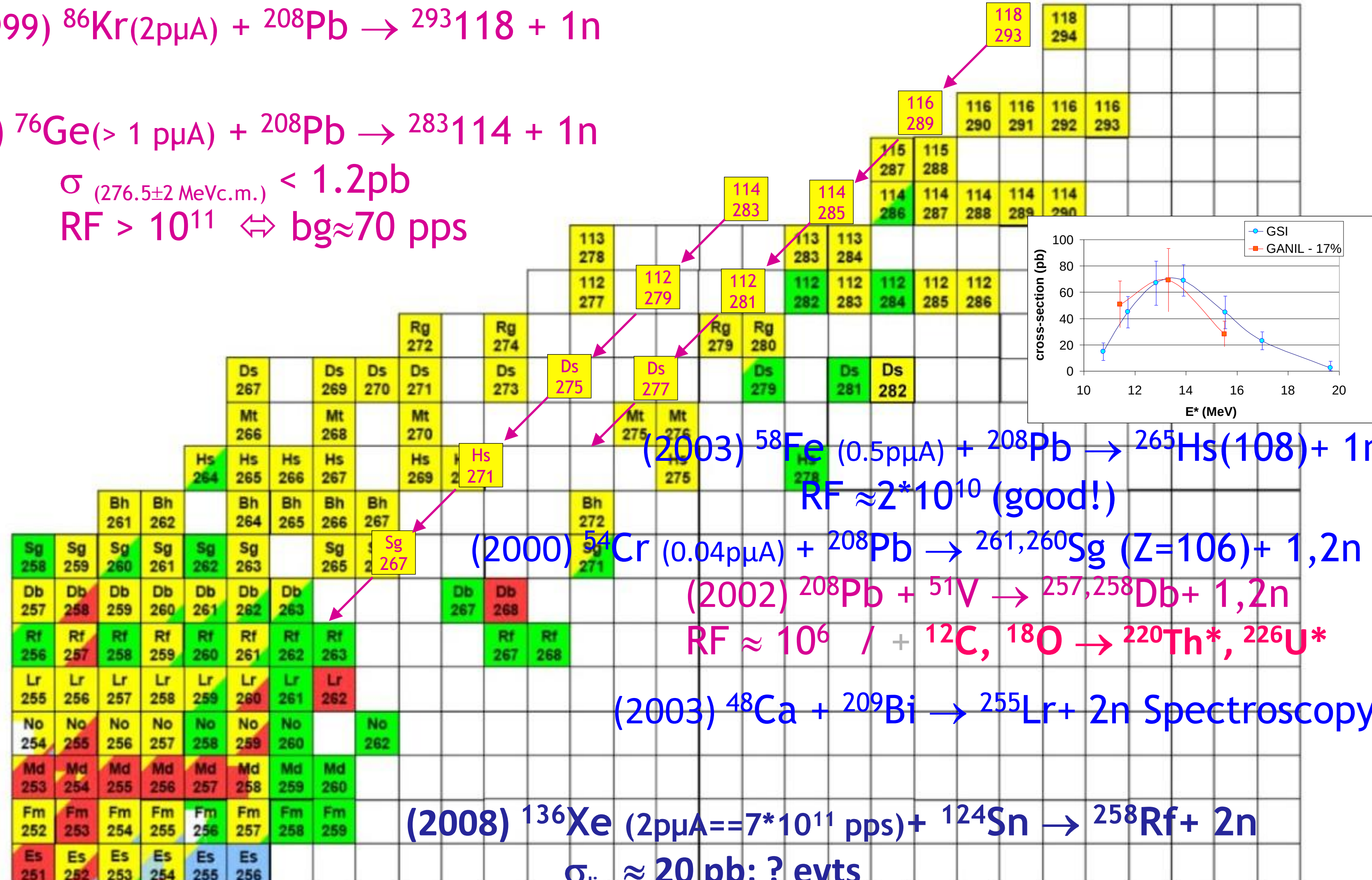
Fusion-evaporation reactions

(1999) ^{86}Kr(2pμA) + ^{208}Pb → ^{293}118 + 1n

(2003) ^{76}Ge(> 1 pμA) + ^{208}Pb → ^{283}114 + 1n

σ (276.5±2 MeVc.m.) < 1.2pb

RF > 10^{11} ⇔ bg≈70 pps



(2003) ^{58}Fe (0.5pμA) + ^{208}Pb → ^{265}Hs(108)+ 1n

RF ≈2*10^{10} (good!)

(2000) ^{54}Cr (0.04pμA) + ^{208}Pb → ^{261,260}Sg (Z=106)+ 1,2n

(2002) ^{208}Pb + ^{51}V → ^{257,258}Db+ 1,2n

RF ≈ 10^{6} / + ^{12}C, ^{18}O → ^{220}Th*, ^{226}U*

(2003) ^{48}Ca + ^{209}Bi → ^{255}Lr+ 2n Spectroscopy

(2008) ^{136}Xe (2pμA==7*10^{11} pps)+ ^{124}Sn → ^{258}Rf+ 2n

σ_{lim} ≈ 20 pb; ? evts

RF ≈ 7*10^{7} ⇔ bg≈ 10^{3} pps

Ch. Stodel et al, CP891, Tours Symposium on Nuclear Physics VI, 2006, p.55-59
A. Wieloch et al, NIMA517 (2004) 364-371

LISE: Small cross-sections measurements in cold fusion reactions

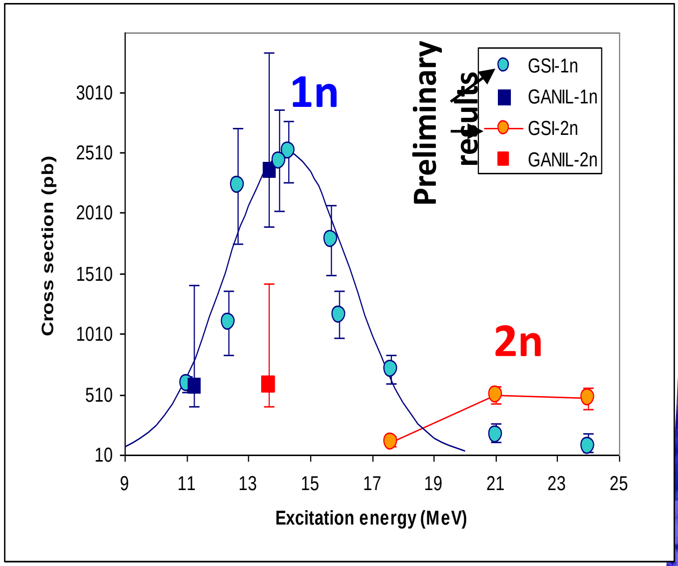
1999 : Search for Z=118;

$^{86}Kr+^{208}Pb$

2000 : characterisation test

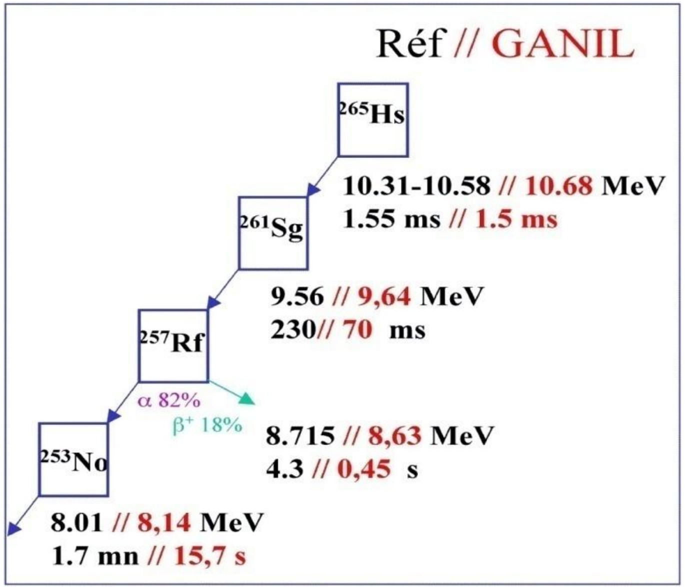
$^{54}Cr + ^{208}Pb \rightarrow ^{261,260}Sg(106) + 1n, 2n$

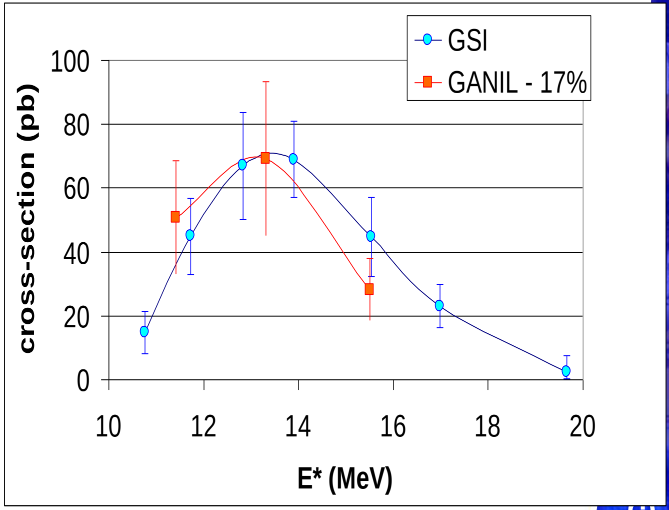
Rejection = 1.7 10^{10}
10 events ε= 15% (poor)
Absolute Energy very similar to GSI



2003 : « test »

^{58}Fe (500 pnA) $+ ^{208}Pb \rightarrow ^{265}Hs(108) + 1n$





Rejection = 2 10^{10}
I= 500 pnA

LISE: Small cross-sections measurements in cold fusion reactions

$^{76}Ge + ^{208}Pb \rightarrow ^{283}114 + 1n$

- 1 beam energy, E = 5.02 MeV/A
- Large intensity: new method developed by Ion Source Group > 1pμA
- Very good rejection factor (low background) > 10^{11} (70 events/s)
- Good behavior of targets (420 μg/cm^2)

- Beam dose of ^{76}**Ge** = $5*10^{18}$

  ⇒ Sensitivity : **1 event = 0.6 pb**

  No event attributed to ^{283}114

  ⇒ **Cross-section < 1.2 pb**

in energy range 274.5-278.5 MeV c.m.

unless decays (α or spontaneous fission) within 3 μs

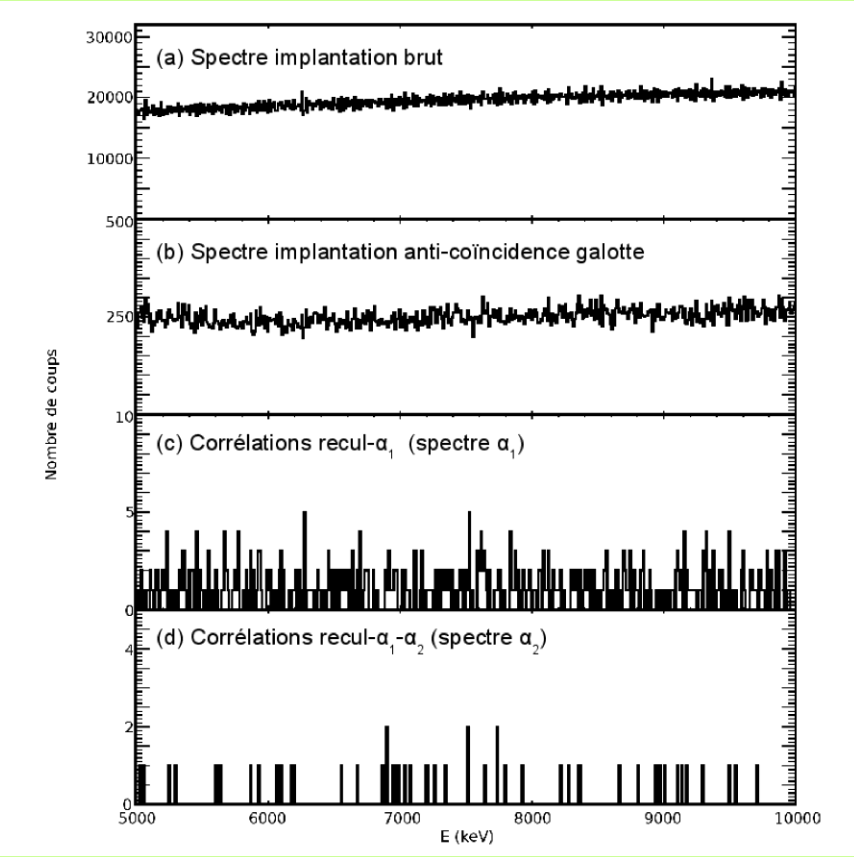
- 3 α and 4 α chains of actinides (transfer products).

$^{136}Xe+^{124}Sn$:Synthesis of very heavy elements: Fusion with (nearly-)symmetric channel

Selectivity (α)

$$^{257}Rf \xrightarrow{\alpha_1} {}^{253}No \xrightarrow{\alpha_2} {}^{259}Fm$$

4.5 s 1.57 min



- **Beam:**
- $^{136}Xe^{18+}$ @ 4.6 MeV/u
- ≈2 μAe (≈7.10^{11} pps)

Target ^{124}Sn-400 μg/cm2

Search for α decays

- (a) ≡ Rough implantation spectrum
- (b) ≡ (a) + No MCP
- (c) ≡ (b) + correlated residue
- (d) ≡ (c) + correlation (c)

Observations

- No clear α spectrum
- Large background

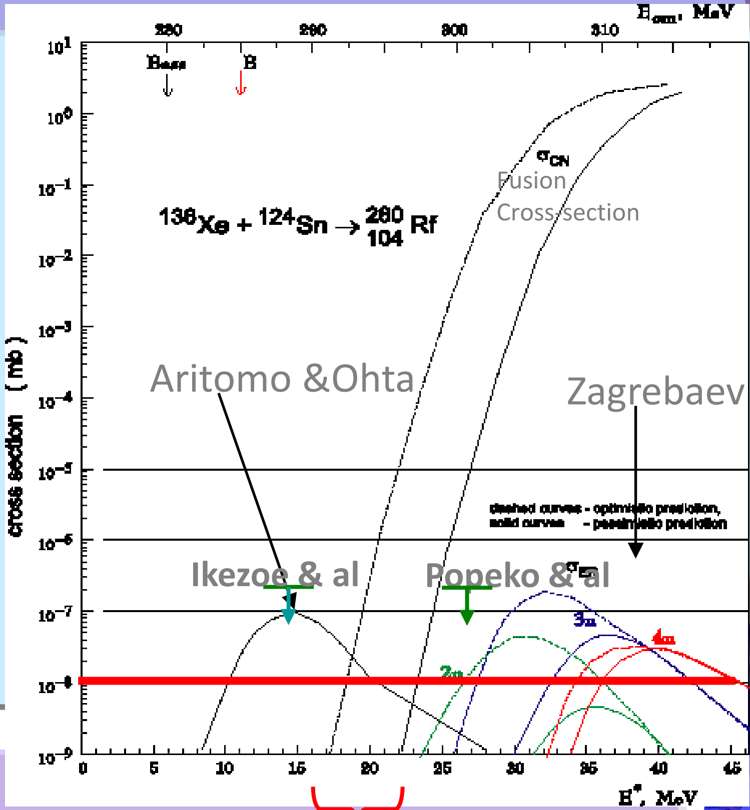
Limit cross-sections

- ^{257}Rf : $\sigma_{3n} < 172.4$ pb
- ^{258}Rf : $\sigma_{2n} < 80.8$ pb
- ^{259}Rf : $\sigma_{1n} < 235.1$ pb

Conclusion $^{136}Xe+^{124}Sn$

Conclusion

Evaporation residues cross sections



E533

- o Results:
  - Upper limits of σ_{xn} (E*=20 MeV)
  - Models ,discrimination
- o Experimental set-up Lise3@GANIL
  - Difficult velocity separation
  - (≈1300 pps in Si-implantation)
  - Need of the ionization chamber

- SHE synthesis
- Reaction mechanism
  (synthesis of heavy nuclei)

Perspectives

- o
- o LISE3@RIB of SPIRAL2
  - o Background?
  - o Technical studies/upgrade (Wien filter, detection..), tests
  - o Rn and Ra isotopes with Ba*, Xe*, Sn* beams

E533

Super-heavy fission times

$^{238}U + Ni \rightarrow (120)^*$
$^{238}U + Ge \rightarrow (124)^*$
$^{238}U + Ge \rightarrow (114)^*$

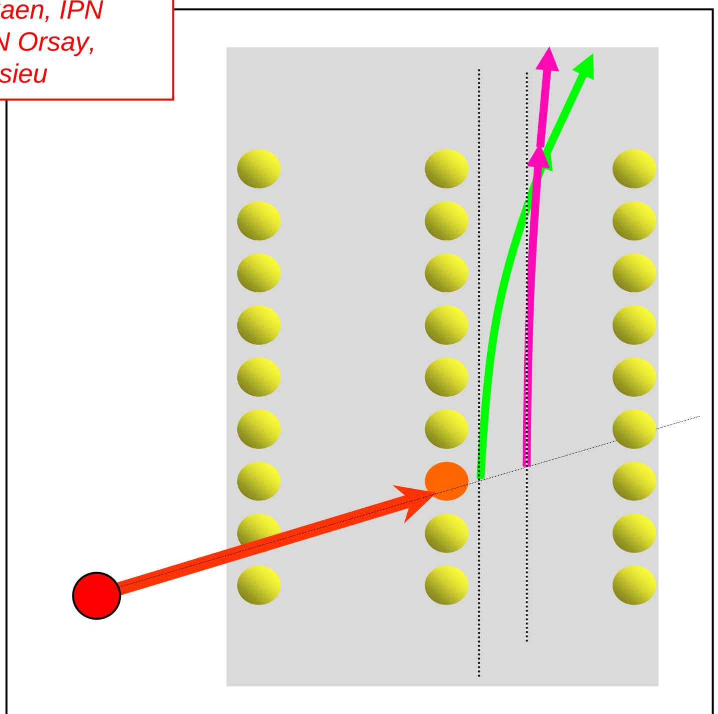
^{238}U @ 6.6 MeV/A

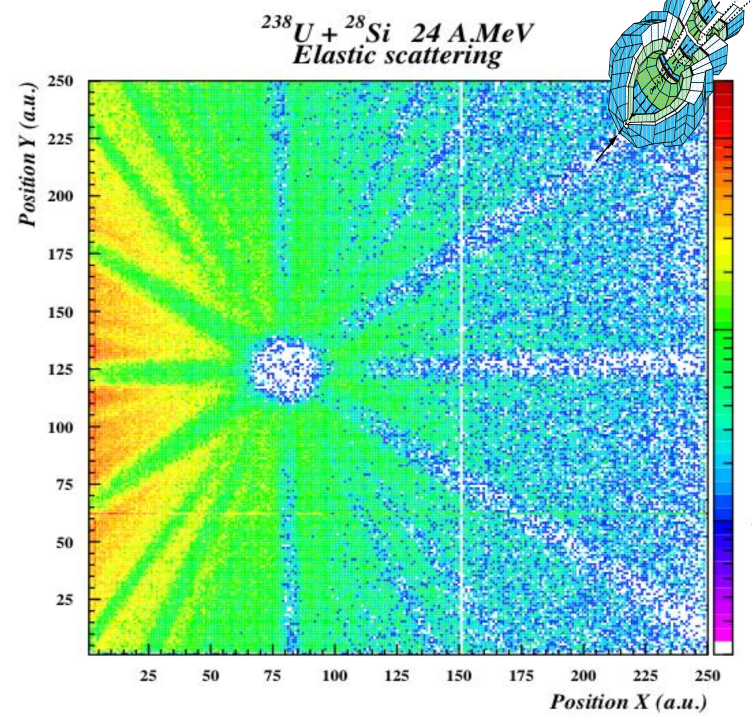
Blocking technique in single crystals:

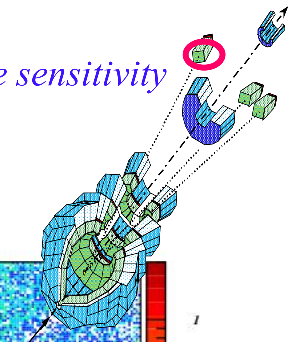
- *Single crystal as target*
- *Dips in the angular distributions (deflection of the fragments by the crystal atoms)*
- *The minimum yield arises from pure geometrical effects:*

thermal vibration amplitude gives rise to a model independent minimum time sensitivity

DAPNIA/SPhN, GANIL Caen, IPN Lyon, IPN Orsay, GPS Jussieu







F. Goldenbaum et al., PRL 82 (1999) 5012

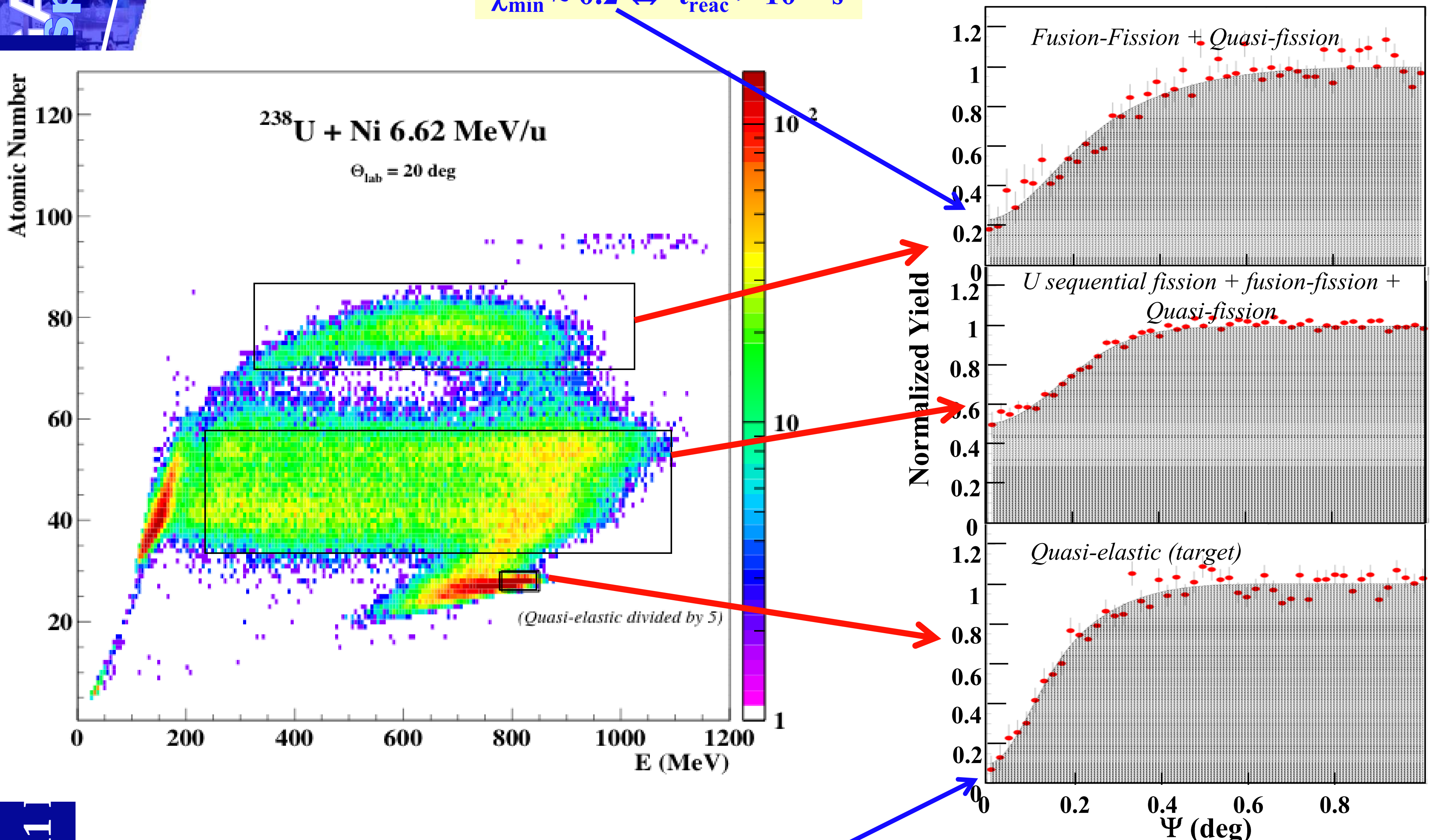
M. Morjean et al, Physical Review Letters 101 (2008) 072701; European Physical Journal D 45 (2007) 27-31

Formation of super-heavy nuclei by fusion:

Caracterisation of total fusion events by INDRA, a 4π charged product detector

Direct evidence for long times: Z=120

$\chi_{min} \approx 0.2 \Leftrightarrow t_{reac} > 10^{-18}$ s



$t_{reac} < t_{min}$(thermal vibrations) $\Leftrightarrow$ $\chi_{min} \approx 0.1$

$t_{min} \approx 10^{-18}$ s

M. Morjean et al., Phys. Rev. Lett. 101 (2008) 072701

X-ray fluorescence

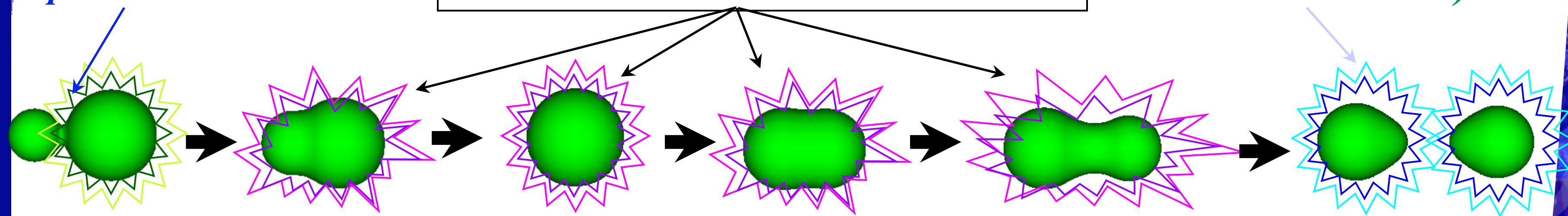
(Reaction time from inner shell vacancy lifetime)

$^{238}U + ^{64}Ni$ 6.6 A.MeV

Vacancy creation in inner electronic shells during the fusion process

Filling of the vacancies with X-ray emission at energies characteristic of the nucleus atomic number

Modification of the characteristic X-ray energies (adiabatic adjustment of the electron shells)



Fusion

Fission

$$N_X = N_{em} N_{vac} \frac{\tau_{nucl}}{\tau_{nucl} + \tau_{atom}}$$

Must be measured

N_x = number of characteristic X-rays detected

N_{em} = number of compound nuclei

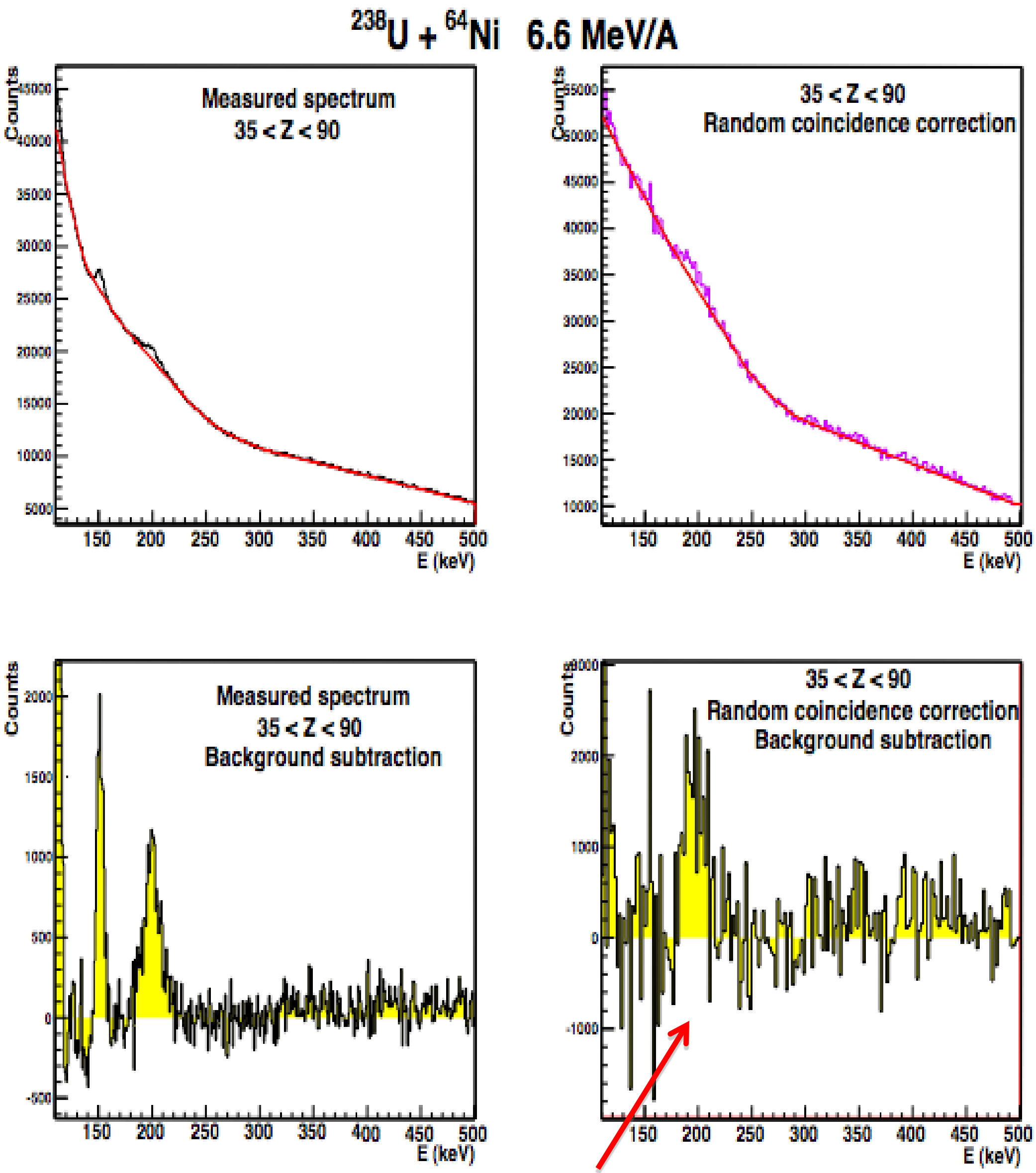
N_{vac} = vacancy number per compound nucleus

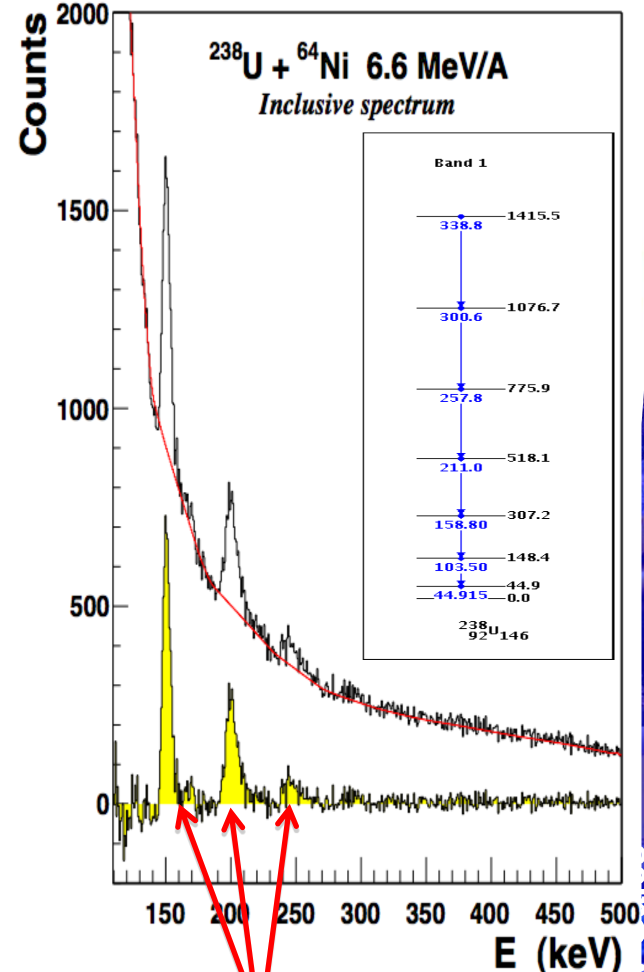
τ_{nucl} = Fission time of the compound nucleus

τ_{atom} = Lifetime of the vacancies

X-ray fluorescence

(Reaction time from inner shell vacancy lifetime)





Characteristic X_K from Z = 120

γ-rays from uranium

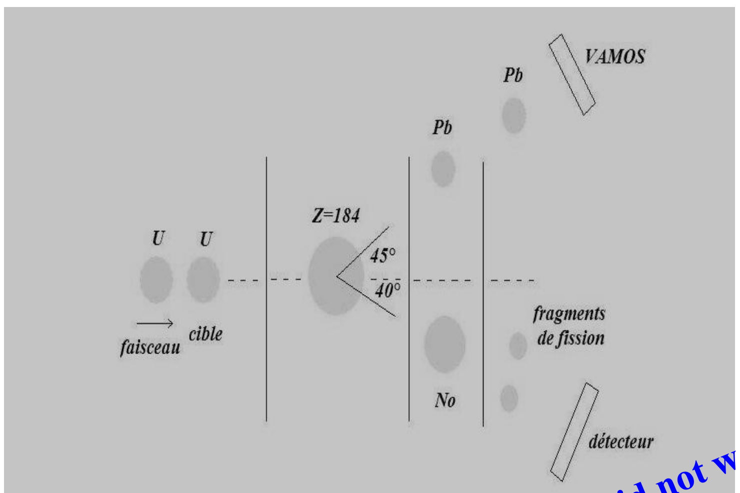
Study of super-heavy nuclear systems

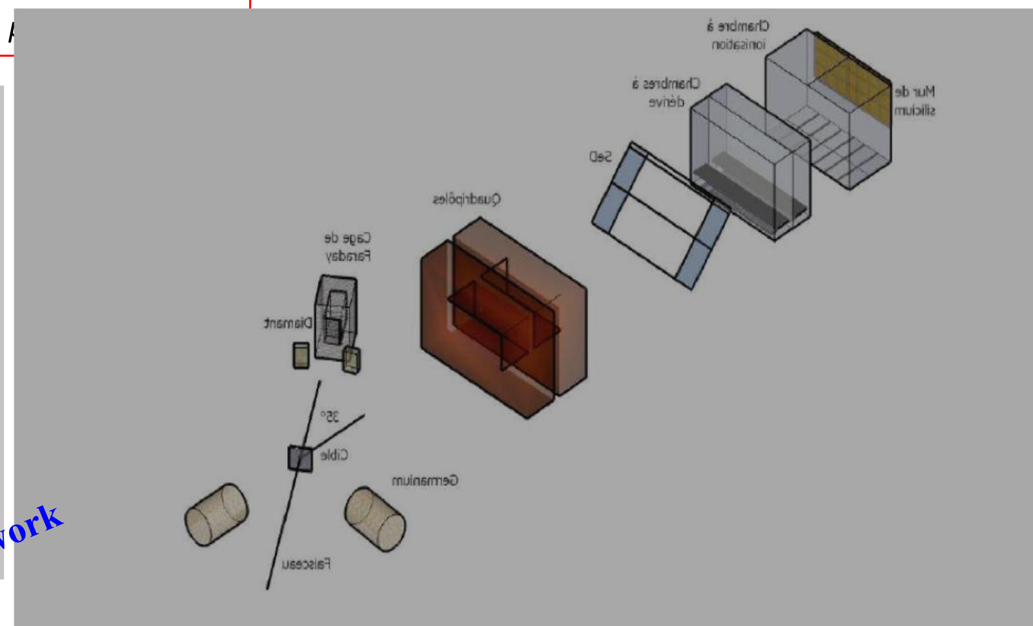
Expérience E511 : $^{238}U+^{238}U$

E=6.1;6.5;6.9;7.1;7.4 A MeV

Ganil – GSI - Dapnia/SphN – CENBG - KVI

Search for a long-lived component in the reaction U+U near the Coulomb barrier, A.C.C Villari et al, *Tours Symposium on Nuclear Physics VI – AIP Conference Proceedings 891 (2007) p*

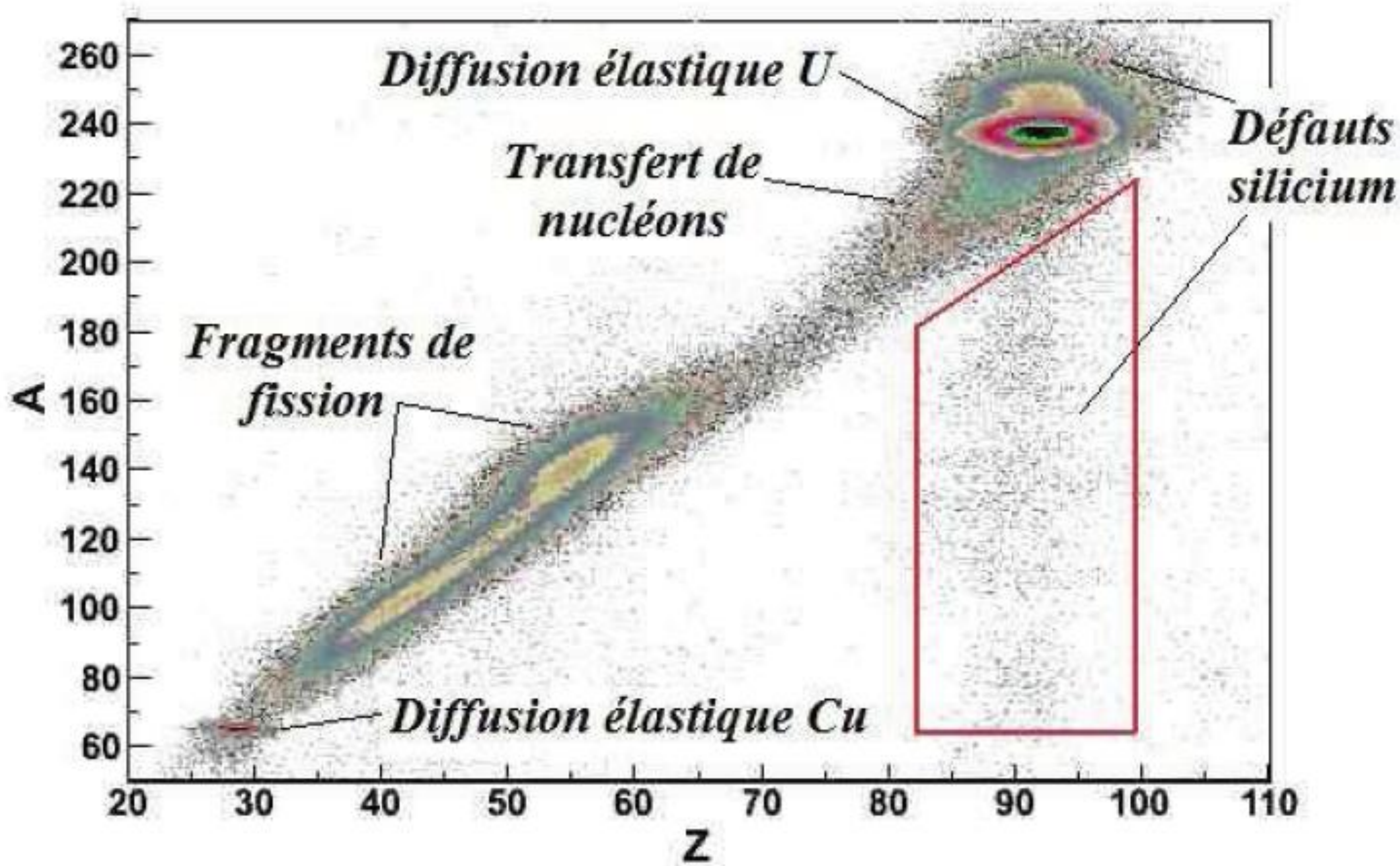




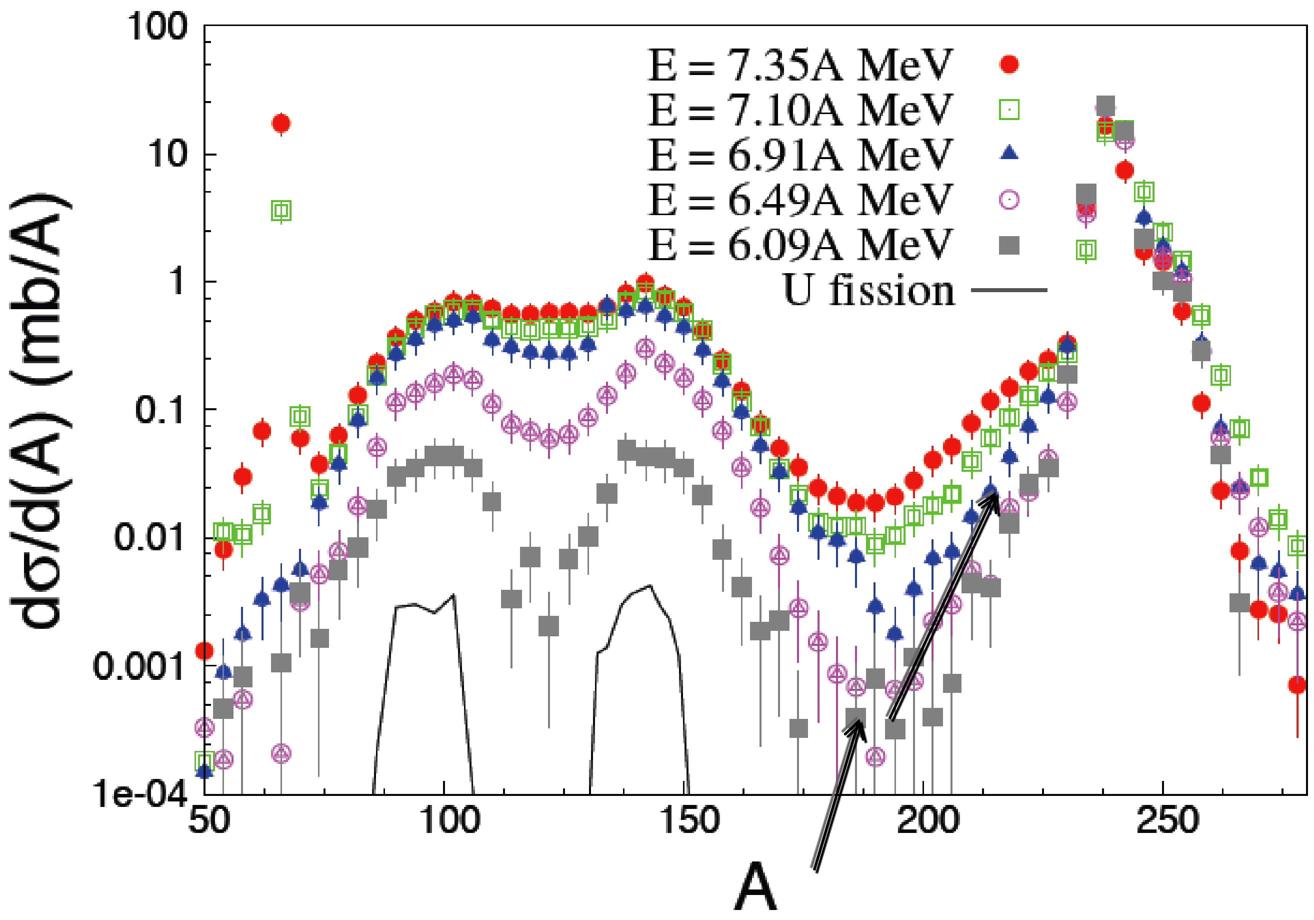
Did not work

C. Golabek PhD Thesis, 2009 Caen
Eur. Phys. J. A 43 (2010) 251
Phys. Rev. Lett. 103, 042701 (2009)

U+U fragment production (E=7.35 A MeV)



Evolution of the fragment distribution with energy

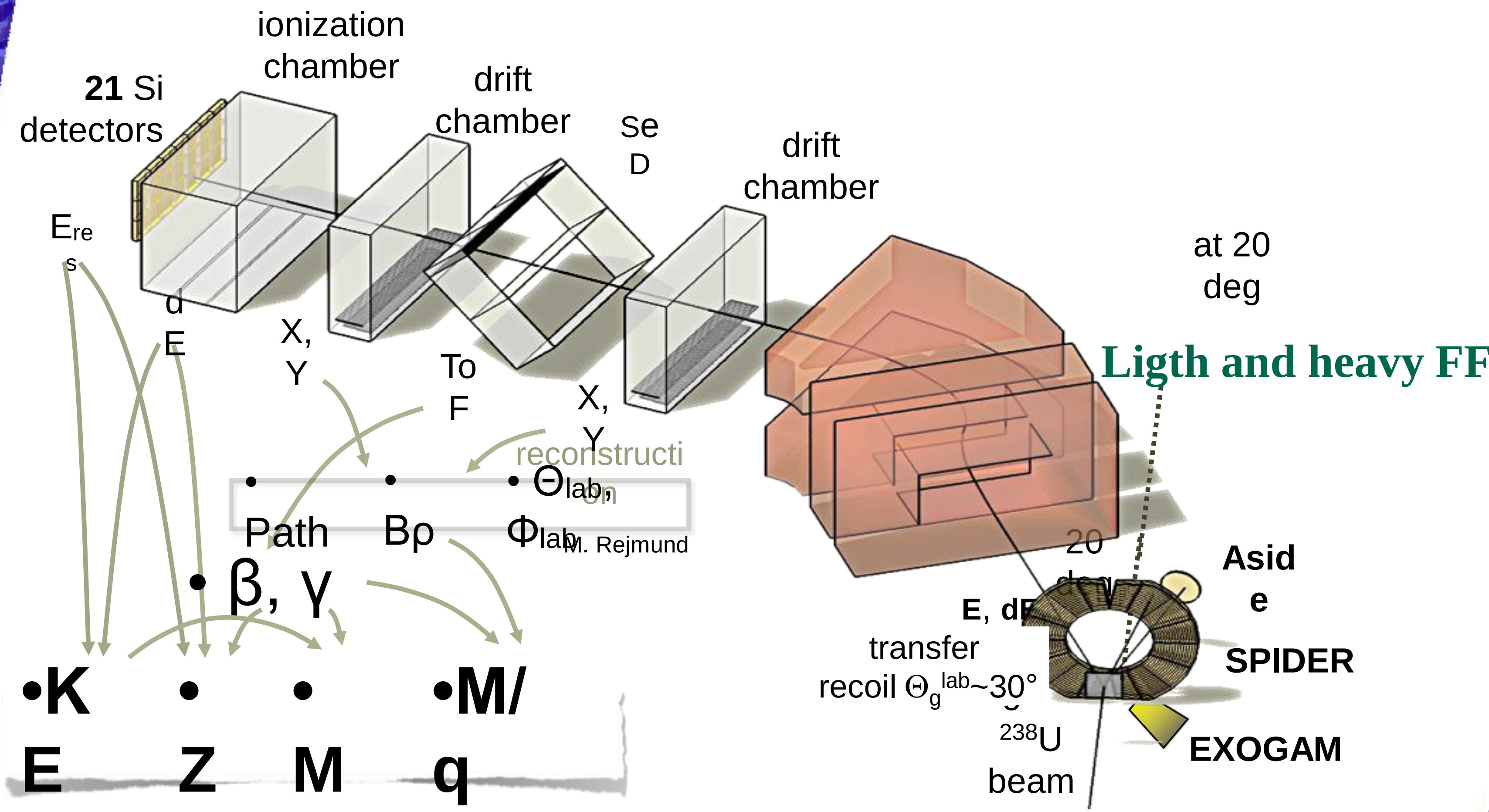


As E* increases, transfer toward Pb increases.
But production above U decreases due to increasing fission probability

Fission investigations using transfer and fusion in inverse kinematics

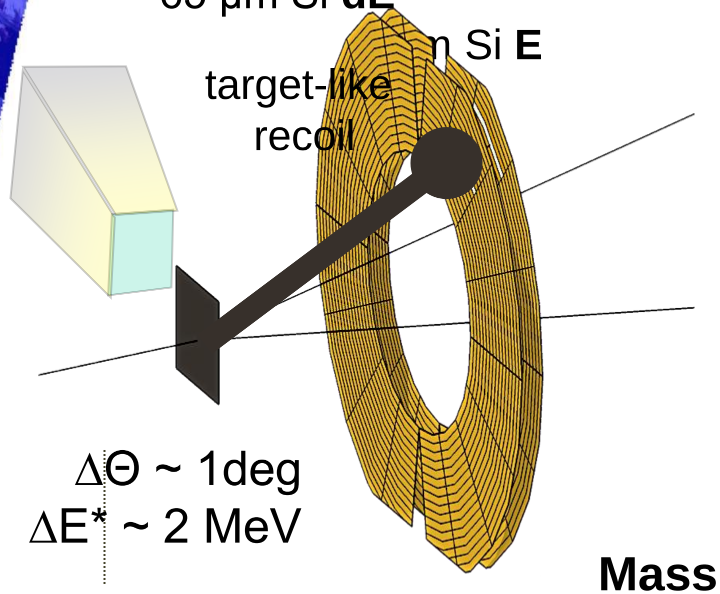
- Inverse kinematics : access to heavy fragments
- Spectrometer VAMOS : isotopic distribution

$^{238}U + ^{12}C$ @ 6.1 MeV/u

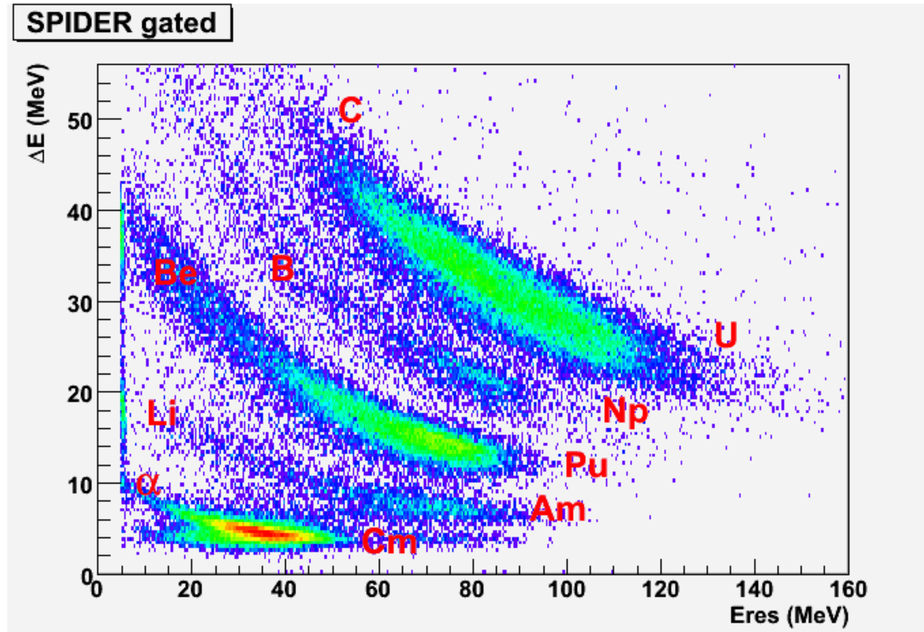


Sydney Gales

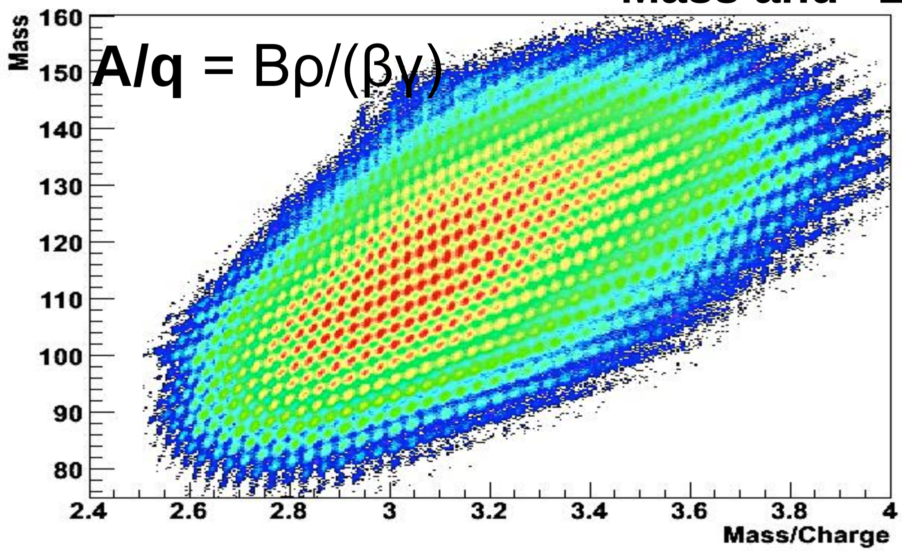
Identification of the fissioning nucleus with SPIDER

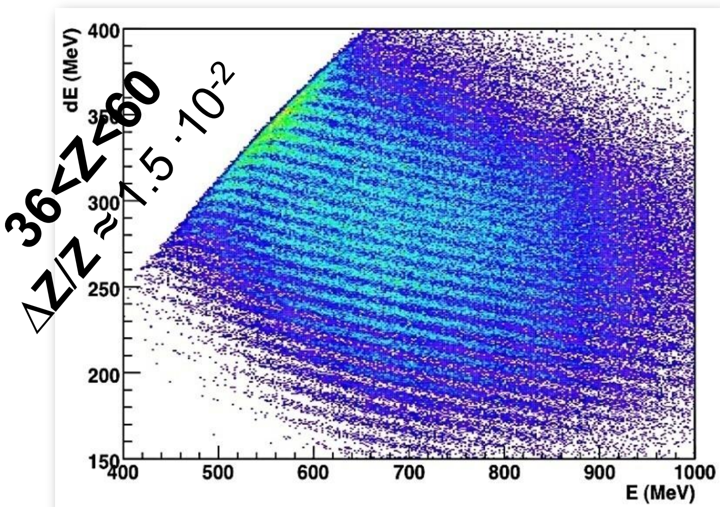


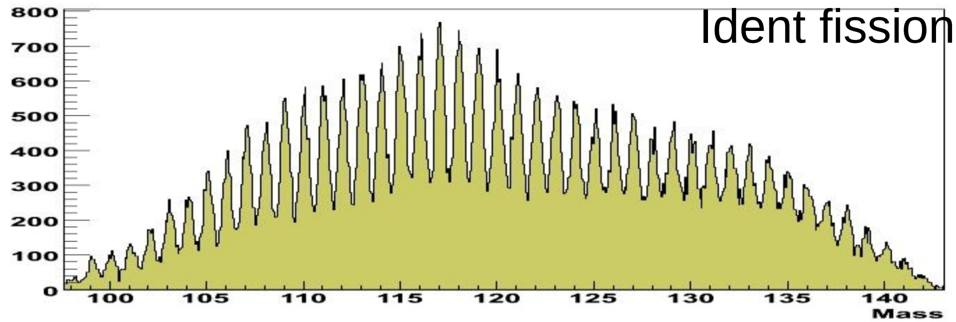
ΔΘ ~ 1deg
ΔE* ~ 2 MeV



Mass and Z identifcation with VAMOS : A, A/q

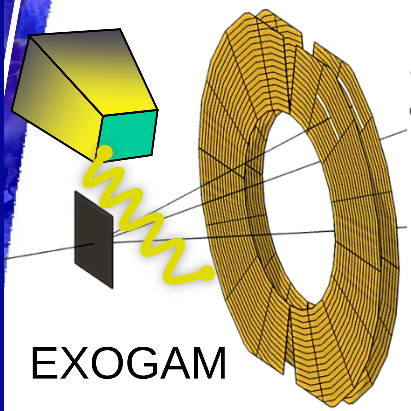


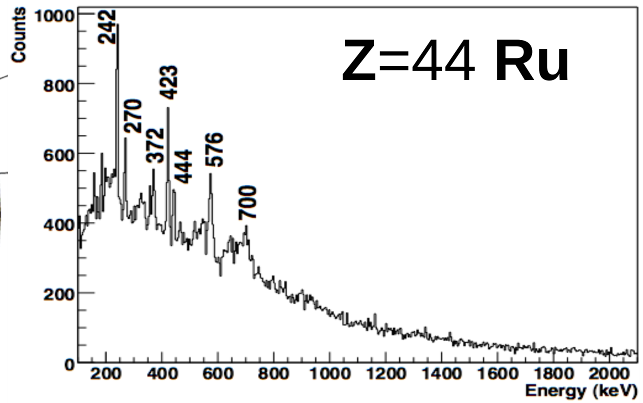


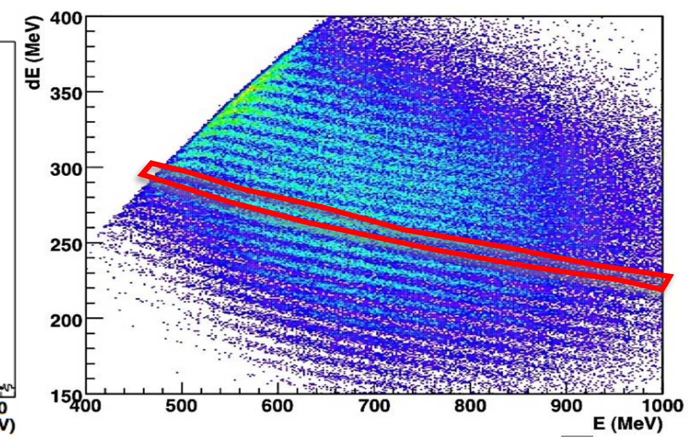


Ident fission fragment **A ≈ 90** à **A ≈ 140**

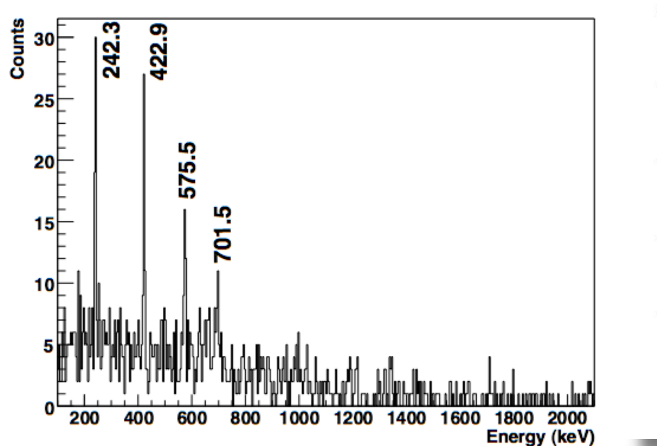
Identification Calibration with EXOGAM

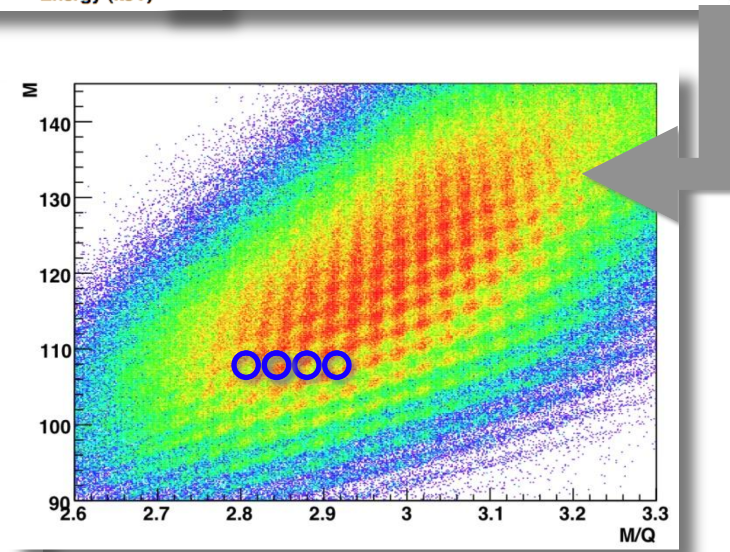






M=108 **^{108}Ru**





non ambigueous Identification in **A**, **Q** et **Z**

Preliminary results

- **Isotopic distribution on 3 orders of magnitude (from l'astatine (Z=33) to promethium (Z=61))**
- **for 5 different actinides (^{238}U, ^{239}Np, ^{240}Pu, ^{243}Am, ^{250}Cf)**
- **our data match with previous measurements for light fragments**

Low excitation energy produce more neutron-rich nuclei
High excitation energy produce broader isotopic distributions

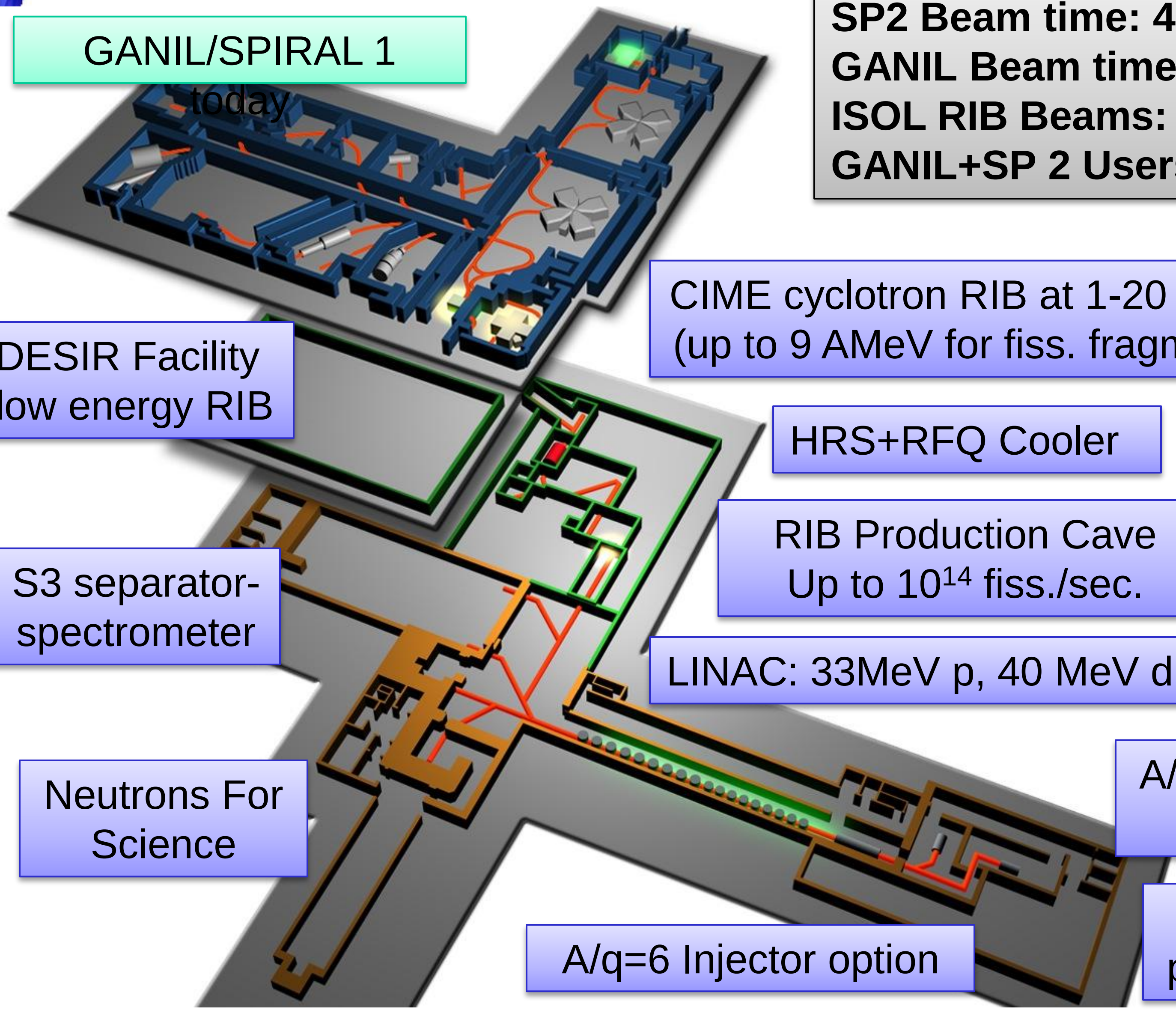
ThèseX. Derkx 2010
O. Delaune 2011
Expérience E516

A. Shrivastava, M. Caamaño, M. Rejmund, A. Navin, F. Rejmund, K. -H. Schmidt, A. Lemasson, C. Schmitt, L. Gaudefroy, K. Sieja, L. Audouin, C. O. Bacri, G. Barreau, J. Benlliure, E. Casarejos, X. Derkx, B. Fernández-Domínguez, C. Golabek, B. Jurado, T. Roger, and J. Taieb, Prompt spectroscopy of isotopically identified fission fragments , Phys. Rev. C 80, 051305 (2009)

« Isotopic resolution of fission fragments from 238U+12C transfer and fusion réactions », M. Caamaño, F. Rejmund, X. Derkx, K.-H. Schmidt, L. Audouin, C.-O. Bacri, G. Barreau, L. Gaudefroy, C. Golabek, B. Fernandez-Dominguez, B. Jurado, A. Lemasson, A. Navin, J. Benlliure, E. Casarejos, M. Rejmund, T. Roger, C. Schmitt, J. Taieb, 4th International Workshop on Nuclear Fission and Fission-Product Spectroscopy, Cadarache, France, May 2009, AIP

GANIL/SPIRAL1/SPIRAL2 facility

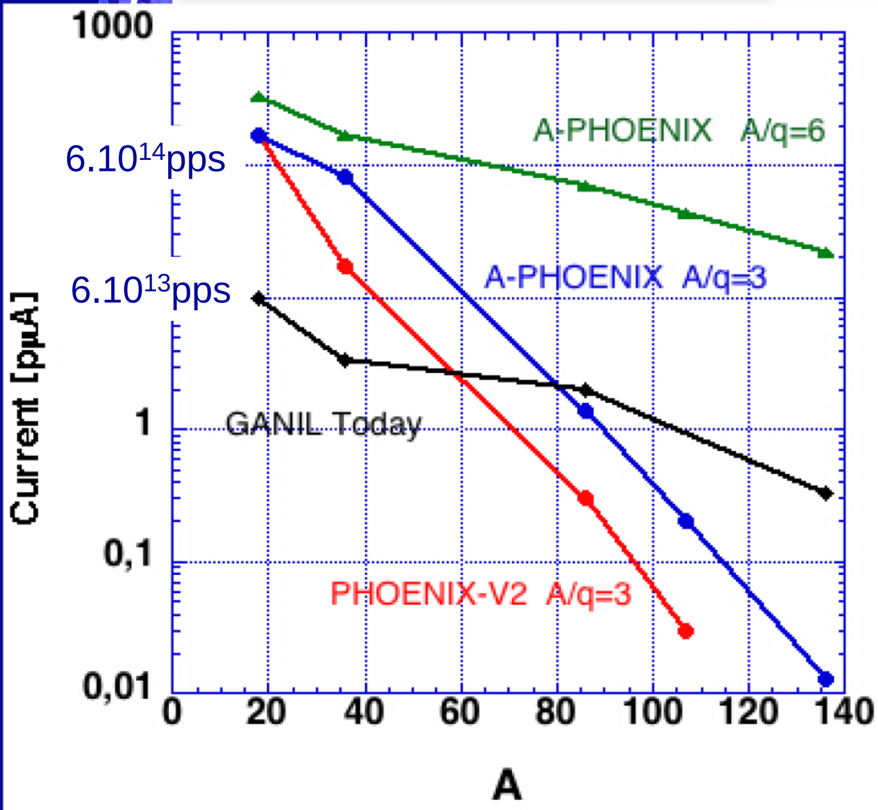
SP2 Beam time: 44 weeks/y
GANIL Beam time: 35 weeks/y
ISOL RIB Beams: 28-33 weeks/y
GANIL+SP 2 Users: 700-800/y



SPIRAL2 is one of the ESFRI list projects (40 most important EU research infrastructure projects)

LINAC stable beams

Energy = 0.75-15 *A.MeV*

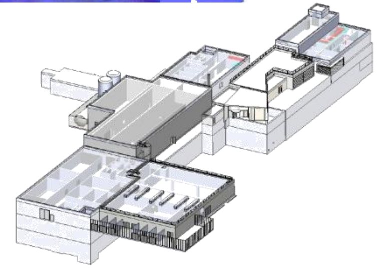


Above one or two order of magnitudes higher than present facilities

LINAC beams for the Day 1 SPIRAL2 Phase 1 experiments$^{*)}$
Based on the recommendations of SPIRAL2 SAC for the LoI
M.L. version 05/10/2009

Ion(s)	Energy Range (MeV/nucleon)	Maximum Intensity (pμA)	Date of availability$^{***)}$	Remarks
$^{1}H^{1+}$	20-33	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{2}H^{1+}$	10-20	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{4}He^{2+}$	10-20	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{12}C^{4+}$	5-7	$^{3}10^{**)}$	February 2013	S3 beam line
$^{18}O^{6+}$	5-7	$^{3}10^{**)}$	February 2013	S3 beam line
$^{22}Ne^{8+}$	5-7	$^{3}10^{**)}$	February 2013	S3 beam line
$^{40}Ar^{14+}$	4-5	$^{3}10^{**)}$	February 2013	S3 beam line
$^{28-30}Si^{10+}$ or $^{32-36}S^{12+}$	5-7	$^{3}10^{**)}$	November 2013	S3 beam line
$^{40}Ca^{14+}$	5-7	$^{3}10^{**)}$	November 2013	S3 beam line
$^{48}Ca^{16+}$	5-7	$^{3}10^{**)}$	November 2013	S3 beam line
$^{58}Ni^{18+}$	4-14	$^{3}1^{**)}$	November 2013	S3 beam line

SPIRAL2 beam schedule scenari
AEL : 16-26 Weeks available/year (more than 4 months/year)



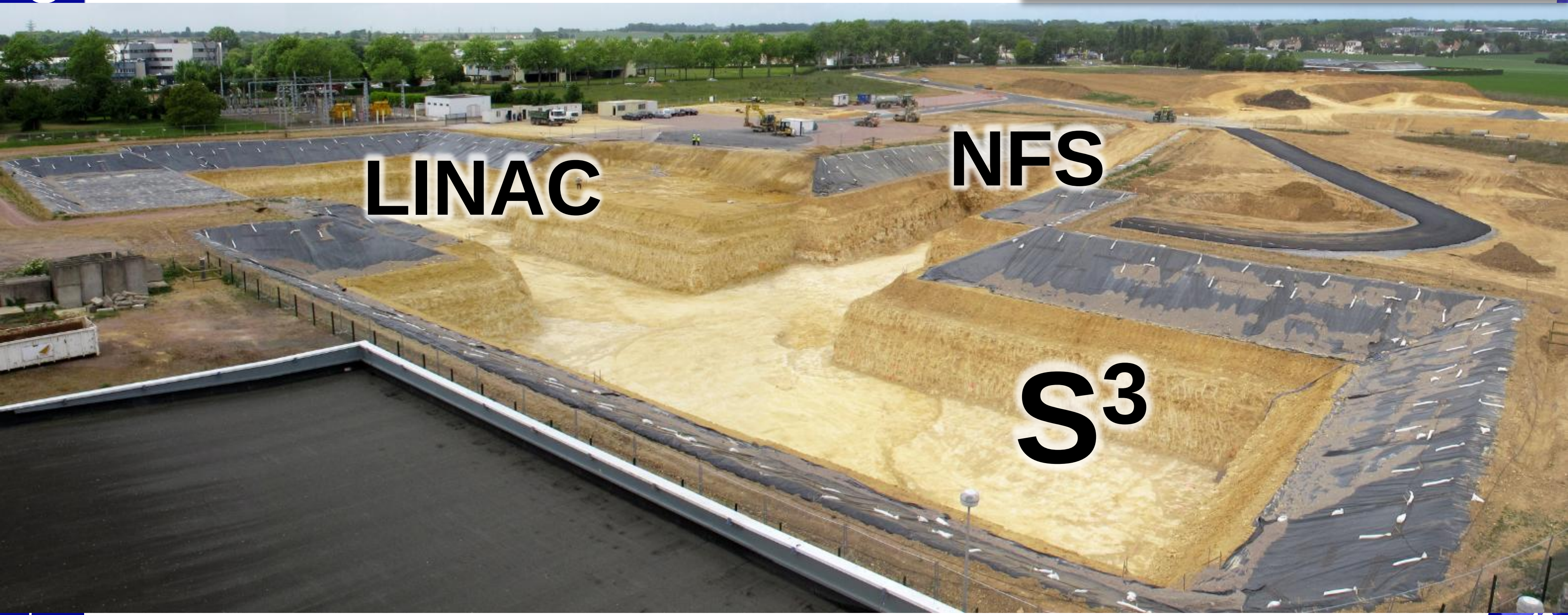
Civil construction SPIRAL2 Phase 1

✓Beginning of ground breaking: December 2010

✓End of excavation phase: May 2011

✓Beginning of construction of buildings : July 2011

✓S3 vault ready for installation : End 2012



S^3

Super Separator Spectrometer

H. Savajols (GANIL)

S^3 Collaboration (LoI signed by 100 physicist, 28 laboratoires)

ANL (US), CENBG, CSNSM, JINR-FLNR (Russia), GANIL, GSI (Germany), INFN Legnaro (Italy), IPHC, IPNL, , Irfu/CEA Saclay, IPNO, JYFL (Finland), K.U. Leuven (Belgium), Liverpool-U (UK), LNS (Italy), LPSC, MSU (US), LMU (Germany), Nanjing-U (China), Northern Illinois-U(US), SAS Bratislava (Slovaquia), Smoluchowski Inst (Poland), CEA-DAM, SUBATECH, TAMU (US), U. Mainz (Germany), York-U (UK), Vinca Institute (Serbia)

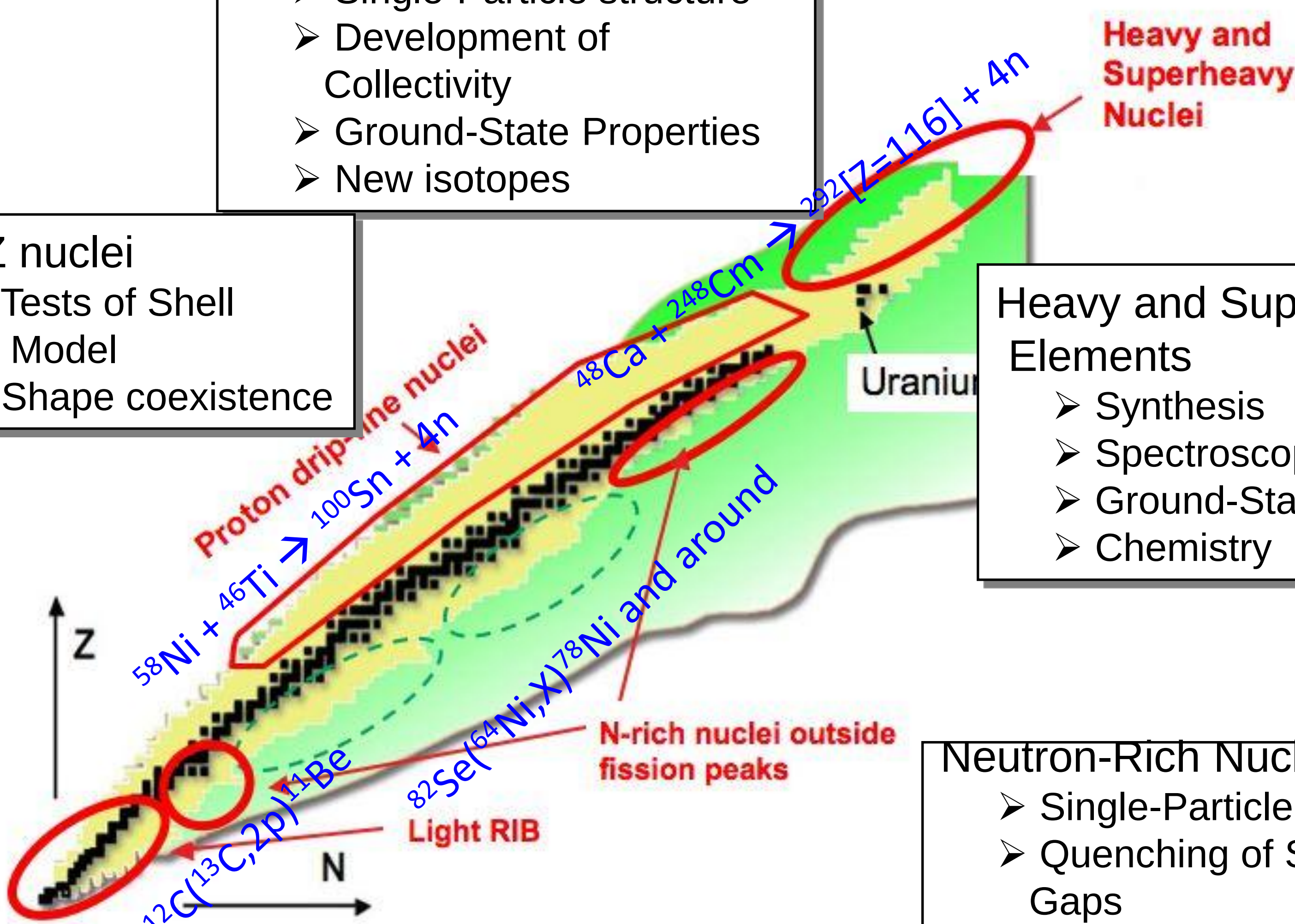
http://pro.ganil-spiral2.eu/spiral2/instrumentation/s3

Physics objectives

10^{14}part/s ➔ 10evt/day @ 1pb

Proton Dripline
- Single-Particle structure
- Development of Collectivity
- Ground-State Properties
- New isotopes

N=Z nuclei
- Tests of Shell Model
- Shape coexistence



Heavy and Superheavy Elements
- Synthesis
- Spectroscopy and Structure
- Ground-State Properties
- Chemistry

Neutron-Rich Nuclei
- Single-Particle structure
- Quenching of Shell Gaps
- Ground-State Properties
- New isotopes

13 LoIs submitted
LoIs signed by 170 physicists
Requested beam time phase 1: 380 days

SHE Studies

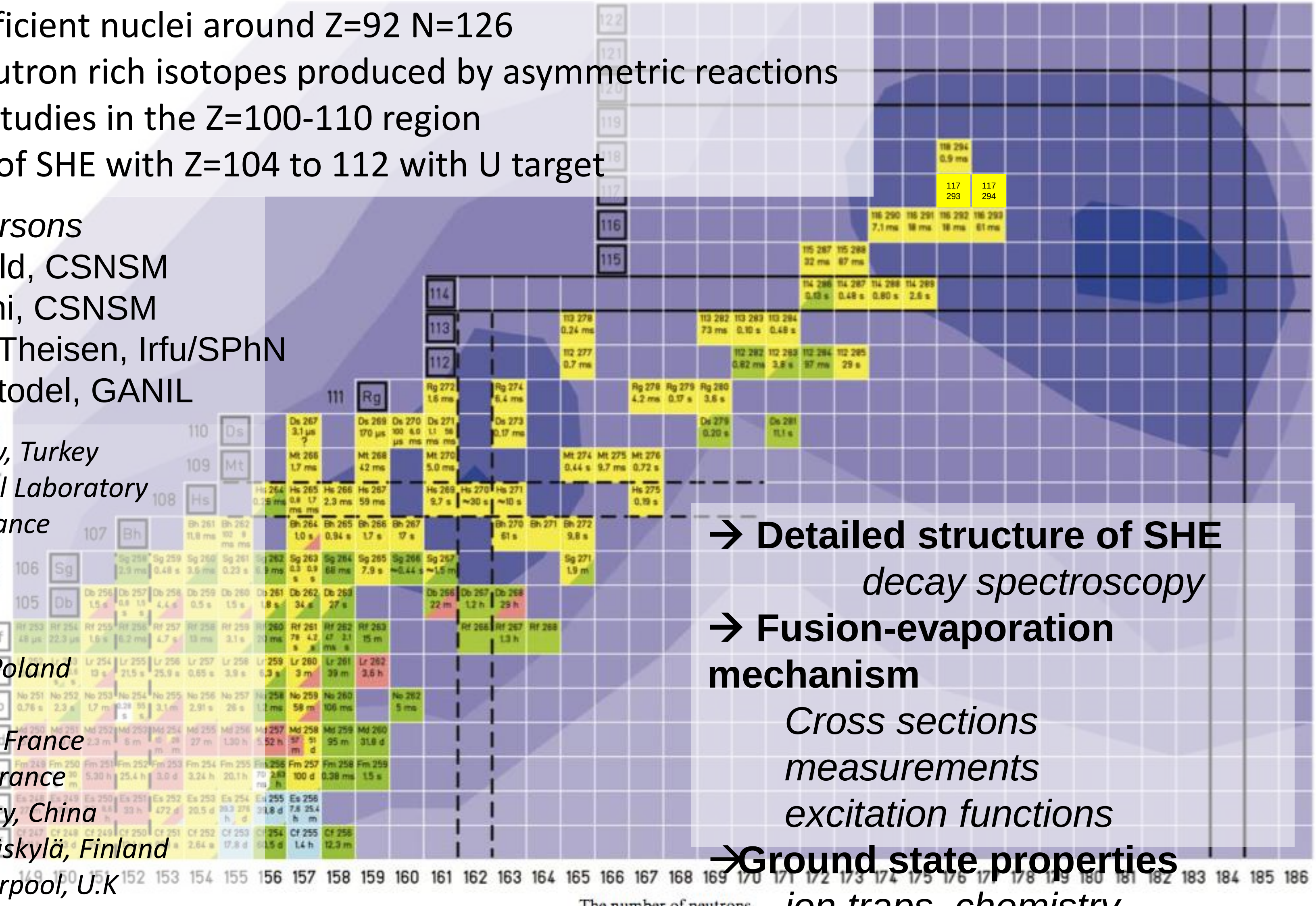
PRODUCTION AND SPECTROSCOPY OF HEAVY AND SUPERHEAVY ELEMENTS USING S^3 AND LINAG (P. GREENLEES, JYVÄSKYLÄ)

- Neutron deficient nuclei around Z=92 N=126
- Study of neutron rich isotopes produced by asymmetric reactions
- Isomerism studies in the Z=100-110 region
- Production of SHE with Z=104 to 112 with U target

Co-Spokespersons

- Karl Haushild, CSNSM
- Amel Korichi, CSNSM
- Christophe Theisen, Irfu/SPhN
- Christelle Stodel, GANIL

Ankara University, Turkey
Argonne National Laboratory
CSNSM Orsay, France
FLNR JINR Dubna
GANIL, France
GSI, Germany
IFJ PAN Krakow, Poland
IPN Lyon, France
IPHC Strasbourg, France
Irfu CEA Saclay, France
Nanjing University, China
University of Jyväskylä, Finland
University of Liverpool, U.K



→ **Detailed structure of SHE**
decay spectroscopy

→ **Fusion-evaporation mechanism**
Cross sections measurements
excitation functions

→ **Ground state properties**
ion traps, chemistry

Study of closed shells

Spherical closed shell

N=184 : common to all models, strong effect observed

Z=114, 120, 126 ?

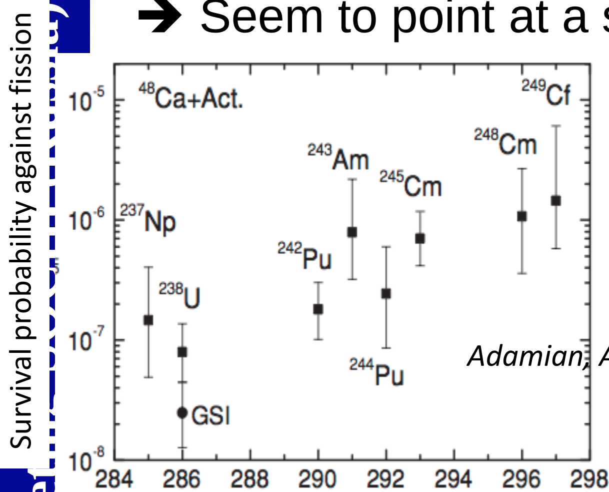
Observables

Decay properties (alpha, fission)

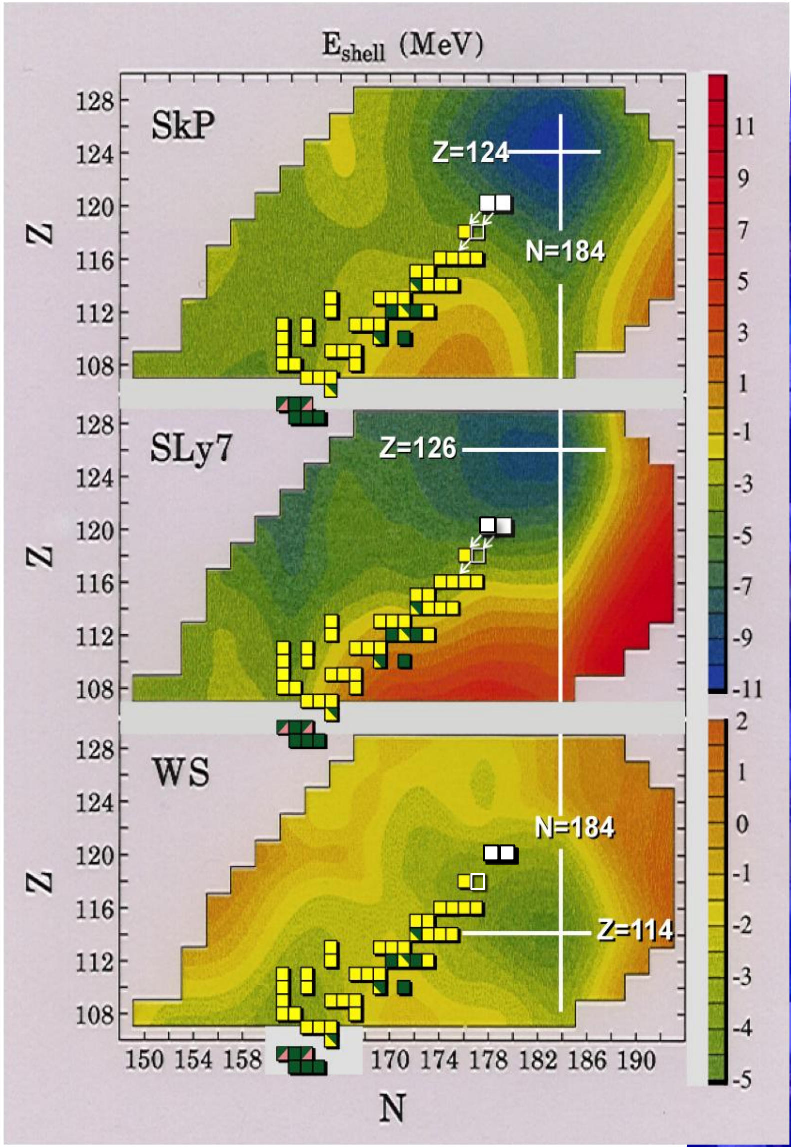
➔Decays half-lives very sensitive to shell closure: Z=114 is weak, decay times gets shorter for Z=120

Production cross sections

➔ Seem to point at a shell closure for Z ≥ 120



Adamian, Antonenko & Sargsyan (2009)



Deformed closed shell around ^{270}Hs

e.g. $^{40}Ar+^{238}U \rightarrow ^{274}Ds+4n \rightarrow ^{270}Hs + \alpha$

I=50pμA ➔ 190evt/week@σ_{th}=2pb

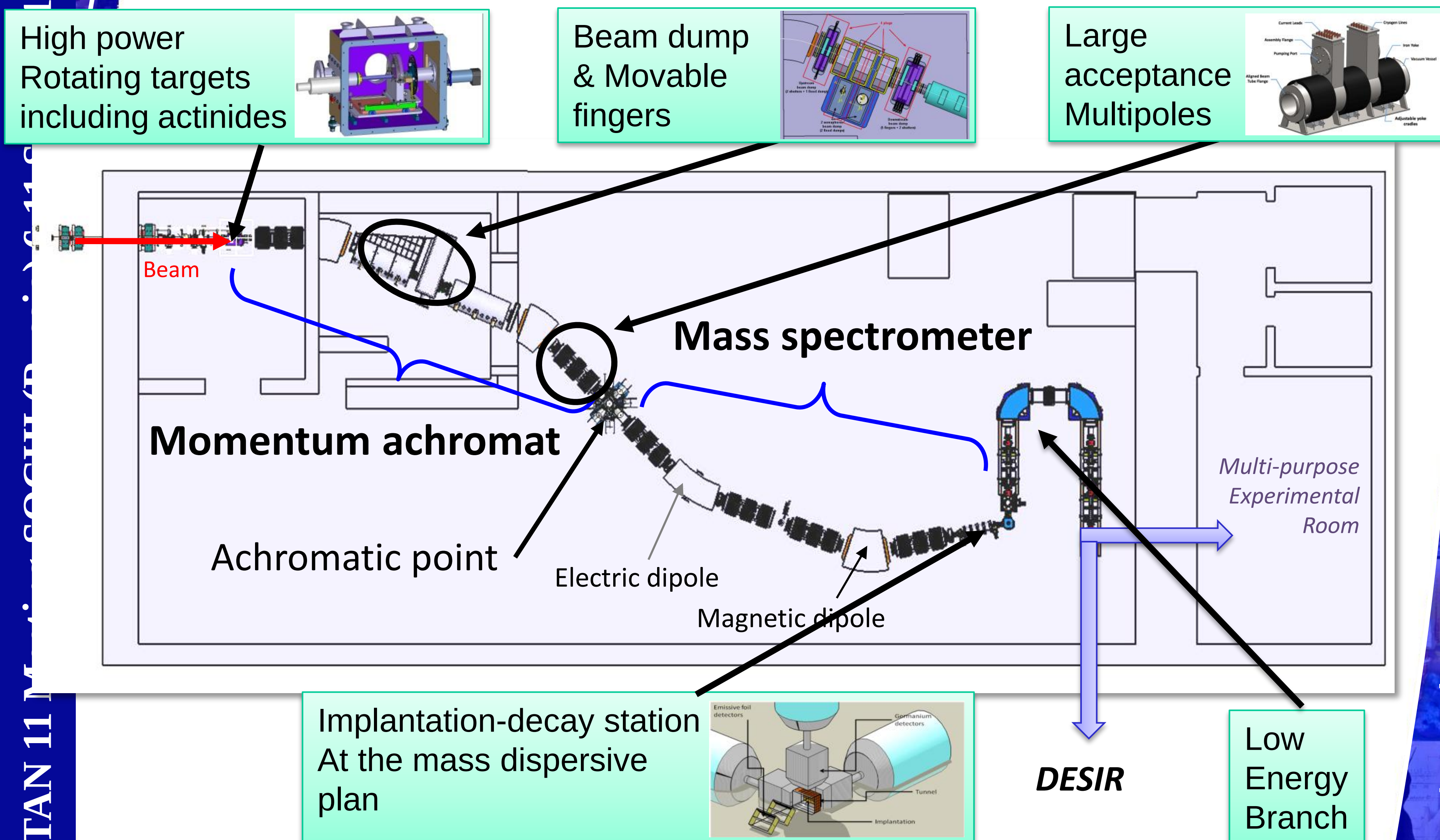
→ Detailed α, e-, γ decay spectroscopy

6-11 Sept 2011

NIM B 266, 4162 (2008), IJMPE-Nuclear Physics, Vol. 18, (2009)
Tours 2009 Proceedings, AIP conference series

S^3 Baseline

Principle : Two-stage selection (Bρ & m/q) that will achieve very good rejection of both the beam and adjacent mass channels of reaction products



S^3 performances for SHE

$^{48}Ca + ^{248}Cm \rightarrow ^{292}116 + 4n$

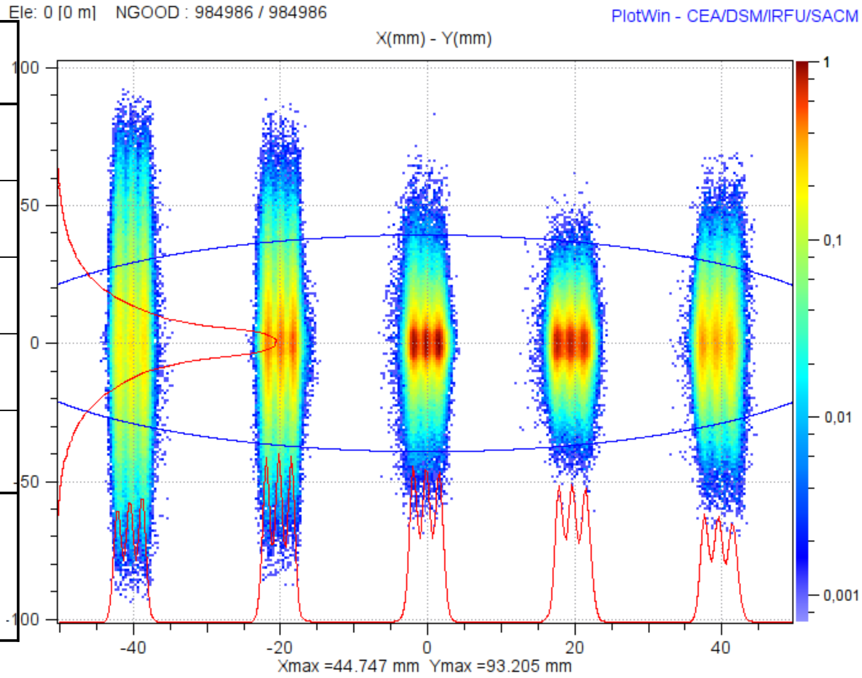
I=10pµA – 300µg/cm^2 – σ=3pb

- *Random interaction point in target*
- *Angular straggling from Meyer + evaporation*
- *Q distribution from Shima-Sagaïdak-Yeremin*
- *All order ray-tracing with field maps*

Transmission

+Q	Population %	Transmission %
18	15.3	39
19	17.3	85
20	16.2	87
21	12.6	75
22	8.4	29
Folded transmission :		47%

Image at focal plane



➔ 40 implantations/week

➔ M/dM= 374 FWHM

Simulations by D. Boutin (Ganil); O. Delferrière J. Payet (Irfu/SACM); F. Déchery (Irfu/SPhN)

Towards the heaviest elements : Reaching Z=120

Possible reactions :

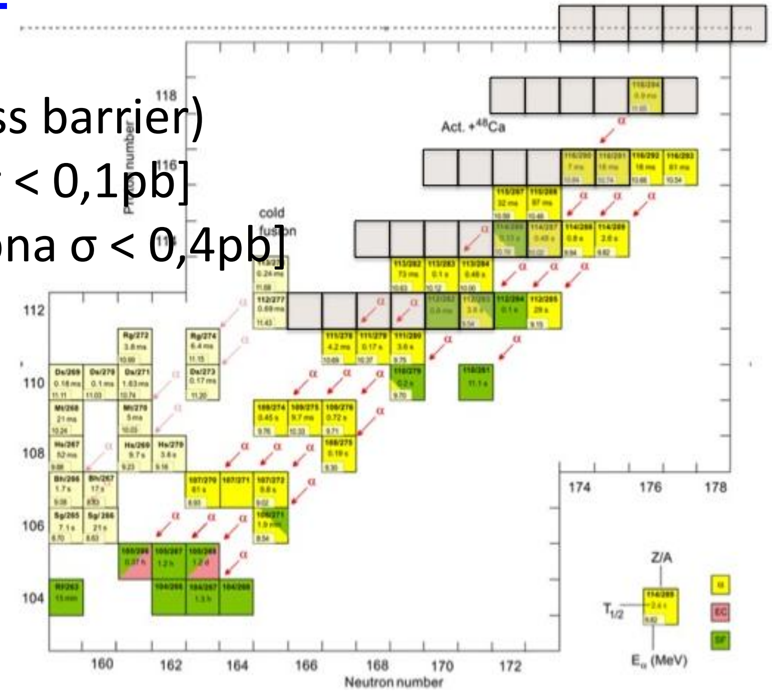
$^{88}Sr + ^{208}Pb \rightarrow ^{296}120^*$ (E*=-4,5MeV @ Bass barrier)

$^{64}Ni + ^{238}U \rightarrow ^{302}120^*$ (E*=26.4MeV) [GSI σ < 0,1pb]

$^{58}Fe + ^{242}Pu \rightarrow ^{300}120^*$ (E*=30,3MeV) [Dubna σ < 0,4pb]

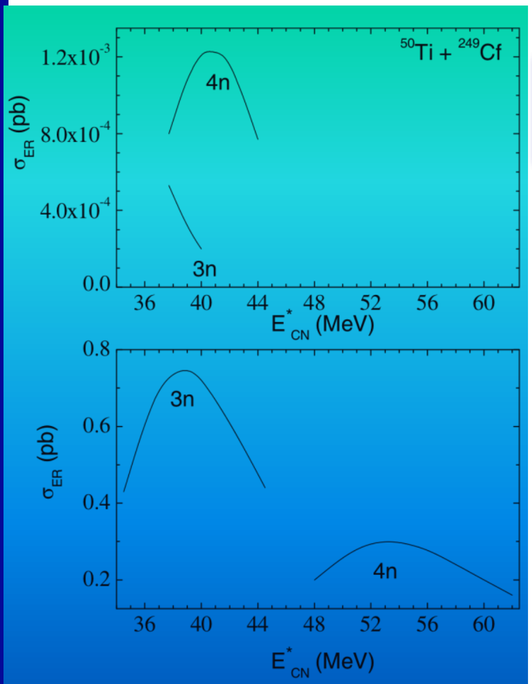
$^{54}Cr + ^{248}Cm \rightarrow ^{302}120^*$ (E*=30,5MeV)

$^{50}Ti + ^{249}Cf \rightarrow ^{299}120^*$ (E*=28,6MeV)



Various σ predictions

- Reaction model ?
- Real stability of the nuclei ?



G.G. Adamian et al. EPJA 41 (2009) 23

→ must reach the 0,01pb sensitivity

Beam = 10pμA

Target = 300μg/cm²

Effective beam on target = 80%

Transmission = 50%

α Detection efficiency = 70%

→ σ(1 α-event) = 0,007pb for 3 months

But before : SHE with Z=104-112 with U targets

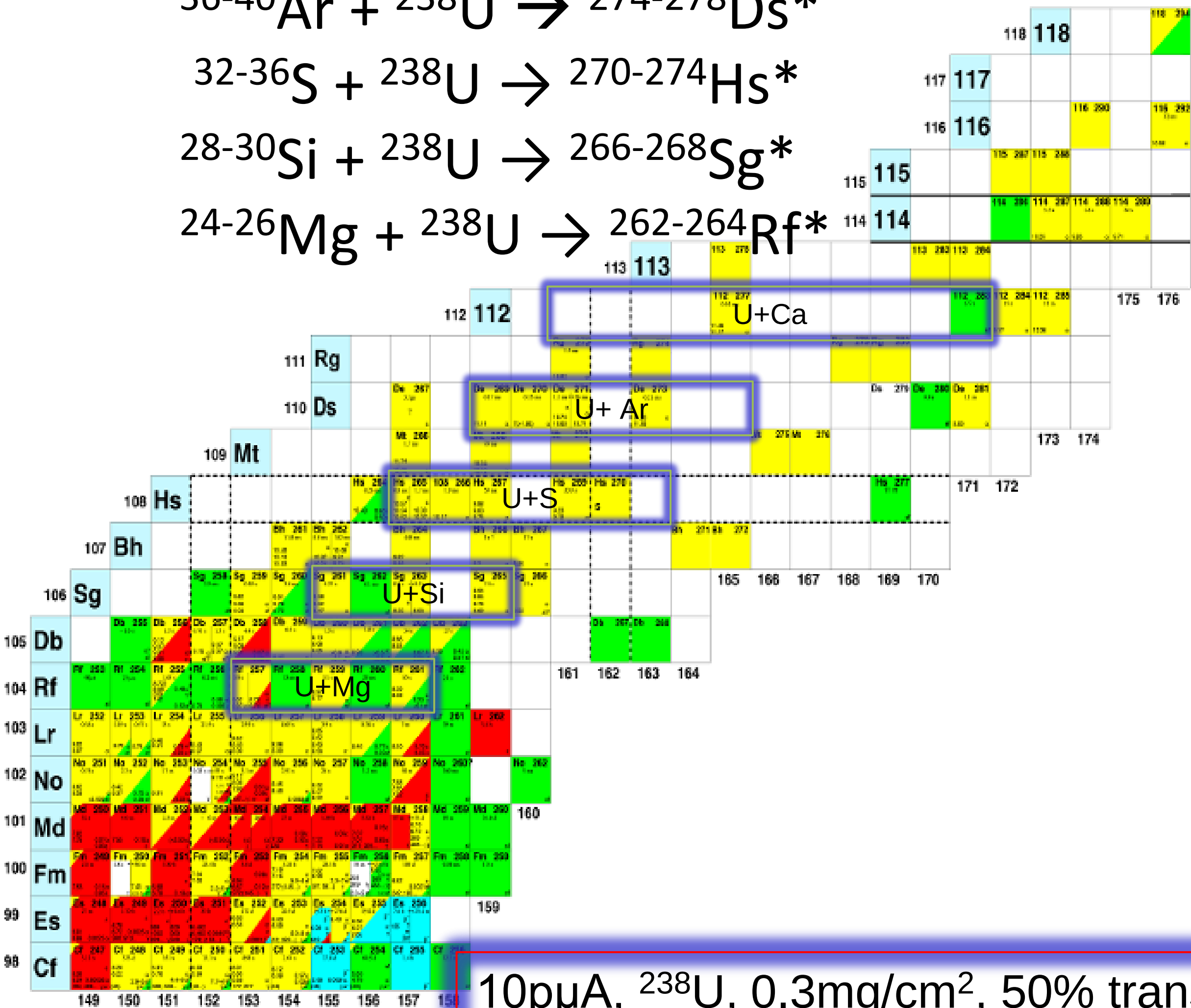
$^{40-48}Ca + ^{238}U \rightarrow ^{278-286}112^*$

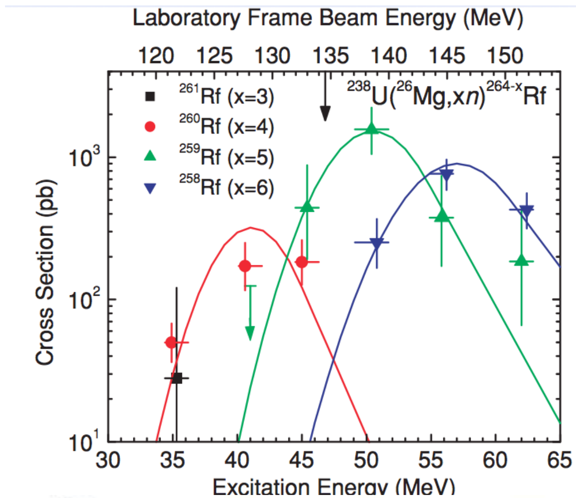
$^{36-40}Ar + ^{238}U \rightarrow ^{274-278}Ds^*$

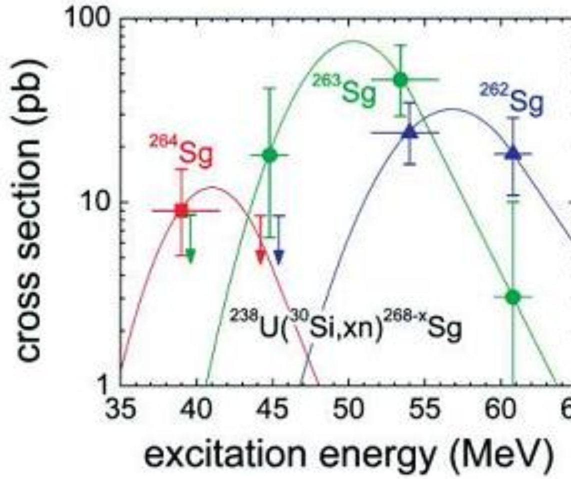
$^{32-36}S + ^{238}U \rightarrow ^{270-274}Hs^*$

$^{28-30}Si + ^{238}U \rightarrow ^{266-268}Sg^*$

$^{24-26}Mg + ^{238}U \rightarrow ^{262-264}Rf^*$





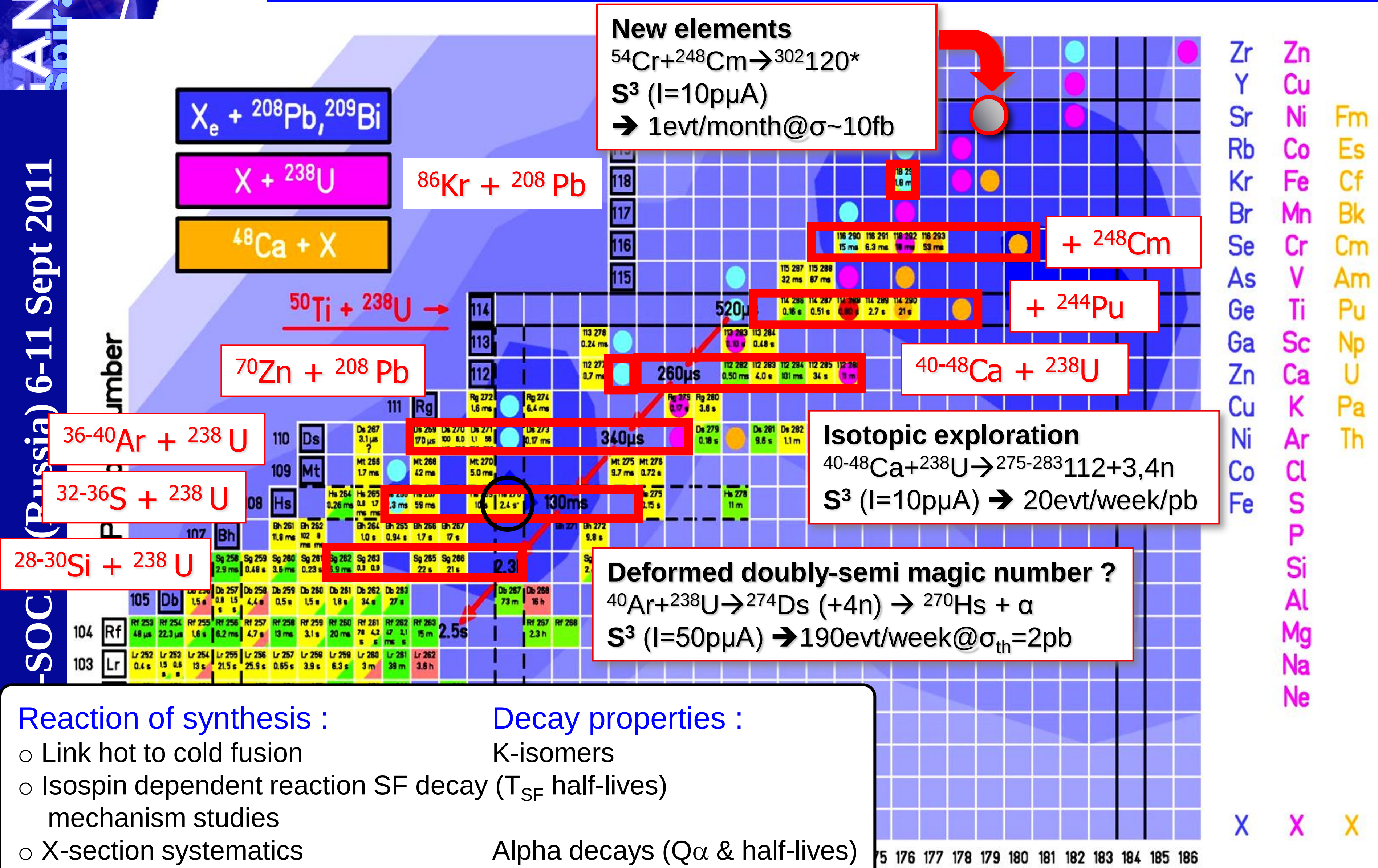


K.E.Gregorich et al., PRC 74, 044611 (2006) J.M.Gates et al., PRC 77, 034603 (2008)

10pμA, ^{238}U, 0.3mg/cm^2, 50% transmission, 55% full energy α

➔ 80 α evts/week @ 10pb

Studying, completing, enlarging



Reaction of synthesis :
- ○ Link hot to cold fusion
- ○ Isospin dependent reaction mechanism studies
- ○ X-section systematics

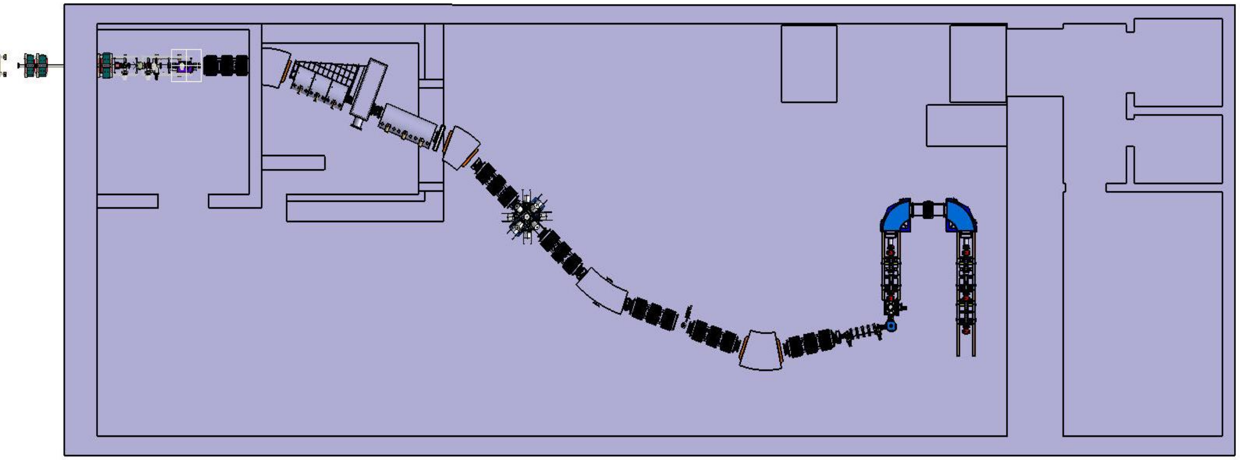
Decay properties :
- K-isomers
- SF decay (T_{SF} half-lives)
- Alpha decays (Qα & half-lives)

GS properties
- ○ Mass measurements …

Trans-actinide chemistry

Conclusions

S^3 will be a unique tool to study of Superheavy Elements



→High intensity beams
→Large transmission
→Mass resolution
→Dedicated detection

➔Structure of nuclei that are today barely known

detailed spectroscopy, new isomers, assignments of states

➔Less sensitive techniques can be applied to the heaviest nuclei

high resolution mass measurement with ion traps

➔Study of fine effects with a high cross section sensitivity

isospin dependance of cross sections

➔ Reach new elements ?

Civil engineering
SPIRAL2 ,May 20 2011

-10m Underground Floor Aug 2011

Infrastructure

Thanks to Orsay colleagues,Christelle Stoedel,Fanny Farget ,M.Morjean ,Herve Savajols S3 and SPIRAL2 Project group

Thanks for your patience and come to visit us At GANIL-SPIRAL2 new facility

END

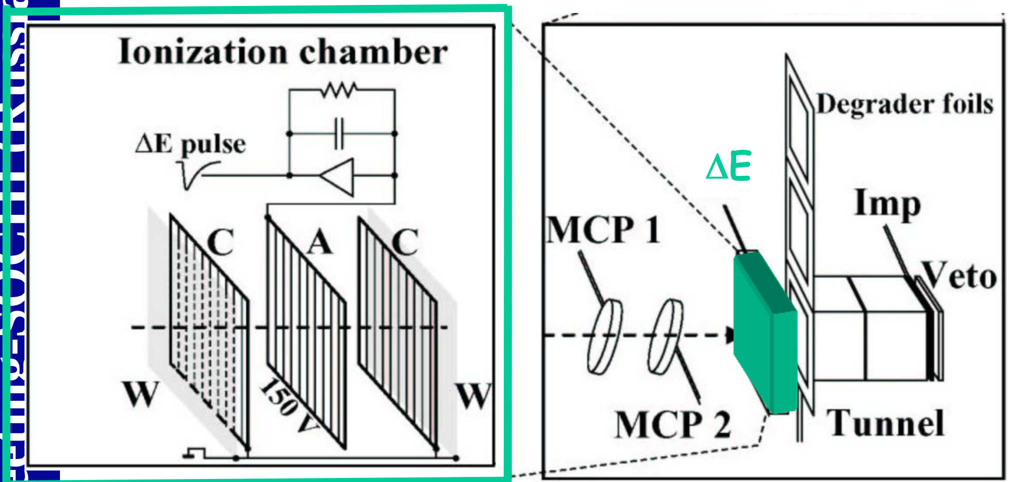
LISE: Small cross-sections measurements in cold fusion reactions

2002 : inverse kinematics

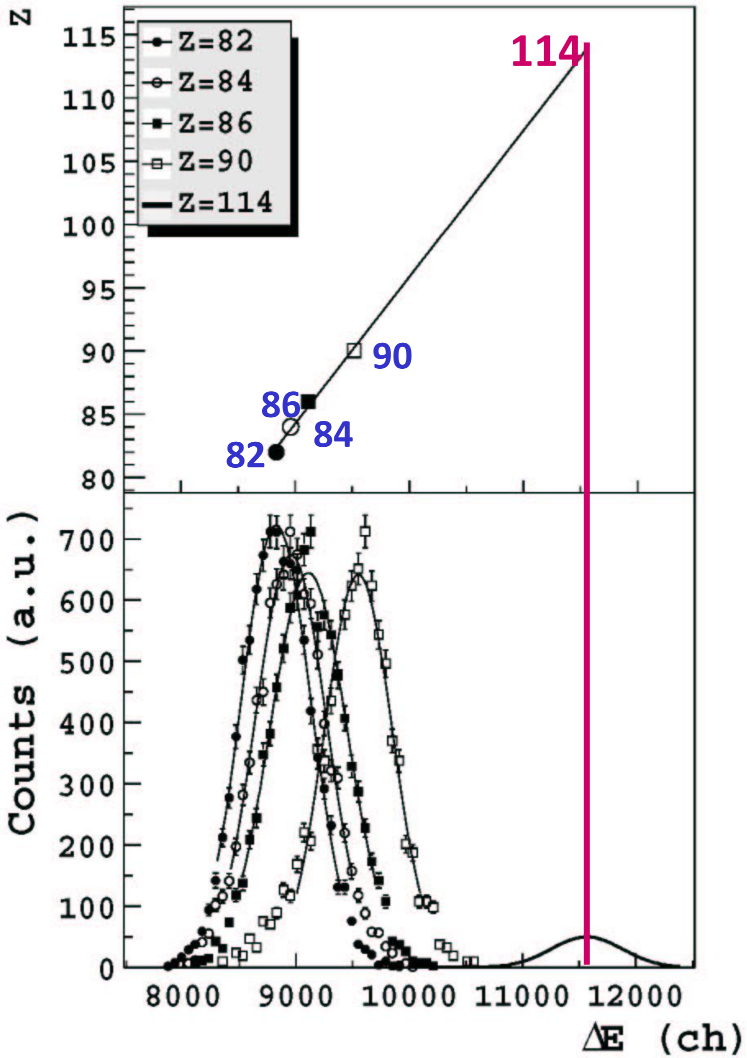
$^{208}Pb + ^{51}V // ^{12}C // ^{18}O$

Ionisation chamber

test for coulomb excitation



Detection chamber

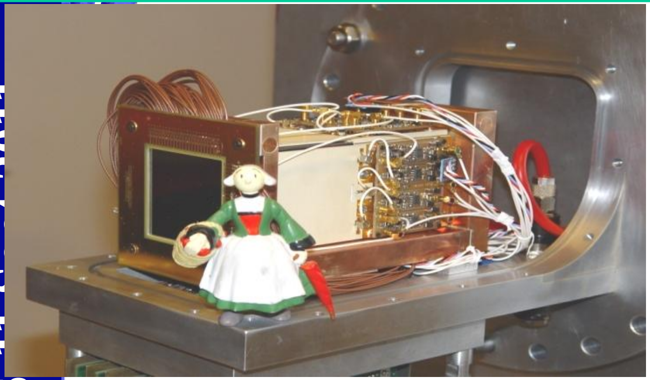


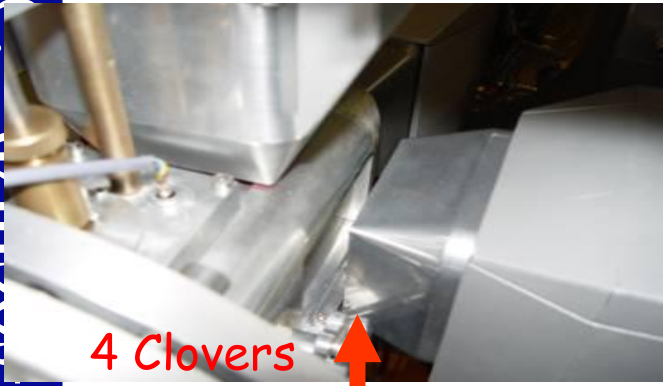
A. Wieloch et al, NIM A 517 (2004) 364-371

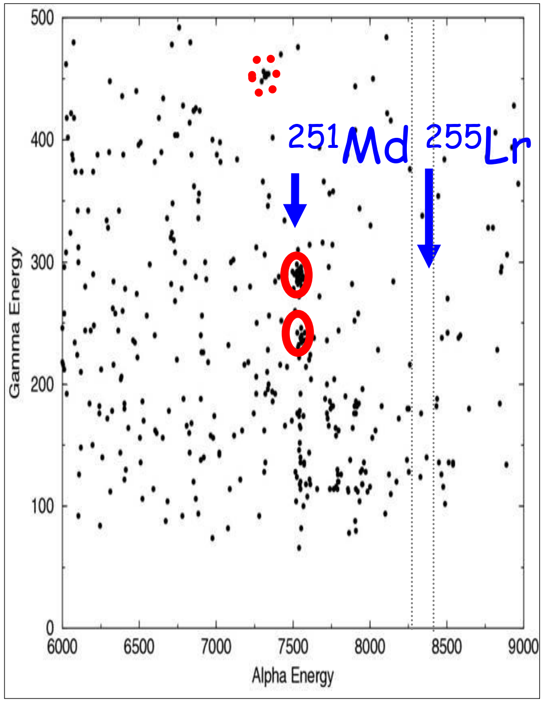
Spectroscopy of transfermium

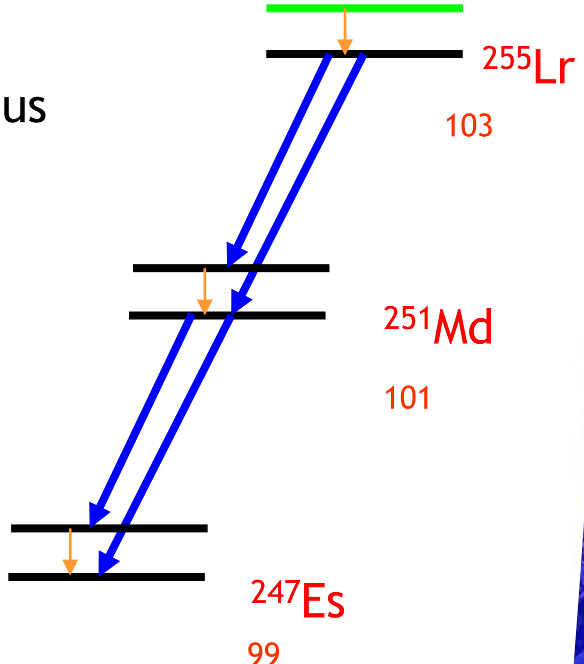
$^{48}Ca + ^{209}Bi \rightarrow ^{255}Lr + 2n \rightarrow ^{251}Md + \alpha$

^{251}Md odd-A nucleus









- New isomeric 7/2$^-$ state in ^{255m}Lr
- Excited states in ^{251}Md
- $Q_{\alpha(gs-gs)}$ for ^{255}Lr revised
- Spin and parity of ground- and excited- states from γ-ray, multipolarities, E(α-decay) and HF
- HFB calculations OK for 7/2$^-$ and 7/2$^+$ states

DAPNIA/SPhN CEN Saclay
Univ.Jyvaskyla, Finland
JINR, Dubna, Russia
Univ. Liverpool, U.K.
G.S.I., Darmstadt
C.S.N.S.M., Orsay
I.R.E.S., Strasbourg
I.F.U., Krakow
GANIL, Caen, LPC, Caen

A. Chatillon et al, European Physical Journal A 2006 30 397-411

Synthesis of very heavy elements: Fusion with (nearly-)symmetric channel

Experimental interest

• Mass symmetry
☹ Synthesis of new super-heavy elements (Z)
•Mass symmetry + shell effects
☺ Synthesis of new heavy (…super) heavy isotopes
☺ Study of fusion mechanisms

Advantages and drawbacks….

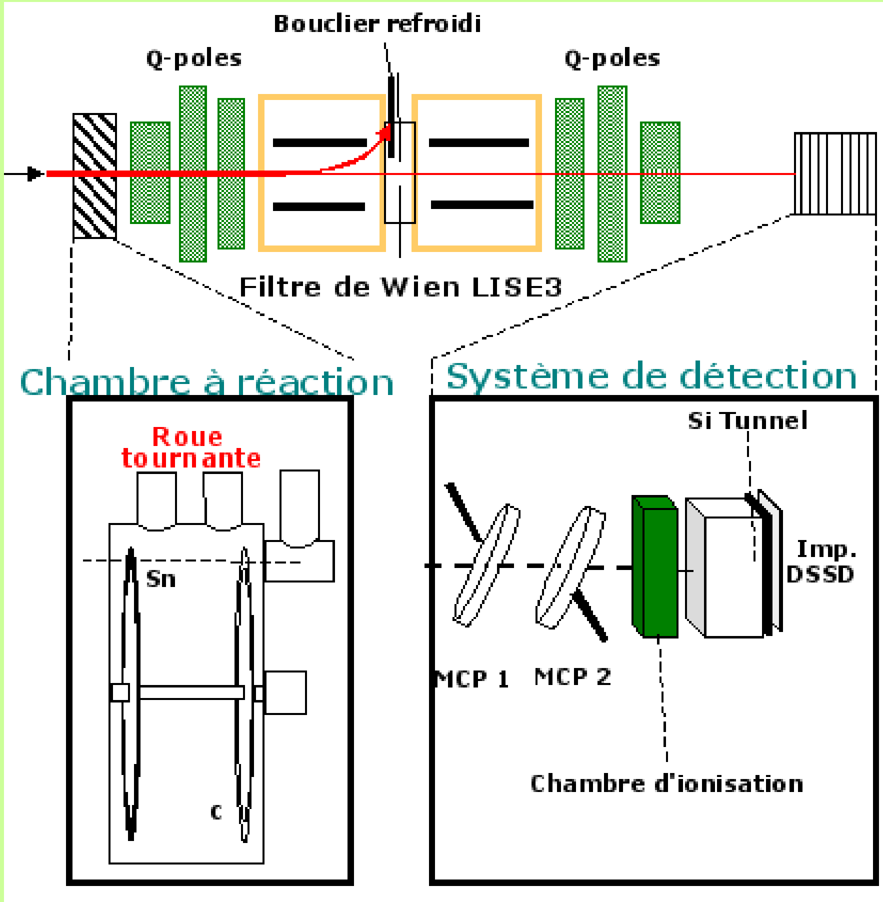
☺ Good transmission (forward focused kinematics)
☹ Very difficult velocity separation

Future : SPIRAL2@GANIL

⇒Highly intense beams of neutron rich nuclei (Xe, Kr)
Systematic study of the neutron influence on fusion
⇒RIB SPIRAL2 + LISE 3 == Fusion with symmetric channel possible ?

Experimental set-up

Experimental Set-up

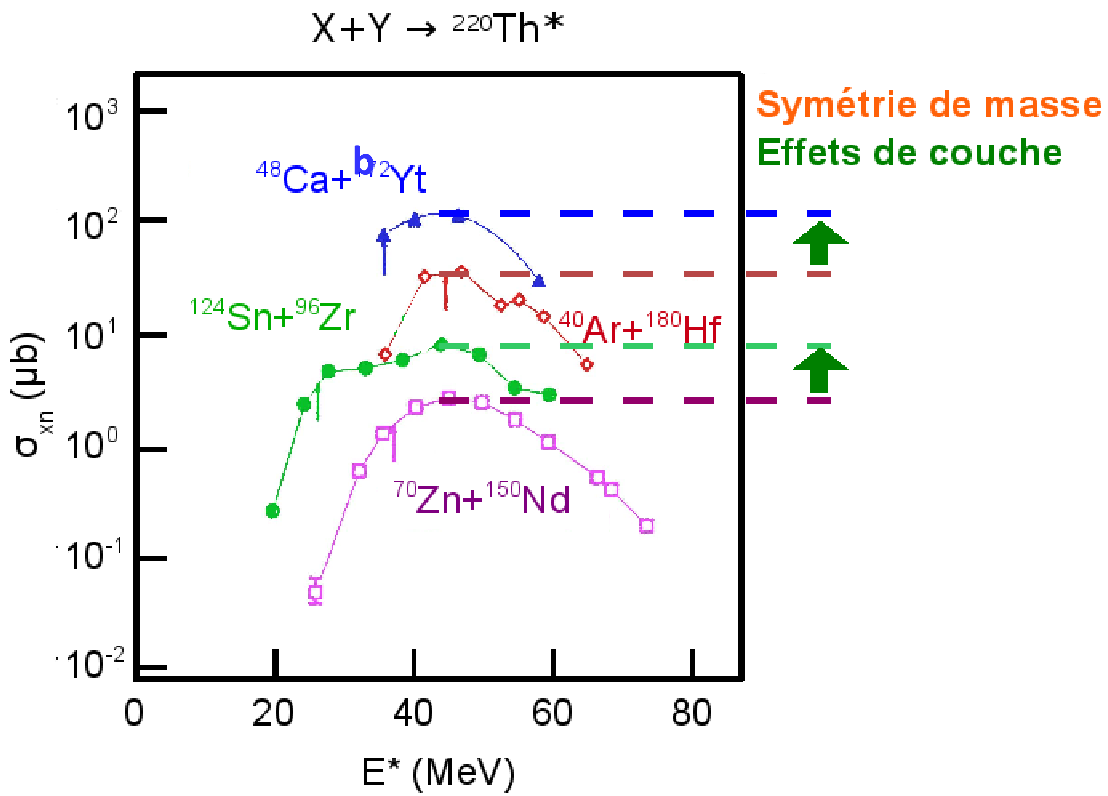


- **Beam:**
  - $^{136}Xe^{18+}$ @ 4.6 MeV/u
  - ≈2 μAe (≈7.10^{11} pps)
- **Targets:**
  - ^{124}Sn (99%) – 400 μg/cm²
  - $\delta E^*=\pm3$ MeV
- **Wien filter:**
  - E= 200 kV/m, B=190 G
  - $\varepsilon_{trans} \approx 37\%$
  - Rejection ≈ 5.10^8
  - Test ☹
- **Detection system:**
  - Micro-channel plates (MCP)
  - ~~Ionisation chamber (Z)~~
  - Si BEST (E) 48*48
  - Universal clock

Asymmetry and shell effect

Ex.: influence of the entrance channel for the formation of ^{220}Th*
Fusion evaporation cross-sections (xn)

- Mass symmetry ☹
- Shell effects (use of highly bound nuclei) ☺



Sydney Gales

Analysis (1)

Events analysis

Isotope	^{257}Rf	^{258}Rf	^{259}Rf
ΔT_1	13,5 s	44,1 ms	7,5 s
ΔT_2	5,1 min	2,75 min	9,3 min

⇒ Observed correlations

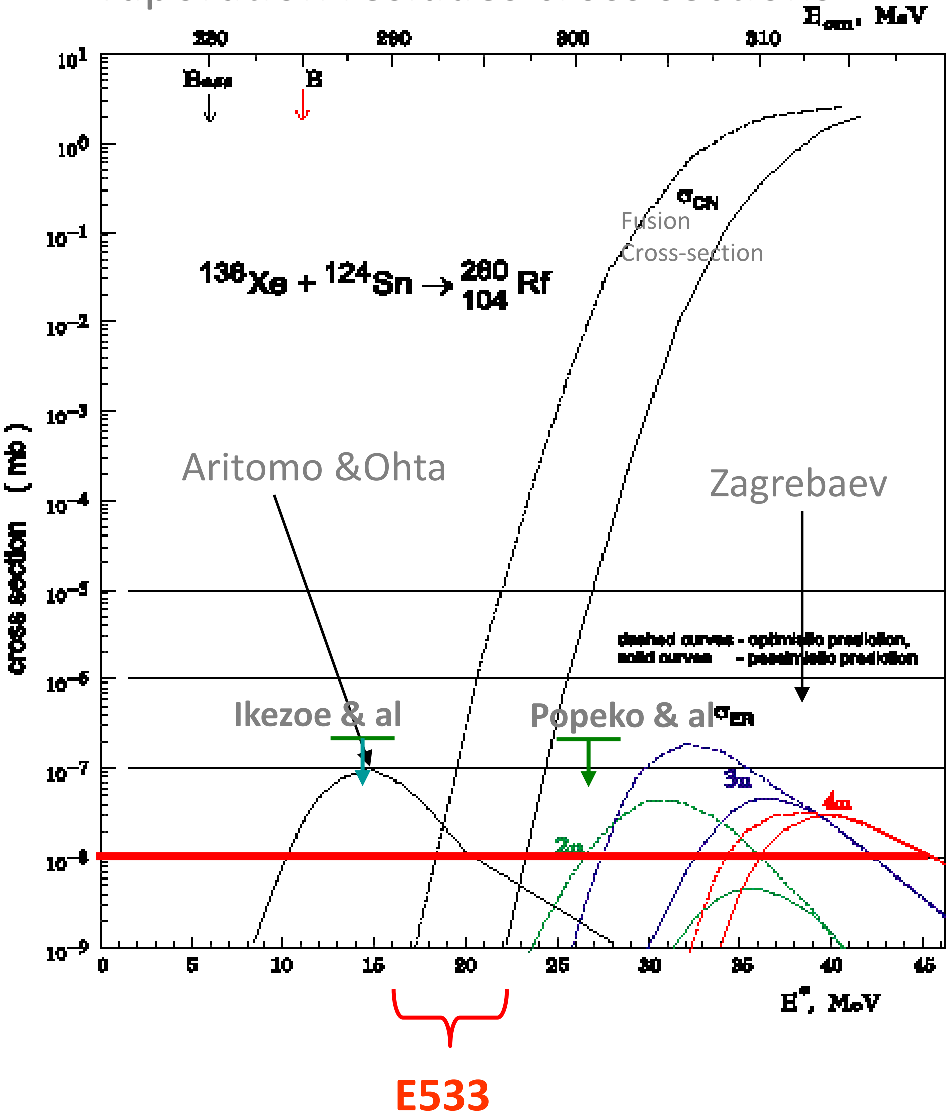
$\{ER-\alpha_1\}$	105	0	22
$\{ER-\alpha_1-\alpha_2\}$	0	0	0
$\{ER-\alpha_1\}$		9	

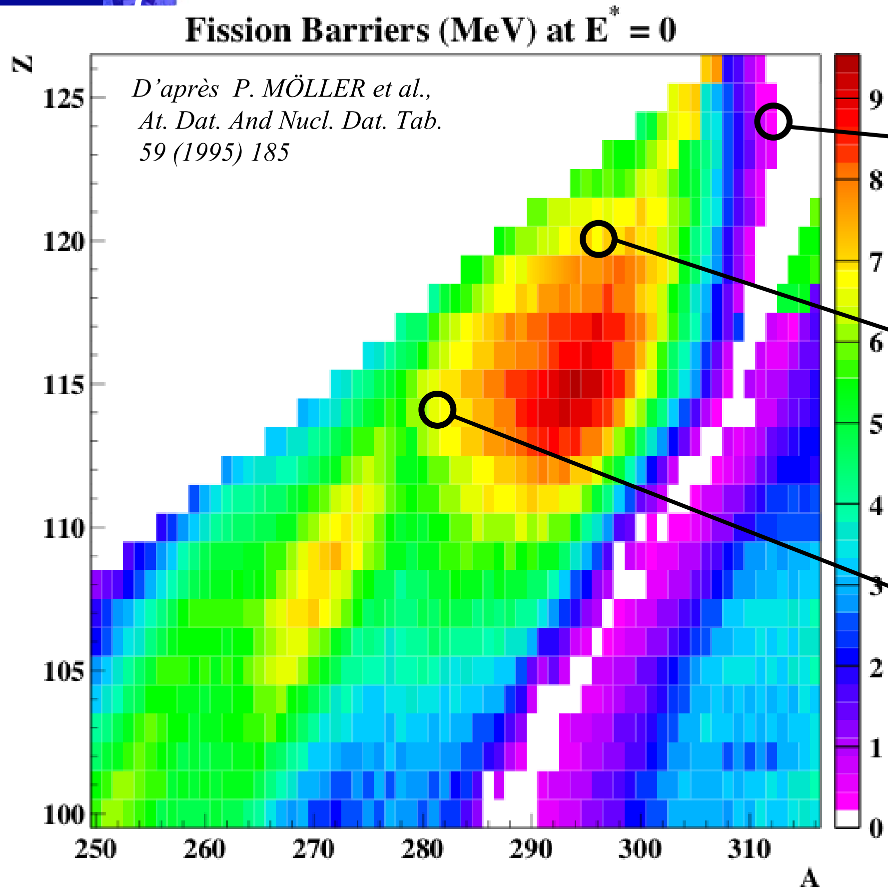
⇒ Estimation of random correlations (inverse reading of data)

$\{ER-\alpha_1\}$	103	0	14
$\{ER-\alpha_1-\alpha_2\}$	2	0	0
$\{ER-\alpha_1\}$		12	

Observed correlations ≡ random correlations

Evaporation residues cross sections





Z = 124 (^{238}U + Ge)

At least 12% of capture events with fission times longer than 10^{-18} s

Z = 120 (^{238}U + Ni)

At least 10% of capture events with fission times longer than 10^{-18} s

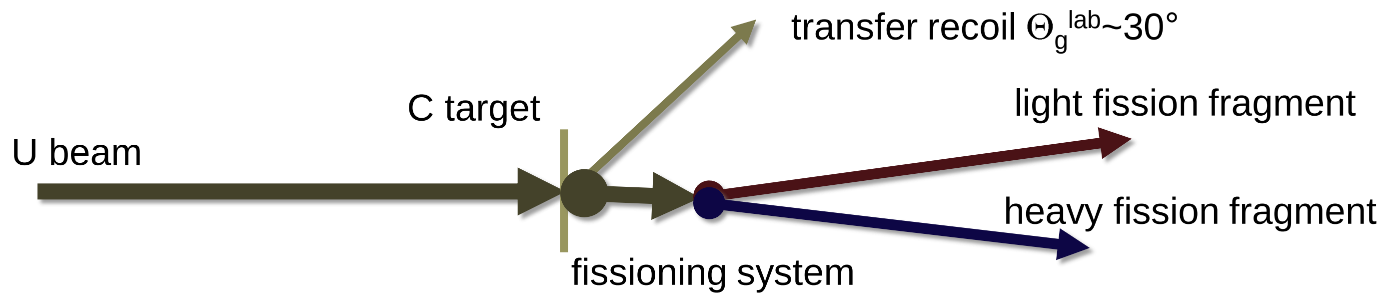
Z = 114 (^{208}Pb + Ge)

No capture events *(below the sensitivity threshold)* with fission times longer than 10^{-18} s

Z = 120 and 124 very stable with respect to fission

Asymmetric fission for Z = 120 and 124

$^{238}U + ^{12}C$ @ 6.1 MeV/u



transfer

- U, Np, Pu, Am, Cm
- different **E***

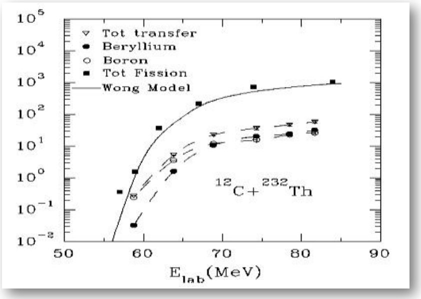
transfer - fission

~ 100 mbarn

Angle de grazing ~35°

fusion - fission

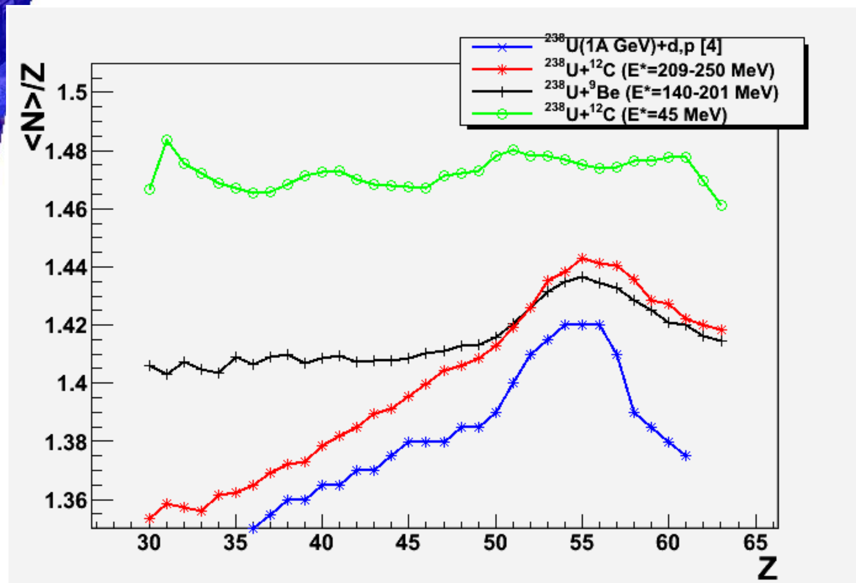
~ 1000 mbarn

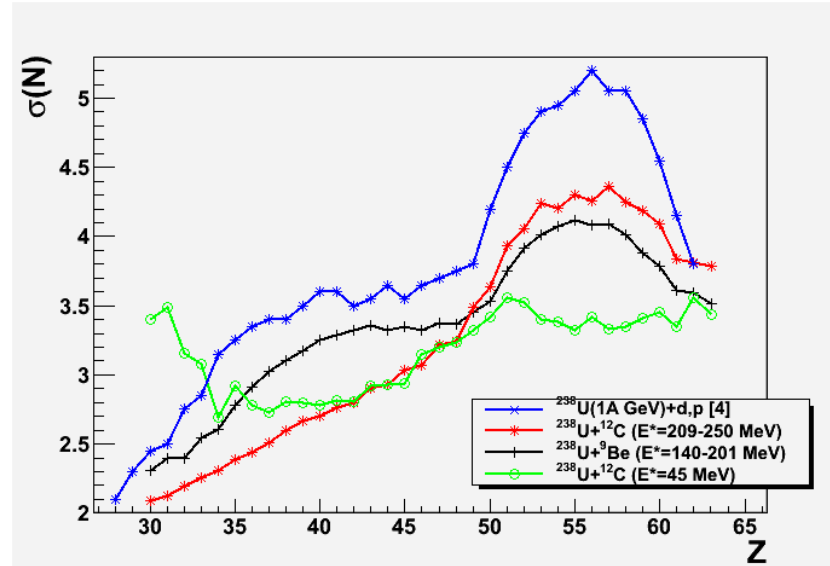


D.C. Biswas et al. *PRC 56 (1997) 1926*

Evolution of global fission-fragment characteristics with excitation energy

Comparison of fusion-fission isotopic distributions at different beam energy.
Comparison with spallation data.





Low excitation energy produce more neutron-rich nuclei
High excitation energy produce broader isotopic distributions

Thèse
X. Derkx 2010
O. Delaune 2011

Expérience E516

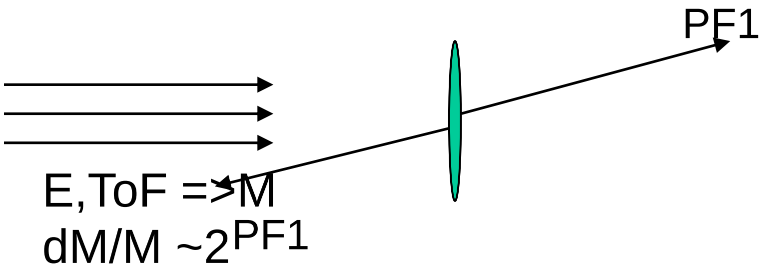
A. Shrivastava, M. Caamaño, M. Rejmund, A. Navin, F. Rejmund, K. -H. Schmidt, A. Lemasson, C. Schmitt, L. Gaudefroy, K. Sieja, L. Audouin, C. O. Bacri, G. Barreau, J. Benlliure, E. Casarejos, X. Derkx, B. Fernández-Domínguez, C. Golabek, B. Jurado, T. Roger, and J. Taieb, Prompt spectroscopy of isotopically identified fission fragments , Phys. Rev. C 80, 051305 (2009)

« Isotopic resolution of fission fragments from 238U+12C transfer and fusion réactions », M. Caamaño, F. Rejmund, X. Derkx, K.-H. Schmidt, L. Audouin, C.-O. Bacri, G. Barreau, L. Gaudefroy, C. Golabek, B. Fernandez-Dominguez, B. Jurado, A. Lemasson, A. Navin, J. Benlliure, E. Casarejos, M. Rejmund, T. Roger, C. Schmitt, J. Taieb, 4th International Workshop on Nuclear Fission and Fission-Product Spectroscopy, Cadarache, France, May 2009, AIP

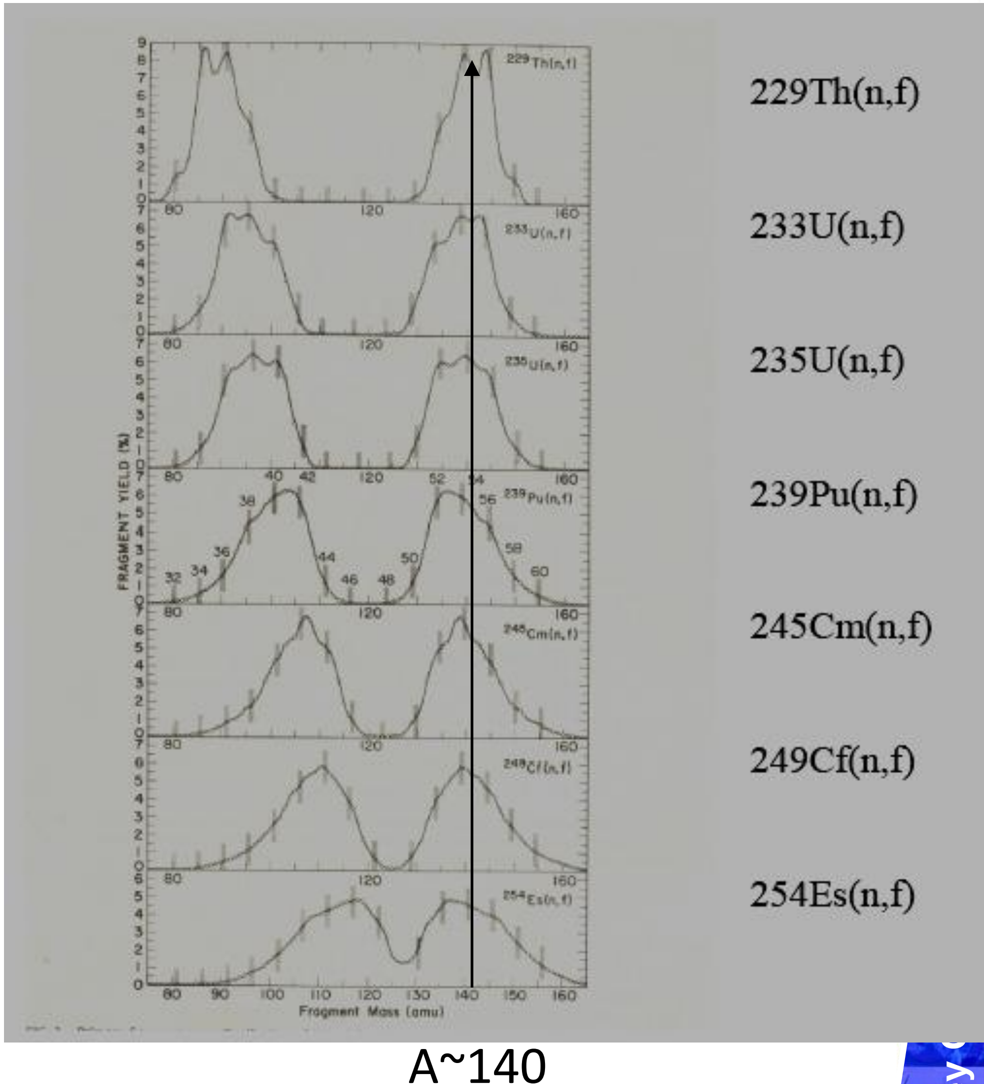
Influence de la structure en couche dans la fission

- **Mass distribution**

n

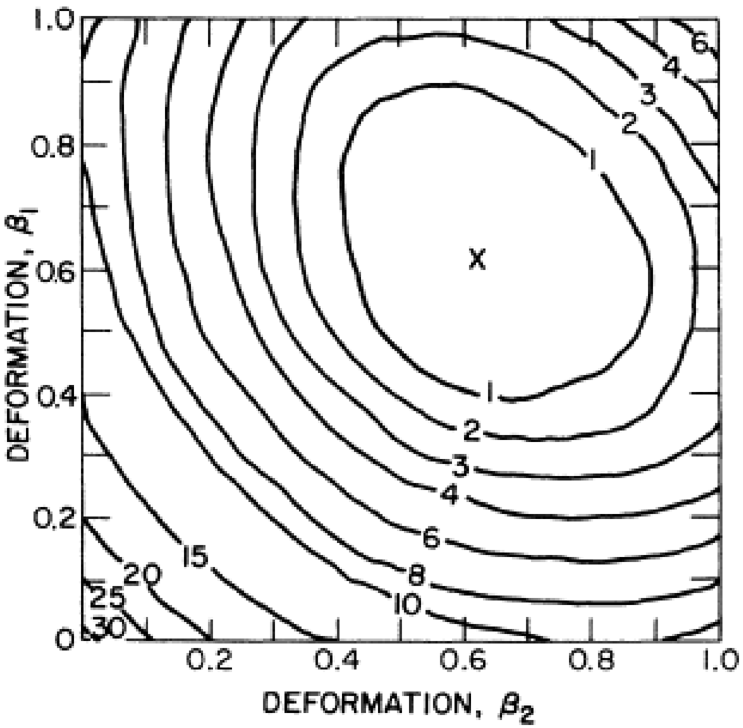


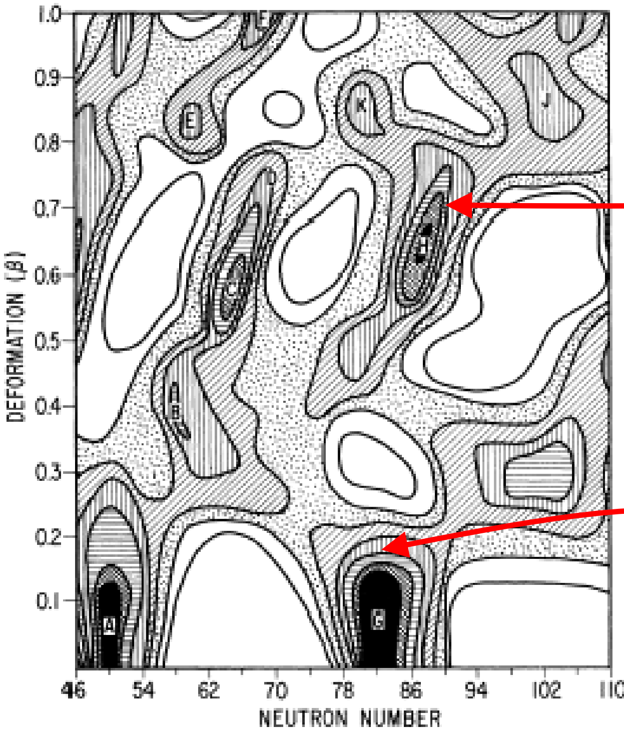
- **Fission: macroscopic process**
- **Fission fragment distribution strongly influenced by structural effects**
- **Neutron shell effects in the nascent fragments produce an asymmetric distribution and stabilize the mass distribution around A=140**



Liquid drop :
Symmetric fission with equally deformed fragments

Shell effects modify the minima of PES



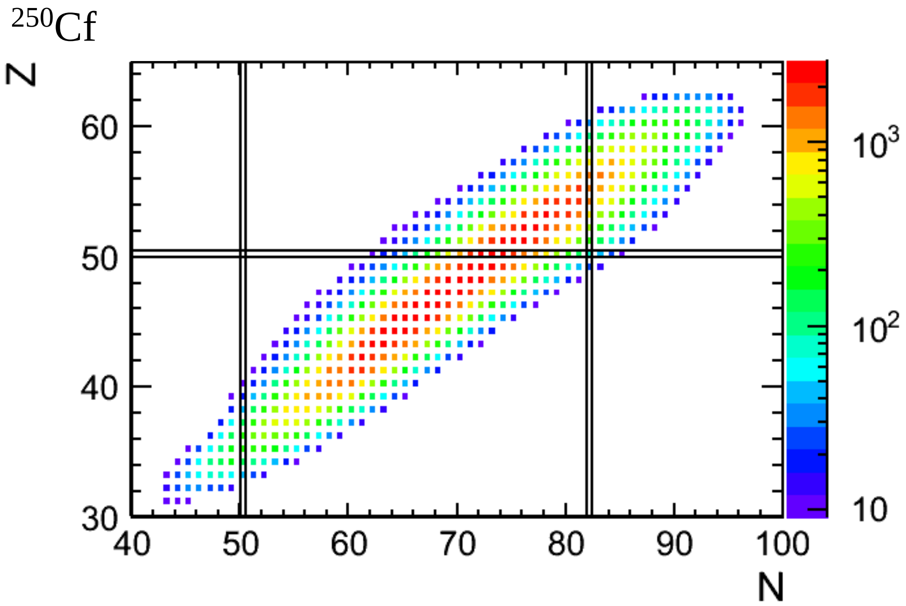


Deformed shell

Spherical shell

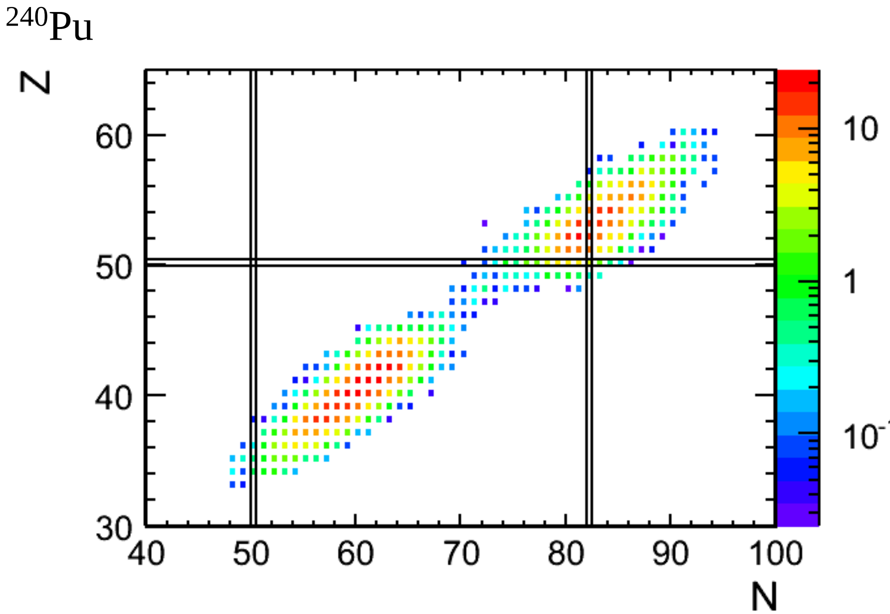
The exact position of the different minima is still controversial
➔ Difficulty (impossibility) to predict fission fragment yields

Preliminary results

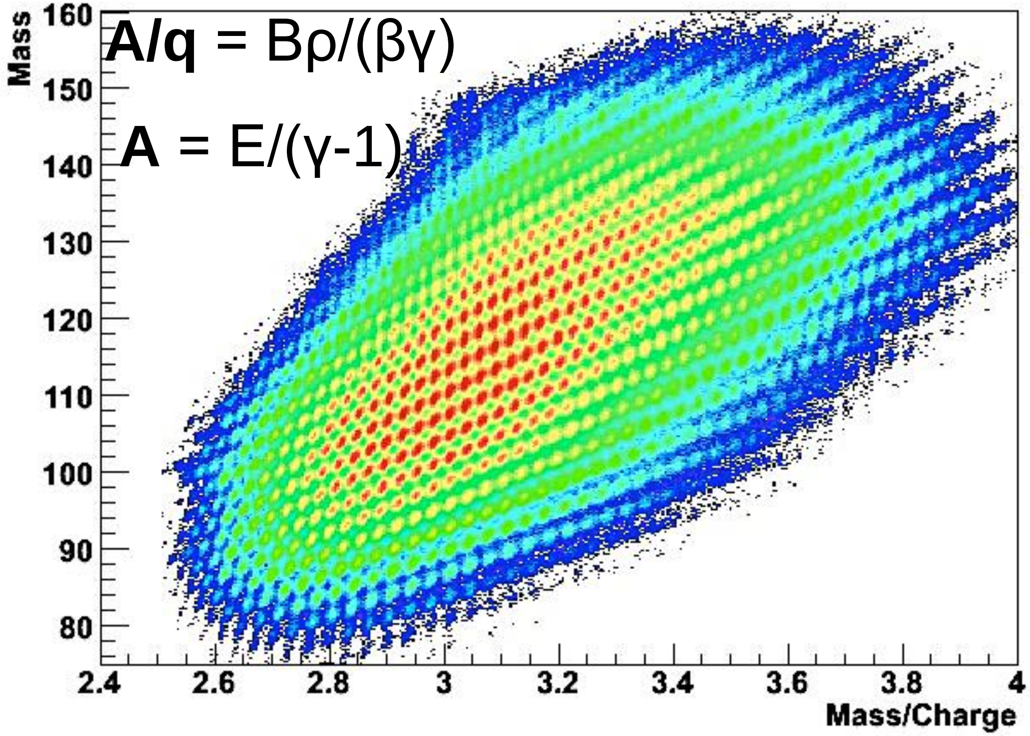


Fusion-fission, E* = 45 MeV symmetric fission

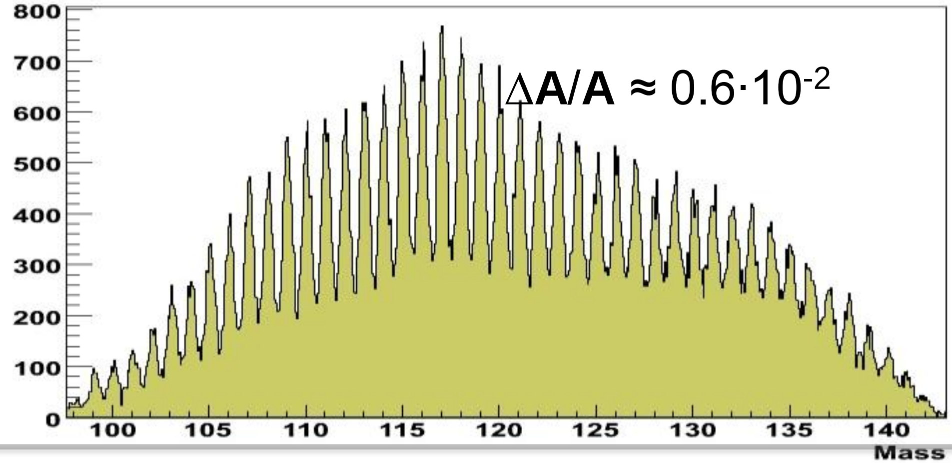
Transfer-fission, E*= 12MeV, assymetric fission



Mass identifcation with VAMOS : A, A/q



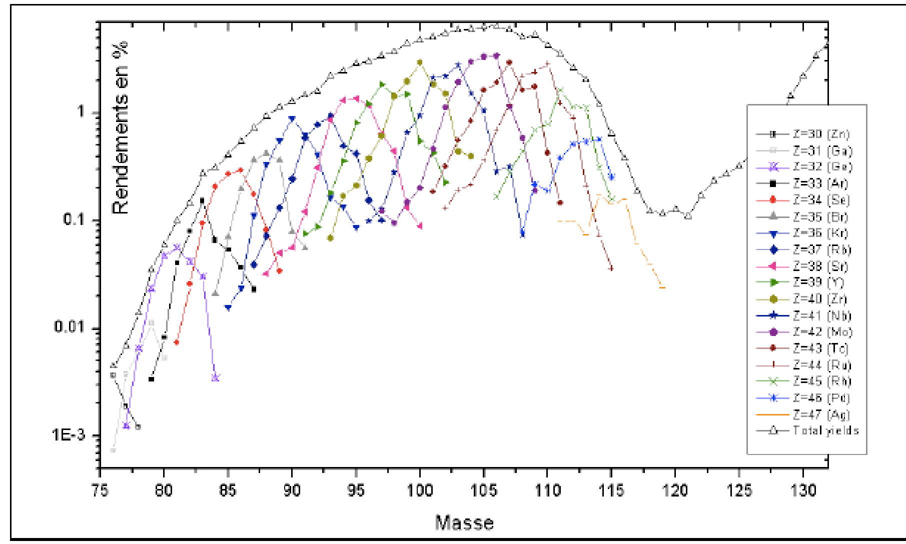
Ident fission fragment **A ≈ 90** à **A ≈ 140**



- Spectromètre (Lohengrin, ILL)

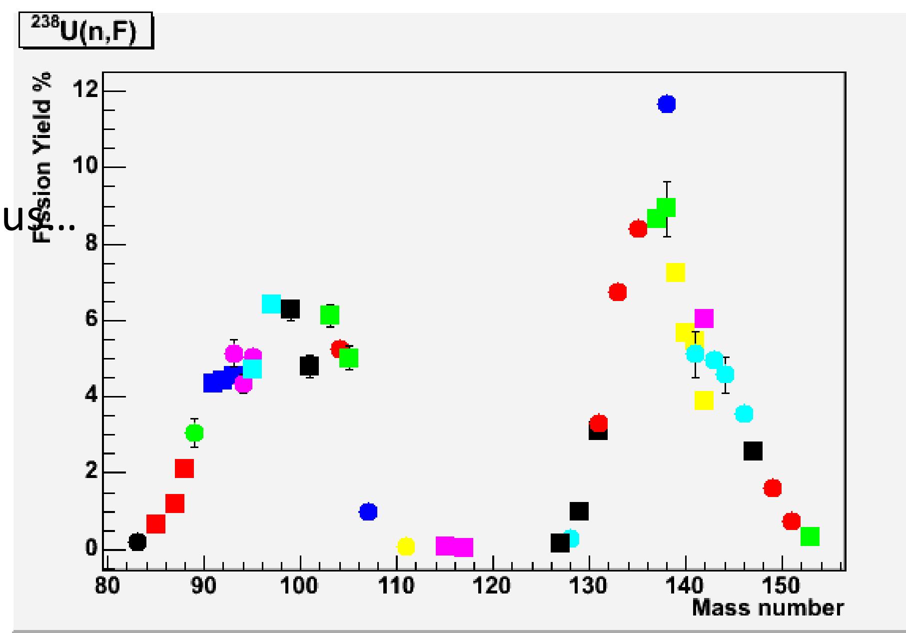
Mesure précise de A
Mesure de Z avec une chambre à ionisation

-Energie cinétique des fragments très basse
=>méthode limitée aux fragments légers
(pas d'information sur les effets de couche
dans les fragments lourds)



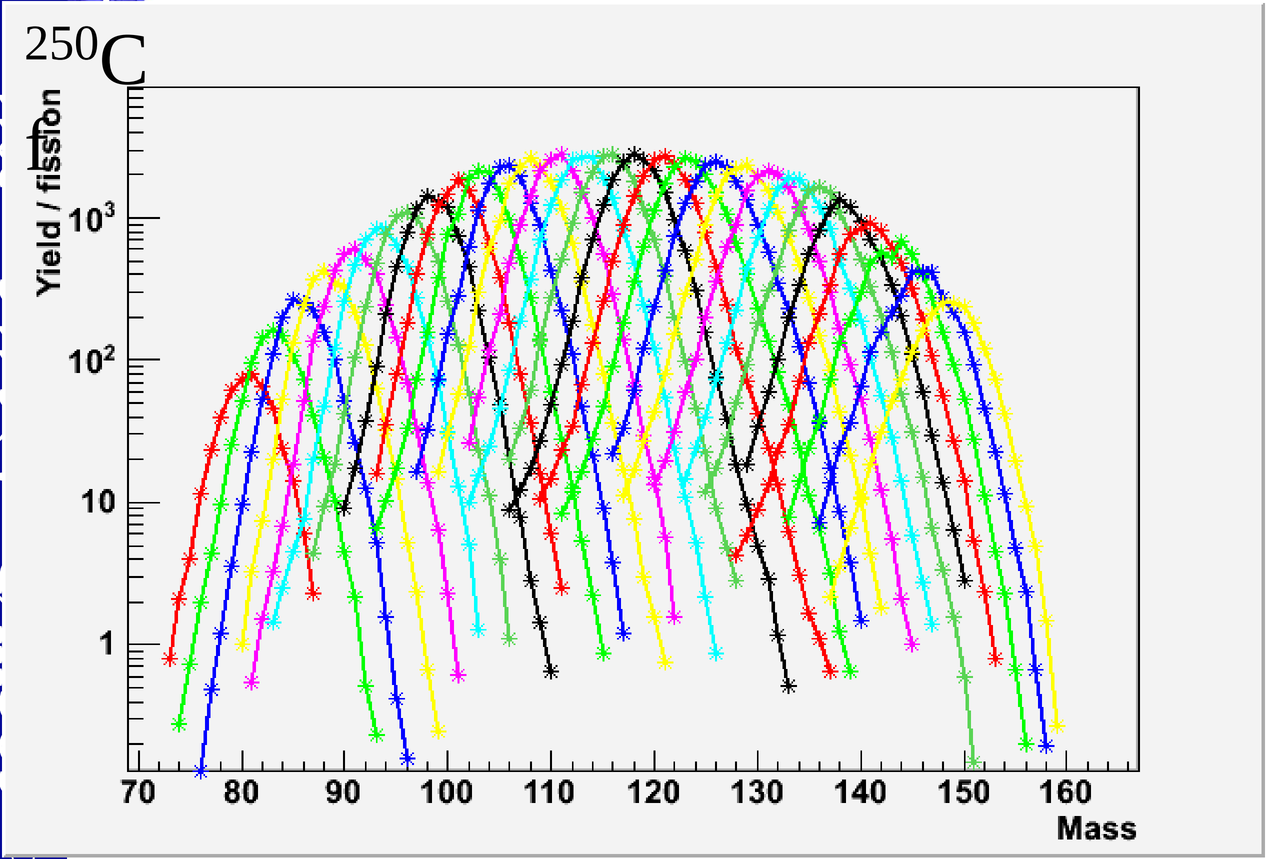
- Spectroscopie γ

Rapports de branchement, isomères inconnus…
⇒Distribution isotopique complète
difficile à mesurer
⇒Conclusions sur le rôle des neutrons
restent incomplètes

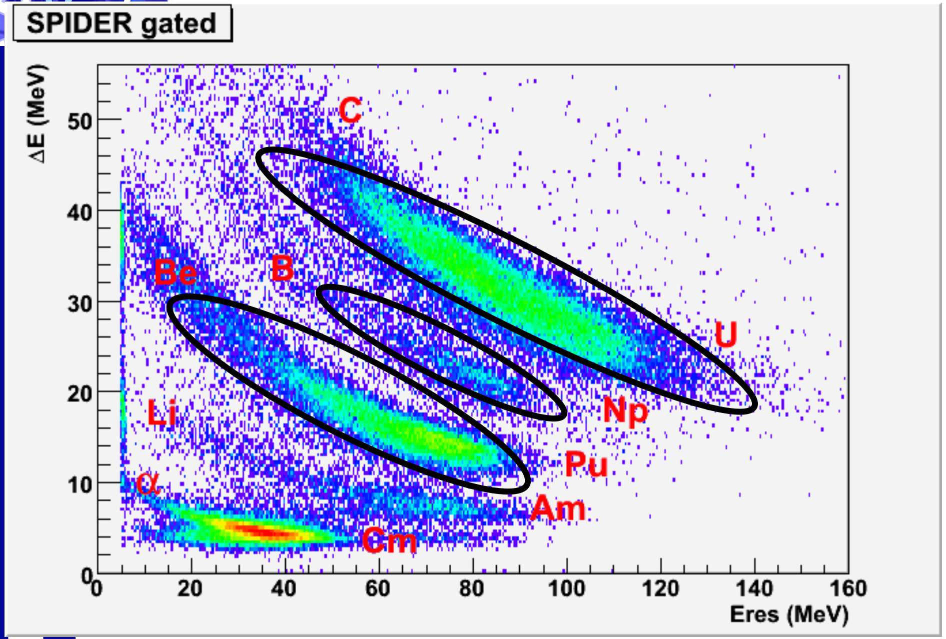


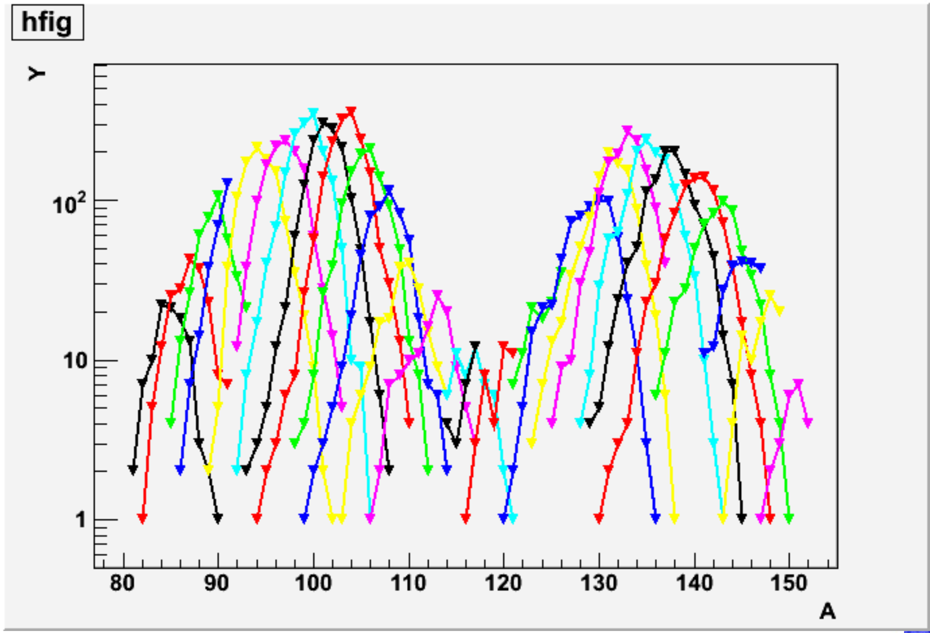
238U(n,F) EXFOR Data tables

Isotopic distribution in fusion-fission reaction



$^{238}U + ^{12}C$
$E^* \approx 45$ MeV
(symmetric fission)





One experiment, different fissioning systems

Access to the complete and isotopic distribution of fission fragments for the first time

SHE in Nature 1975

Tome 36 N° 2 Février 1975

LE JOURNAL DE PHYSIQUE

Classification
Physics Abstracts
4.490

SEARCH FOR SUPERHEAVY ELEMENTS IN NATURE

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C.Stephan (IPNO)

(*Reçu le 2 juillet 1974*)

Résumé. — Des essais de mise en évidence d'éléments superlourds par leur fission induite par neutrons ont été faits sur divers échantillons (minéraux, nodules de manganèse, poussière lunaire, météorite), préalablement analysés dans un séparateur de masse. Des masses subissant la fission ont effectivement été collectées dans la région de masse $A = 300$. Aucune conclusion sur l'existence des éléments superlourds n'a pû être obtenue en raison d'une contamination possible de cette région de masse par des molécules contenant des atomes d'uranium ou de thorium. Cependant, la plupart des mesures de sections efficaces de fission qui ont été effectuées ne peuvent s'expliquer par la présence d'atomes d'uranium ou de thorium. Des résultats complémentaires concernant les propriétés des atomes contenus dans ces masses sont également donnés.

Abstract. — Superheavy elements have been searched for by neutron induced fission of mass separated samples. Various natural materials have been investigated : minerals, manganese nodules, lunar dust, meteoritic materials. Fissioning masses have been collected in the $A = 300$ mass region. However, one cannot conclude that these masses are superheavy elements because of a possible contamination of this mass region by molecules containing natural uranium or thorium. To test for this possibility, the ratios of fast to thermal neutron events have been determined in each separated mass region. These ratios cannot be completely understood as due to the fission of U or Th atoms. Some complementary results concerning the properties of the atoms contained in these masses are also given.

1. **Introduction.** — A few years ago, some superheavy elements were predicted by theory to have half lives of more than 10^8 years, which prompted experimentalists to search for superheavy elements in nature [1, 2, 3, 4]. At that time calculations had not been done about their rate of formation during the nucleosynthesis of elements. All calculations, since then, are pessimistic about the occurence of superheavy elements in nature and some even predict that their formation is impossible [5, 6]. However, the parameters used in these calculations may not be known with enough precision to warrant such a drastic conclusion. For example, O. Johns [7] has shown that the possibility of formation of superheavy nuclei depends critically on the neutron density and the temperature existing in supernovae, neither of which are known with the necessary accuracy. It is inte-

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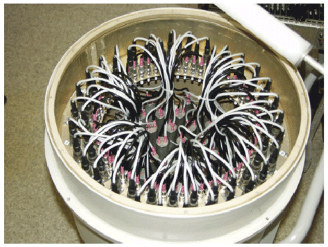
New method with a mass separator to search uranium and thorium in very low quantity, sensitivity limit of 10^{-11} or 10^{-13} g/g of SHE

Super Heavy elements In Nature

SHIN

Laboratoire Souterrain de Modane

LSM



Dr. Evgeny Sokol

Since April 2009, search for Z=114 in a sample of Xe

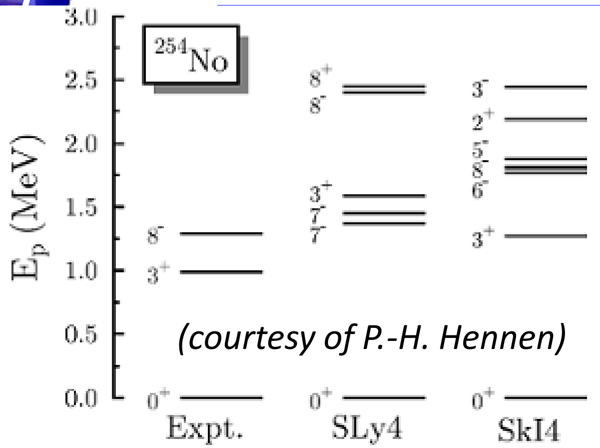
Neutrons from spontaneous fission of long-lived super- heavy nuclei
Svirikhin, A.; Briançon, Ch.; Dmitriev, S.; Oganessian, Yu.; Sokol, E.; Testov, D.; Yeremin, A.

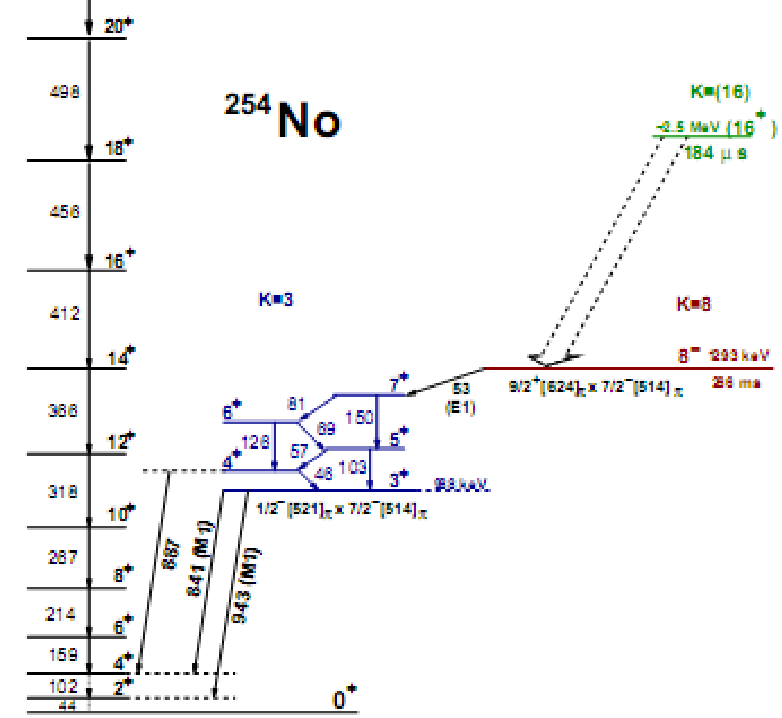
AIP Conference Proceedings;10/15/2009, Vol. 1175 Issue 1, p297

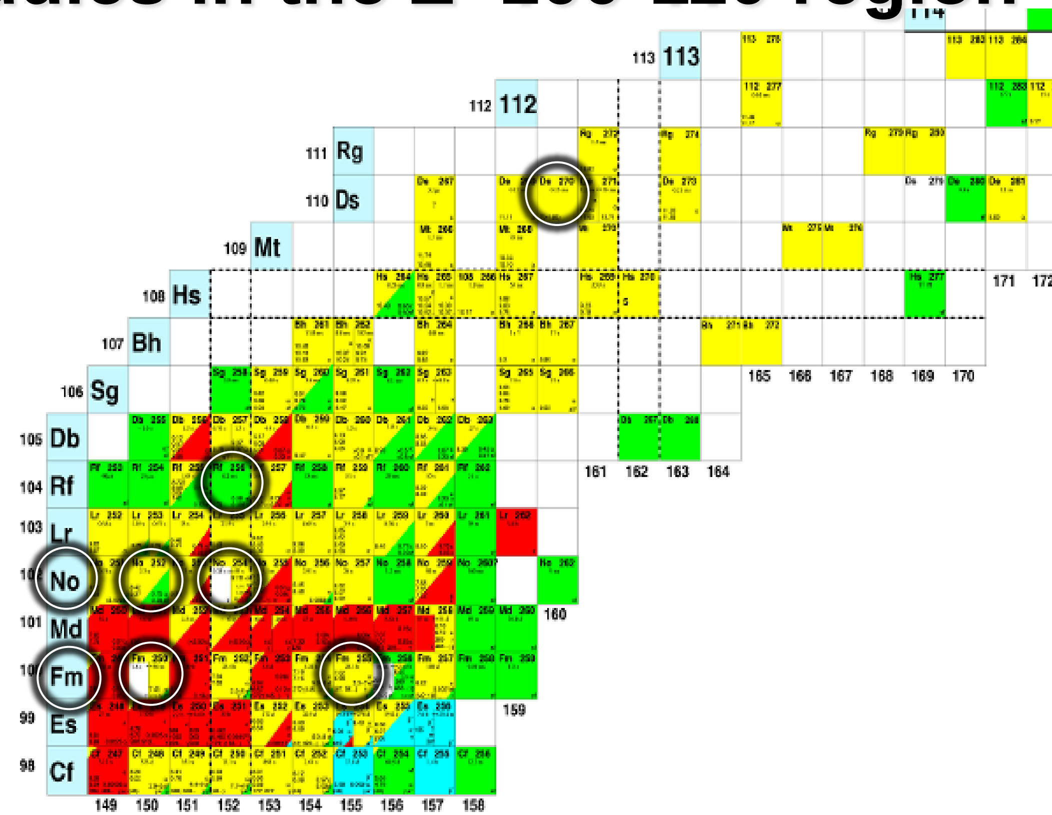
Concentration of Z=108 in Os sample 10^{-14} g/g

Sydney Gales

K-isomerism studies in the Z=100-110 region







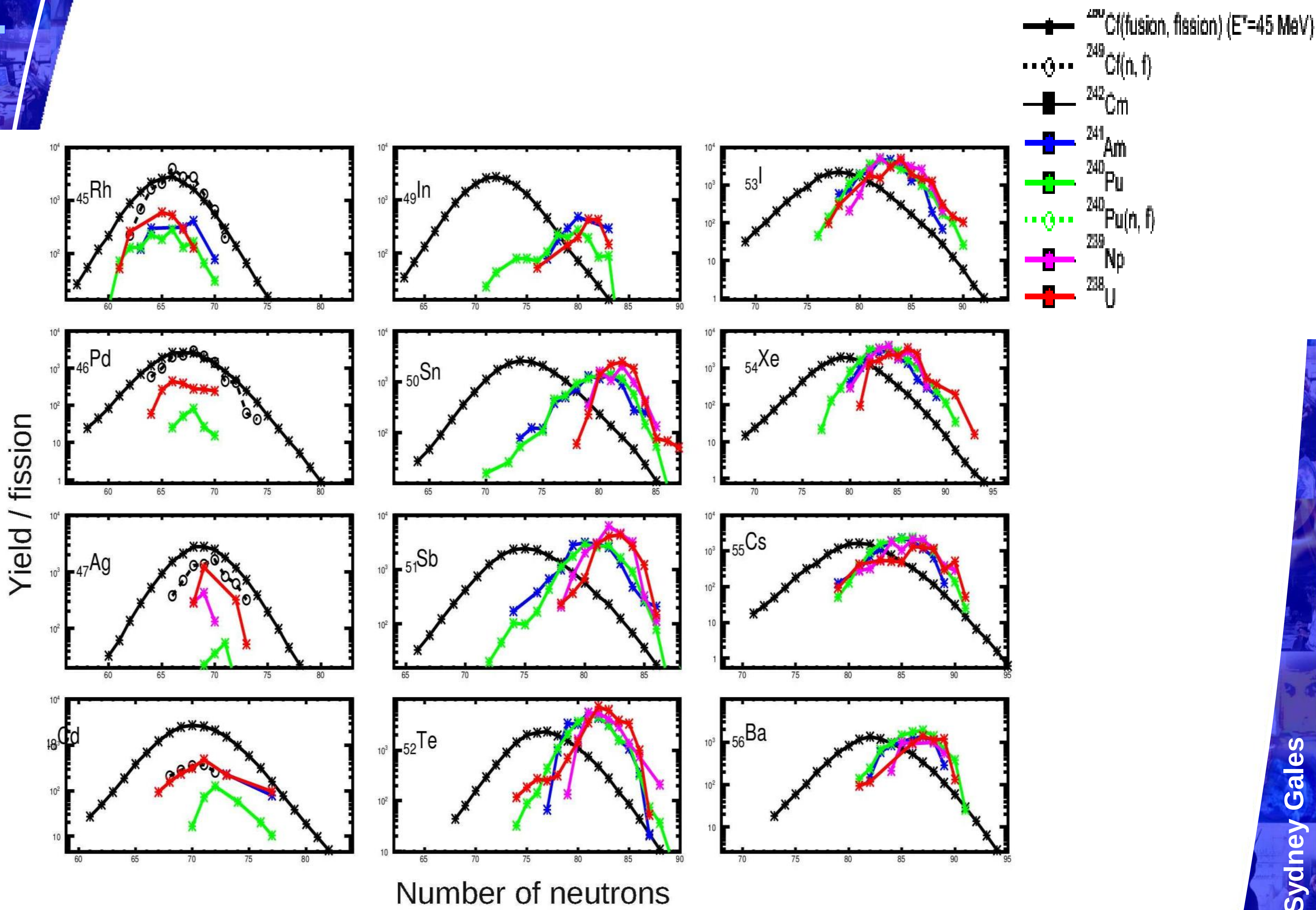
R.-D. Herzberg et al., Nature 442, 896-899 (2006)
S.K. Tandel et al., PRL 97, 082502 (2006)

- No isomers known in Sg, Hs isotopes
- High-statistics allow better assignments of multipolarities, etc

Experimental Challenges

➔Very low cross sections (<10-100pb)
➔with I=10pµA, ≈100evt/week
➔stringent demands on focal plane set-up

Isotopic distributions in fusion-induced and transfer-induced fission



Production of SHE with Z=106-108-110-112

$^{40-48}Ca + ^{238}U \rightarrow ^{278-286}112^*$

$^{36-40}Ar + ^{238}U \rightarrow ^{274-278}Ds^*$

$^{32-36}S + ^{238}U \rightarrow ^{270-274}Hs^*$

$^{28-30}Si + ^{238}U \rightarrow ^{266-268}Sg^*$

Isotopic exploration

$^{40-48}Ca + ^{238}U \rightarrow ^{275-283}112 + 3,4n$

S³ (I=10pμA) ➔ 20evt/week/pb

At the crossing road for

Reaction of synthesis :

- Link hot to cold fusion
- Isospin dependent reaction mechanism studies
- X-section systematics

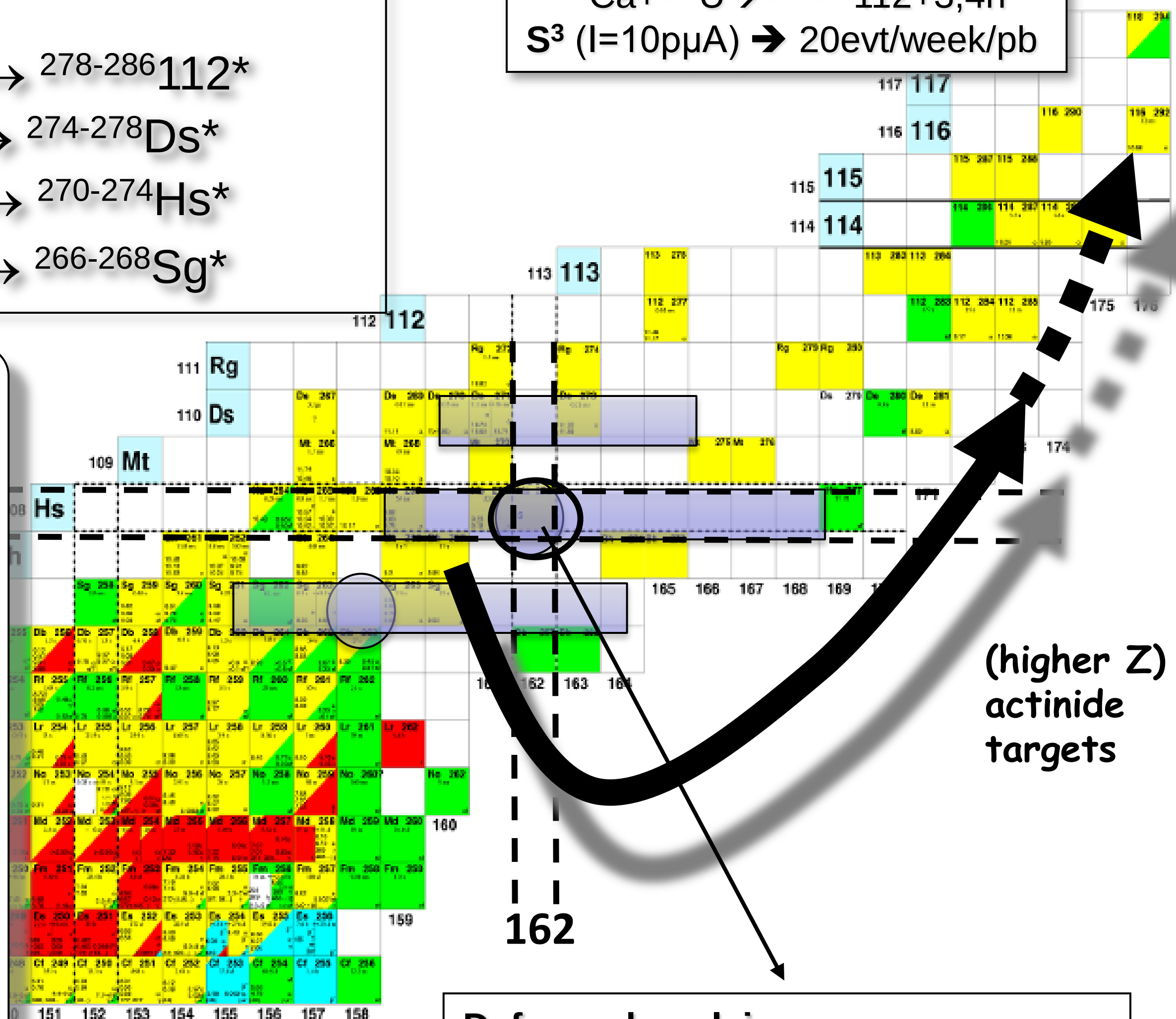
Decay properties :

- K-isomers
- SF decay (T_{SF} half-lives)
- Alpha decays (Qα & half-lives)

Trans-actinide chemistry

GS properties

- Mass measurements …



Deformed nuclei

$^{40}Ar + ^{238}U \rightarrow ^{274}Ds$ (+4n) → $^{270}Hs + \alpha$

S³ (I=50pμA) ➔190evt/week@σ_{th}=2pb

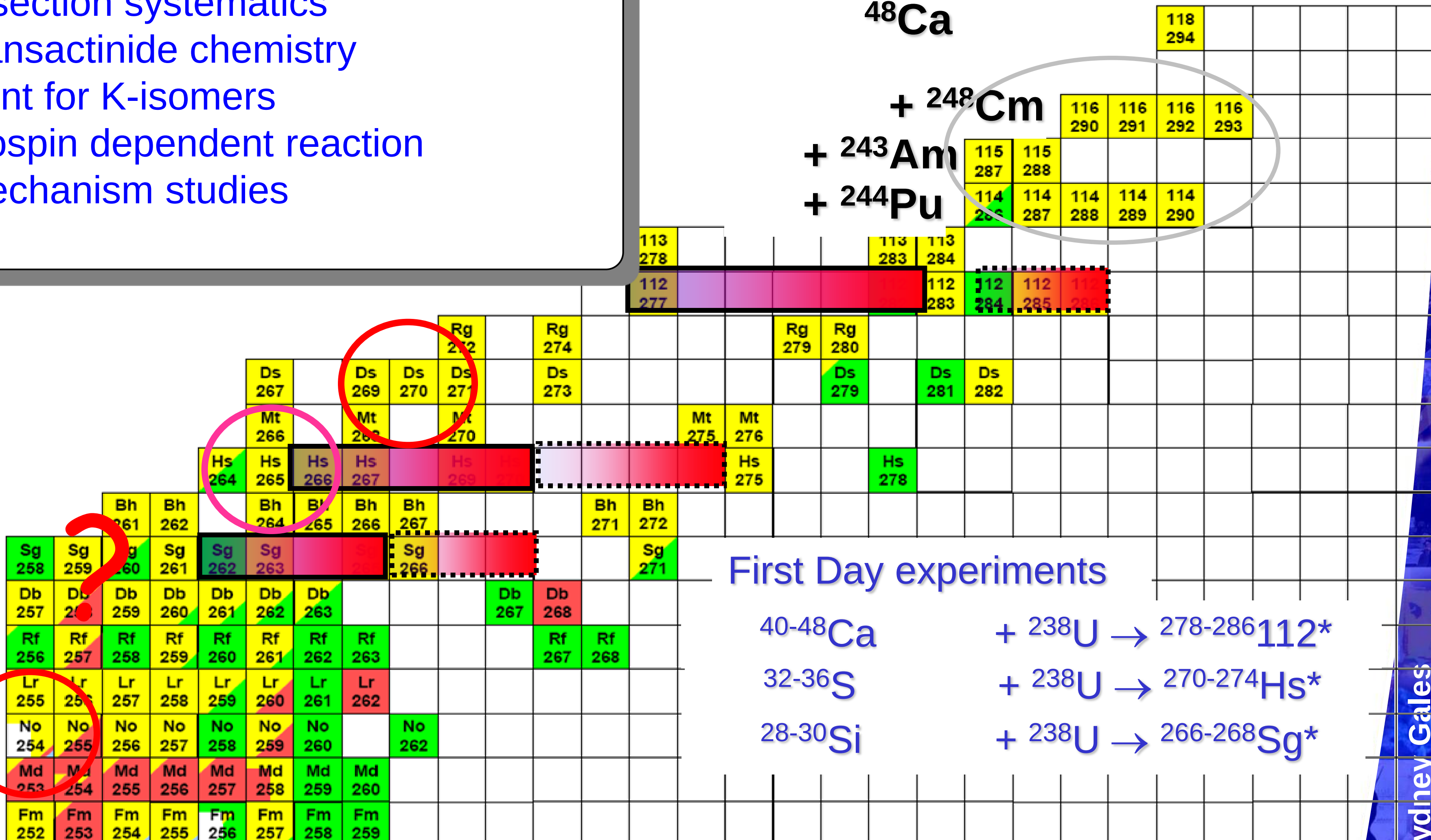
Very/Super heavy Elements Studies

- link hot to cold fusion
- x-section systematics
- transactinide chemistry
- hunt for K-isomers
- isospin dependent reaction mechanism studies

Mid-term experiments (reproductibility)

^{48}Ca

+ ^{248}Cm
+ ^{243}Am
+ ^{244}Pu



First Day experiments

$^{40-48}Ca + ^{238}U \rightarrow ^{278-286}112^*$

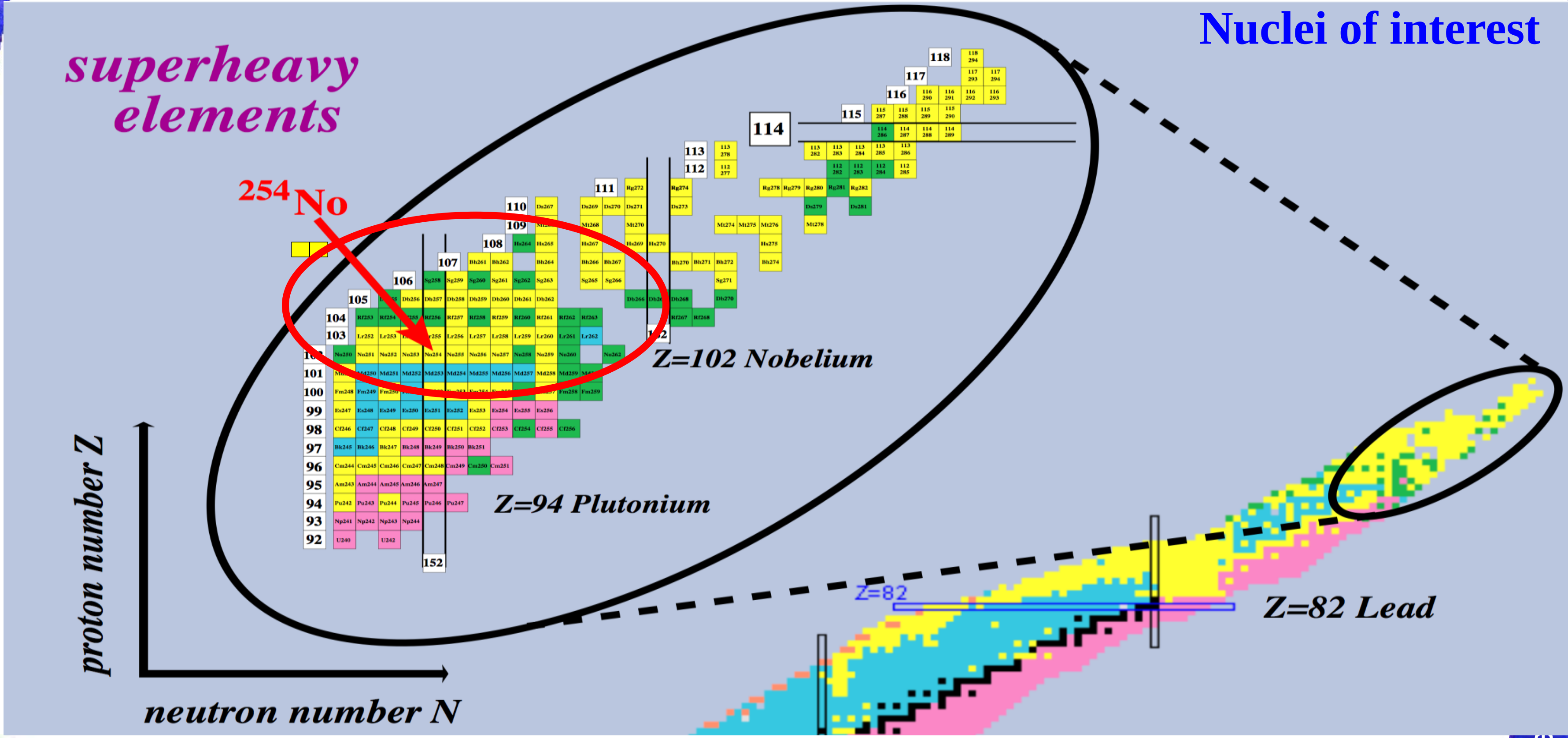
$^{32-36}S + ^{238}U \rightarrow ^{270-274}Hs^*$

$^{28-30}Si + ^{238}U \rightarrow ^{266-268}Sg^*$

Sydney Galès

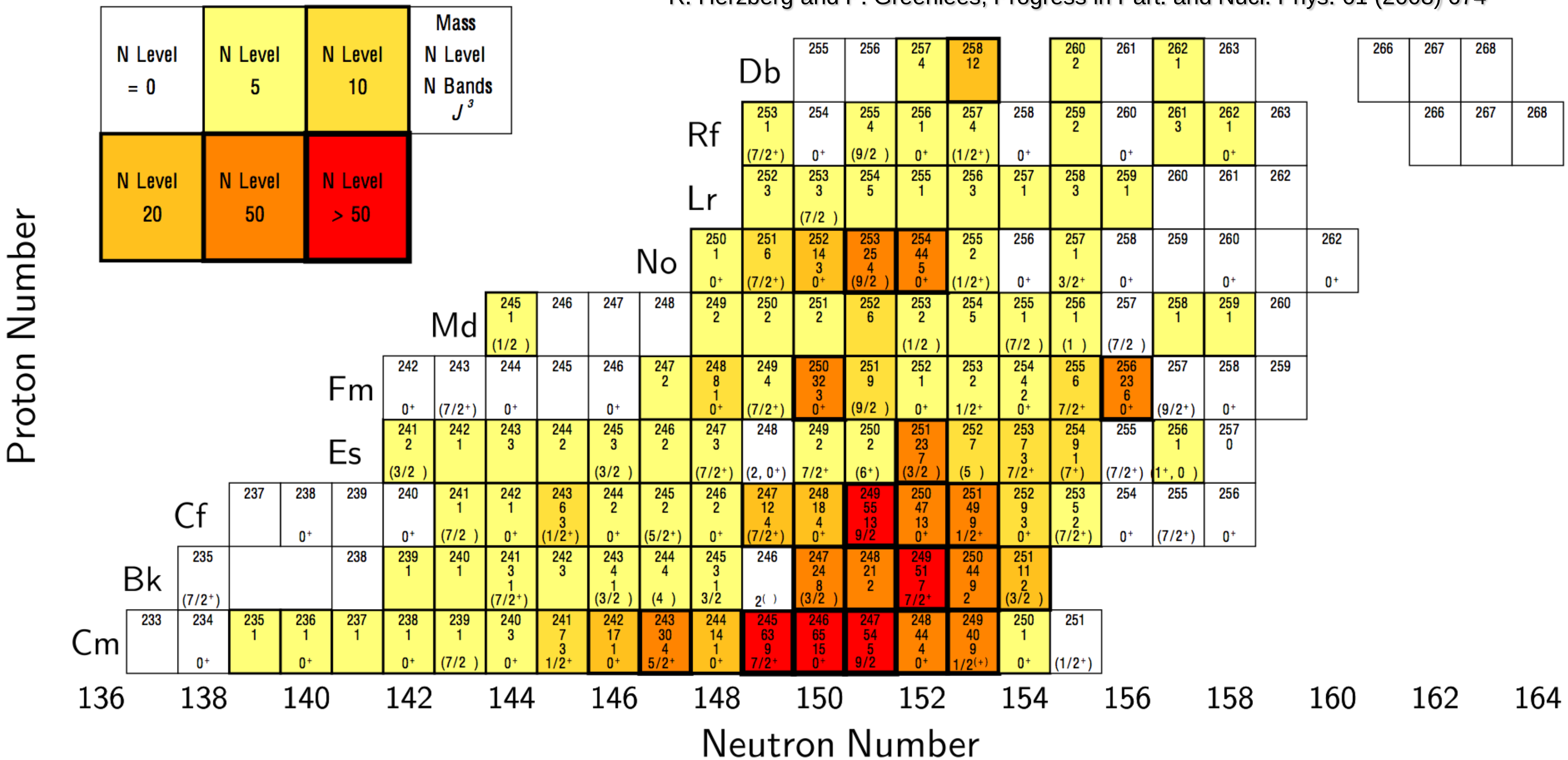
GABRIELA Campaign

Spectroscopic studies of heavy elements at FLNR



Very little data

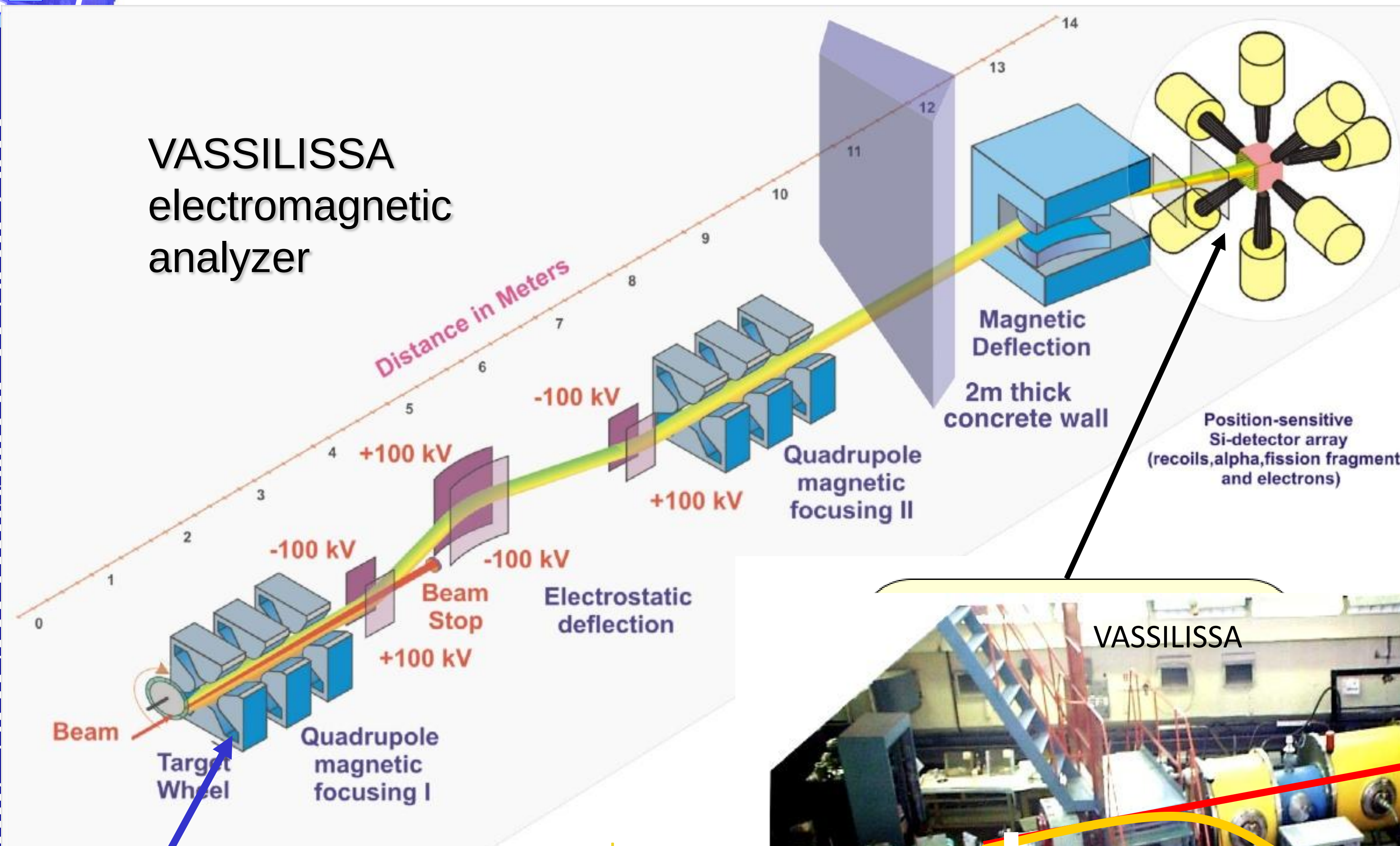
R. Herzberg and P. Greenlees, Progress in Part. and Nucl. Phys. 61 (2008) 674

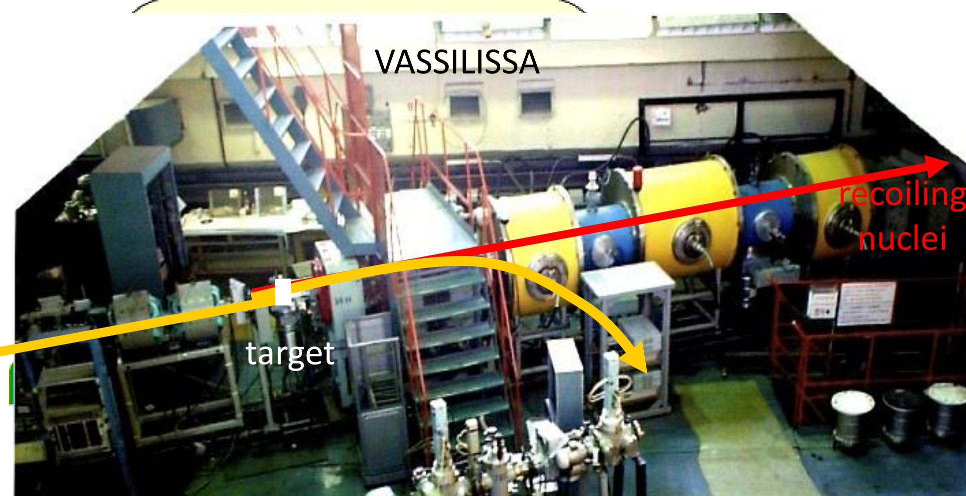


Gamma spectroscopy towards super heavy nuclei at the FLNR

Collaboration JINR (FLNR) - IN2P3 (CSNSM-IPHC)

VASSILISSA electromagnetic analyzer





beam

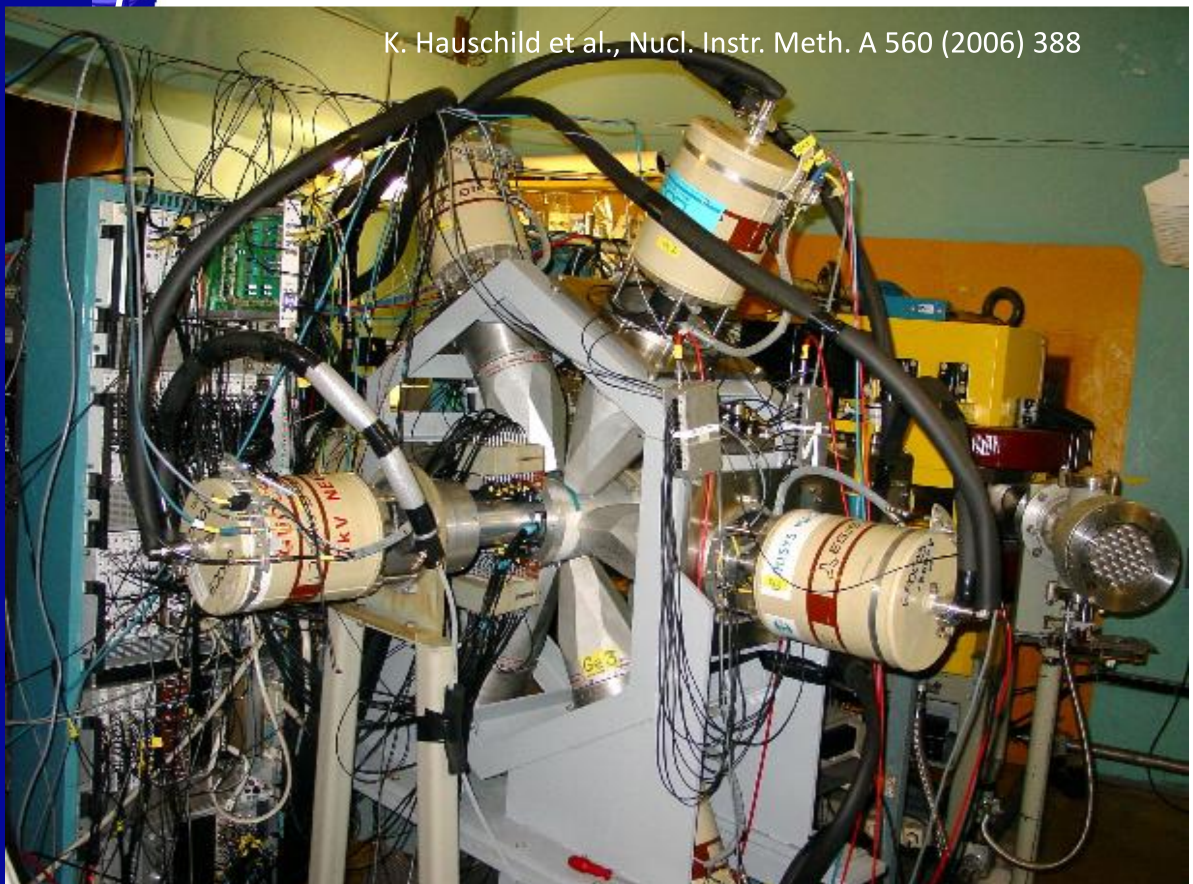
-intense beams
-stable & radioactive targets

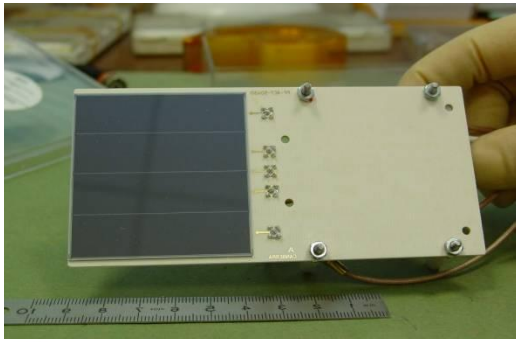
fission

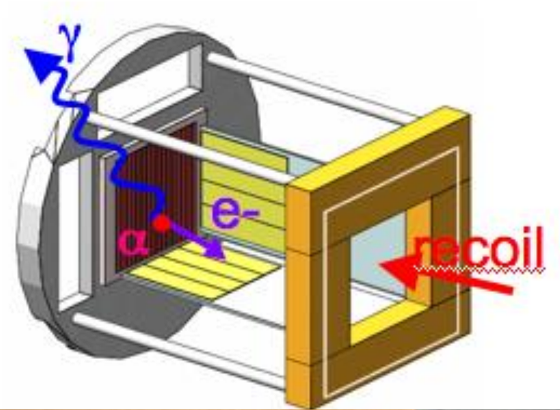
Z-2,A-4

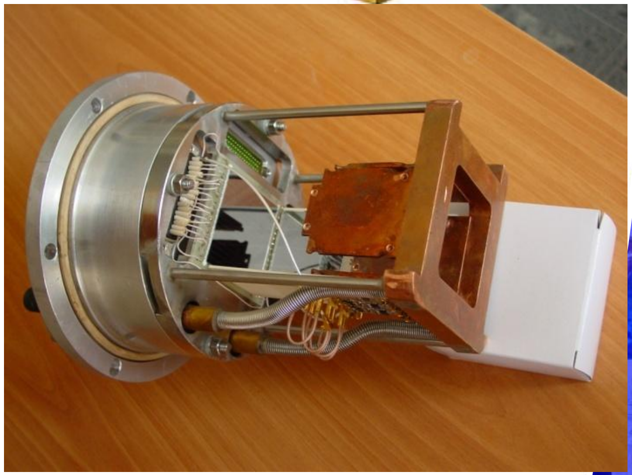
Gamma Alpha Beta Recoil Investigations ELectromagnetic Analyser

http://www.csnsm.in2p3.fr/-GABRIELA-


K. Hauschild et al., Nucl. Instr. Meth. A 560 (2006) 388







- 1st tests with beam: spring 2004
- 1st campaign: fall 2004
- 4 campaigns in 2005,2006,2008 et 2009

GABRIELA campaigns

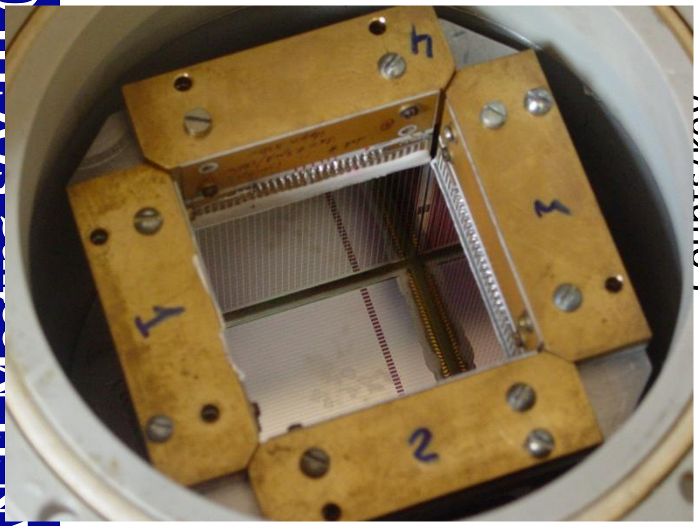
4. February 1st – March 10th 2008:

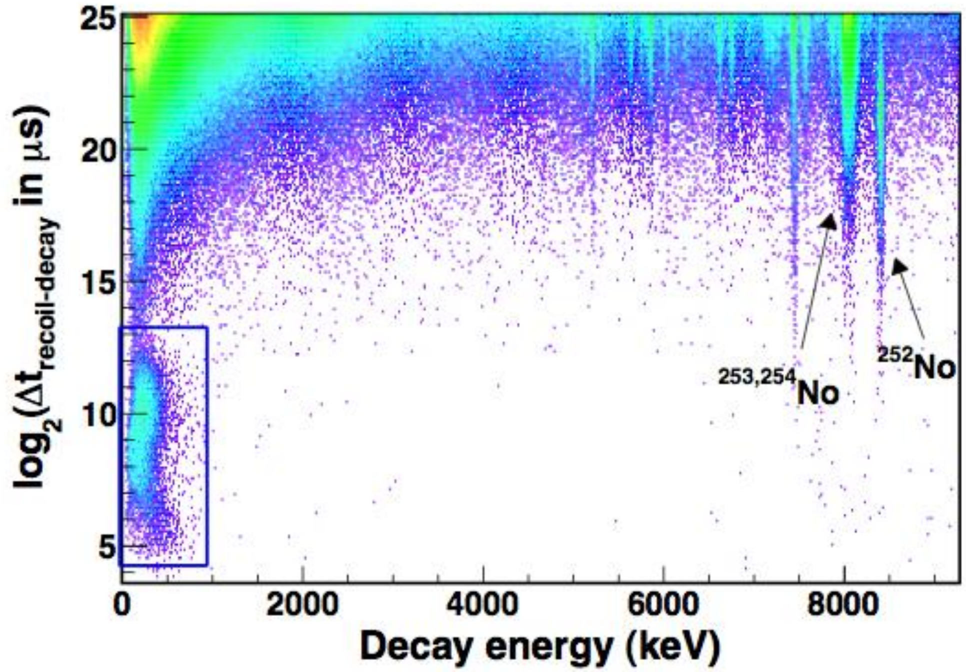
$^{22}Ne + ^{238}U \rightarrow ^{255}No + 5n$, $^{40}Ar + ^{182}W \rightarrow ^{222}U^*$, $^{40}Ar + ^{nat}Hf \rightarrow ^{216-220}Th^*$,
$^{40}Ar + ^{165}Ho \rightarrow ^{205}At^*$, $^{40}Ar + ^{181}Ta \rightarrow ^{221}Pa^*$, $^{40}Ar + ^{208}Pb \rightarrow ^{248}Fm^*$

- New larger and thicker 32-strip detectors instead of 4-strip detectors for tunnel
- 48x48 DSSD instead of 16-strip position sensitive stop detector
- New electronics for DSSD

5. February 9th – March 14th 2009:

$^{48}Ca + ^{207}Pb \rightarrow ^{255}No^*$, $^{40}Ca + ^{159}Tb \rightarrow ^{199}At^*$,
$^{48}Ca + ^{181}Ta \rightarrow ^{229}Np^*$





1. First full scale experiment: September 23^{d} – October 25th 2004

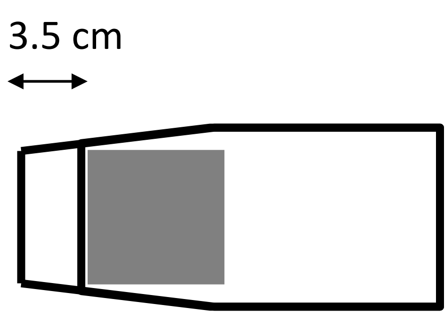
$^{48}Ca + ^{207,208}Pb \rightarrow ^{255,256}No^*$, $^{48}Ca + ^{209}Bi \rightarrow ^{257}Lr^*$

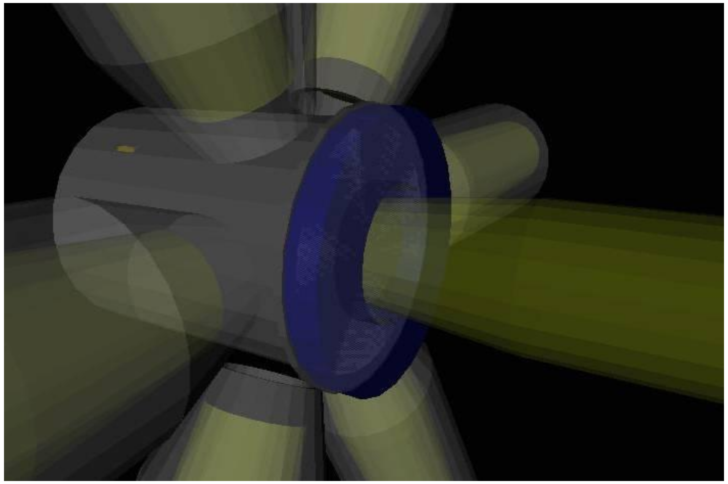
2. October 3^{d} – November 9th 2005

$^{48}Ca + ^{208,210}Pb \rightarrow ^{256,258}No^*$, $^{48}Ca + ^{209}Bi \rightarrow ^{257}Lr^*$

$^{22}Ne + ^{238}U \rightarrow ^{260}No^*$, $^{22}Ne + ^{209}Bi \rightarrow ^{231}Np^*$

-37 degree magnet replaced by 8 degree magnet
-More compact focal plane detection system and thinner ToF foils
-Gamma-ray efficiency doubled





3. October 30th - December 4th 2006

$^{22}Ne + ^{197}Au \rightarrow ^{219}Ac^*$, $^{22}Ne + ^{238}U \rightarrow ^{260}No^*$, ~~$^{22}Ne + ^{242}Pu \rightarrow ^{262}Rf^*$~~,
$^{40}Ar + ^{184}W \rightarrow ^{224}U^*$, $^{40}Ar + ^{181}Ta \rightarrow ^{221}Pa^*$

transmission tests with Ne beam

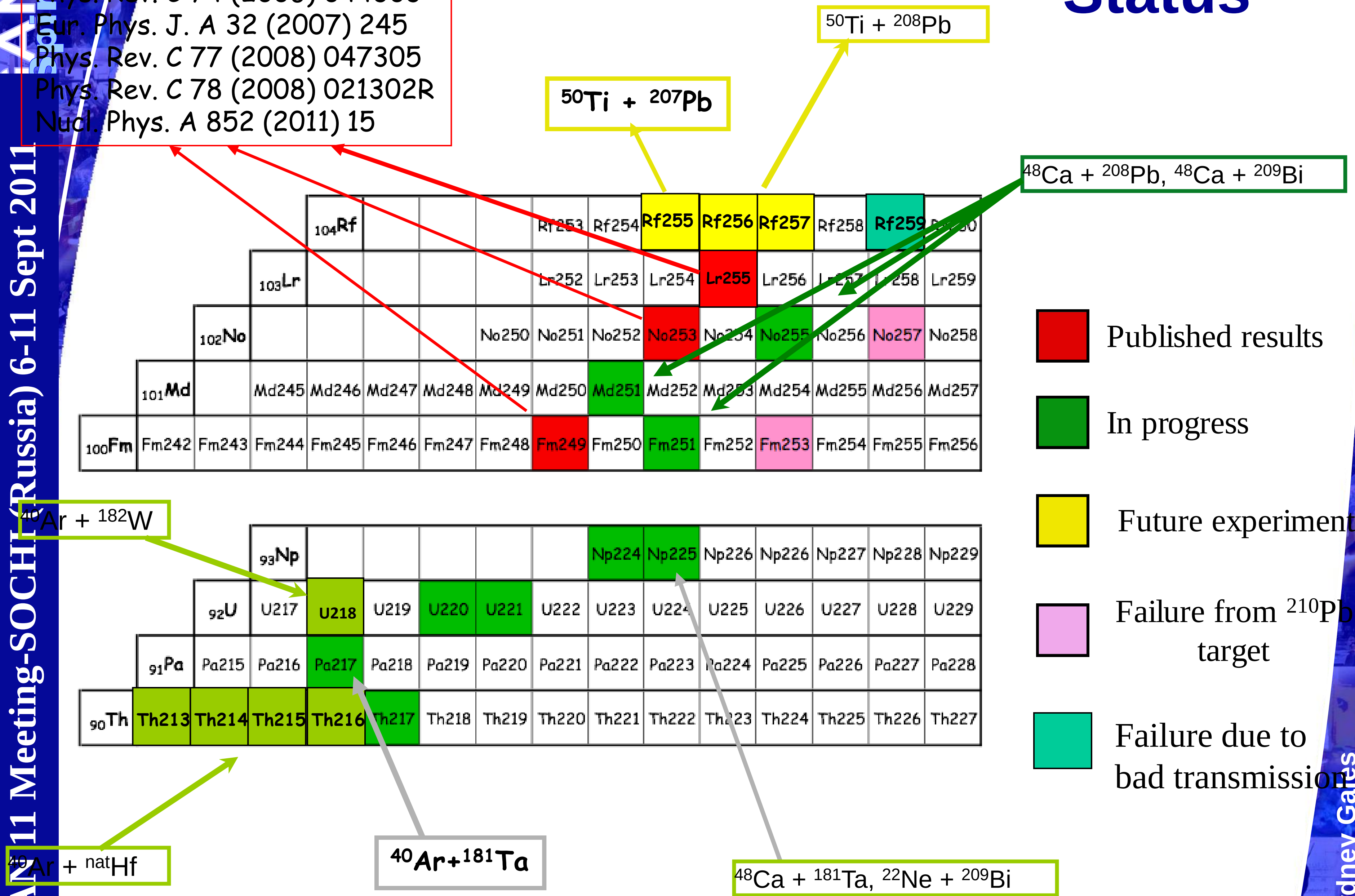
1) VASSILISSA ToF : 2 thin foils (20 μg each)
$^{22}Ne + ^{197}Au \rightarrow ^{214}Ac + 5n \quad \varepsilon = 2\ \%$
2) VASSILISSA ToF : 1 thin foils
$^{22}Ne + ^{197}Au \rightarrow ^{214}Ac + 5n \quad \varepsilon = 5\ \%$

1) VASSILISSA ToF : 1 thin foil
$^{22}Ne + ^{238}U \rightarrow ^{255}No + 5n \quad \varepsilon = 1.5\ \%$
2) VASSILISSA ToF : without foils
$^{22}Ne + ^{238}U \rightarrow ^{255}No + 5n \quad \varepsilon = 2\ \%$

Use of metallic targets helps to improve transmission

Status

Phys. Rev. C 74 (2006) 044303
Eur. Phys. J. A 32 (2007) 245
Phys. Rev. C 77 (2008) 047305
Phys. Rev. C 78 (2008) 021302R
Nucl. Phys. A 852 (2011) 15



Results

Available online at www.sciencedirect.com
SCIENCE DIRECT
Nuclear Instruments and Methods in Physics Research A 560 (2006) 388–394
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Letter to the Editor

GABRIELA: A new detector array for γ-ray and conversion electron spectroscopy

K. Hauschild[a,*], A. ... Yeremin

ToF

Sp...

A. Lop...
M.L. Chelnok...
B. Gall[c], A. ...
A.P. Kabache...
A.C. Larsen[c], ...
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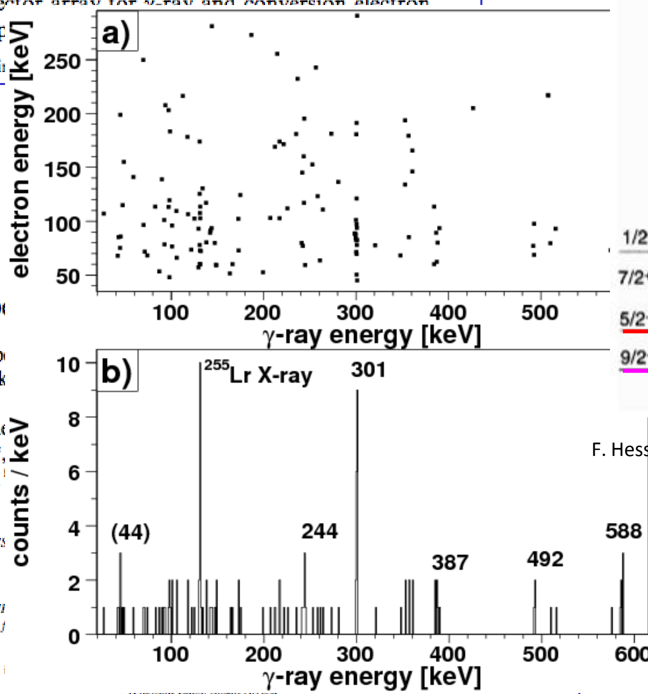

Abstract

New high-statistics data have been obtained on the decay properties of ^{253}No and its daughters using the reaction ^{207}Pb(^{48}Ca, 2n)^{253}No. This was made possible thanks to an improved transmission of fusion–evaporation residues through the VASSILISSA recoil separator and an increased efficiency of the GABRIELA detector setup. The decay schemes of ^{253}No and ^{249}Fm have been revisited. The known level scheme of ^{249}Fm has been confirmed, including a new level at 669 keV excitation energy. The observation of L X-rays in coincidence with the α decay of ^{249}Fm gives additional support to the ground-state configu-

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[1] Deceased.

doi:10.1016/j.nuclphysa.2011.01.012

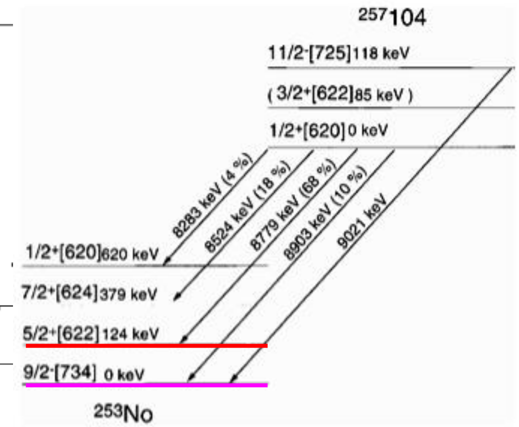
Ele... existen... when ... shell-li... field. ... heavy ... system... only w... study ... can giv... single-... Stru... nuclei ... [1]. Th... ^{253}No ... Z = 10... x rays ... only r... system... making... nuclea... have b... and ha... states ... states ... can be ... leap fo...

presence of orbitals with large spin projections Ω on the symmetry axis. Isomeric states are therefore extremely revealing of the underlying structure of the nucleus: nature and ordering of single-particle states, deformation, config-

as a two-proton K = 8 isomer via the properties of its electromagnetic decay [9,10].

Long-lived spin isomers have been observed in ^{257}Rf [11], ^{253}Lr and ^{257}Db [12], ^{251}No [13] and ^{255}Lr [14]. The isomers in ^{251}No, ^{253}Lr and ^{257}Db involve a low-spin single-particle neutron (for No) or proton (for Lr and Db)

* e-mail: Araceli.Lopez-Martens@csnsm.in2p3.fr



F. Hessberger et al., Z. Phys. A 359 (1997) 415

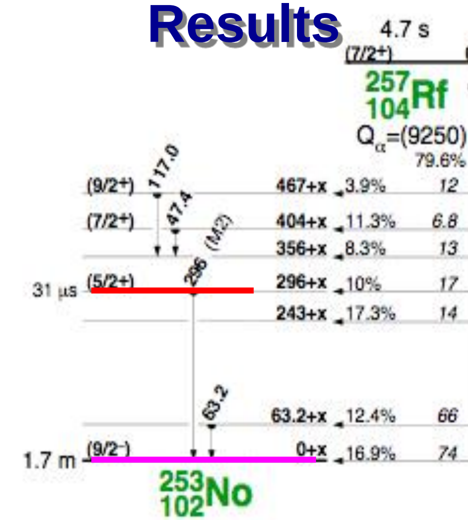
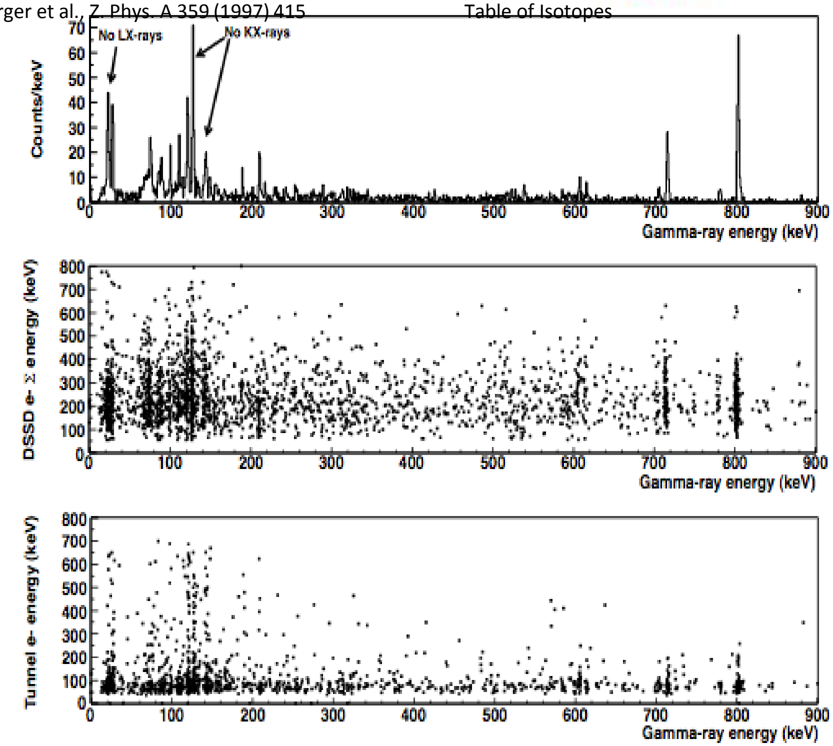


Table of Isotopes



TAN ...