Study of collective modes of excitations in neutron rich Ba isotopes via fusion-evaporation reactions and SPIRAL2-Day1 beams

Spokespersons: Adam Maj, Silvia Leoni
GANIL contact: Christell Schmitt

A. Maj[a], K. Mazurek[a], P. Bednarczyk[a], M. Ciemala[a], B. Fornal[a], M. Kmiecik[a], J. Grebosz, M. Zieblinski, W. Meczynski et al.,
S. Leoni[b], A.Bracco[b], G.Benzoni[b], F. Camera[b], F.C.L. Crespi[b], N. Blasi[b], B. Million[b], O. Wieland[b],
P.F. Bortignon, G. Colò, E. Vigezzi et al. ,
Ch. Schmitt[c], J.P. Wieleczko[c], M. Lewitowicz[c], G. de France[c], M. Rejmund[c] et al.,
F. Azaiez[d] , I. Matea[d], I. Stefan[d] et al.,
O. Stezowski[e], N. Redon[e] et al.,
J. Dudek[f], O. Dorvaux[f], S. Courtin[f], M. Rousseau[f] et al.,
D.R. Chakrabarty[g], V. Nanal[g], I. Mazumdar[g] et al.,
T. Dossing[h], B. Herskind[h], et al.,
G. DeAngelis[i], D. Napoli[i], J.J. Valiente-Dobon[i] et al.,
D. Bazzacco[l], E. Farnea[l], S. Lenzi [l], S.Lunardi[l], C.Ur[l], et al.
A. Gadea et al.,

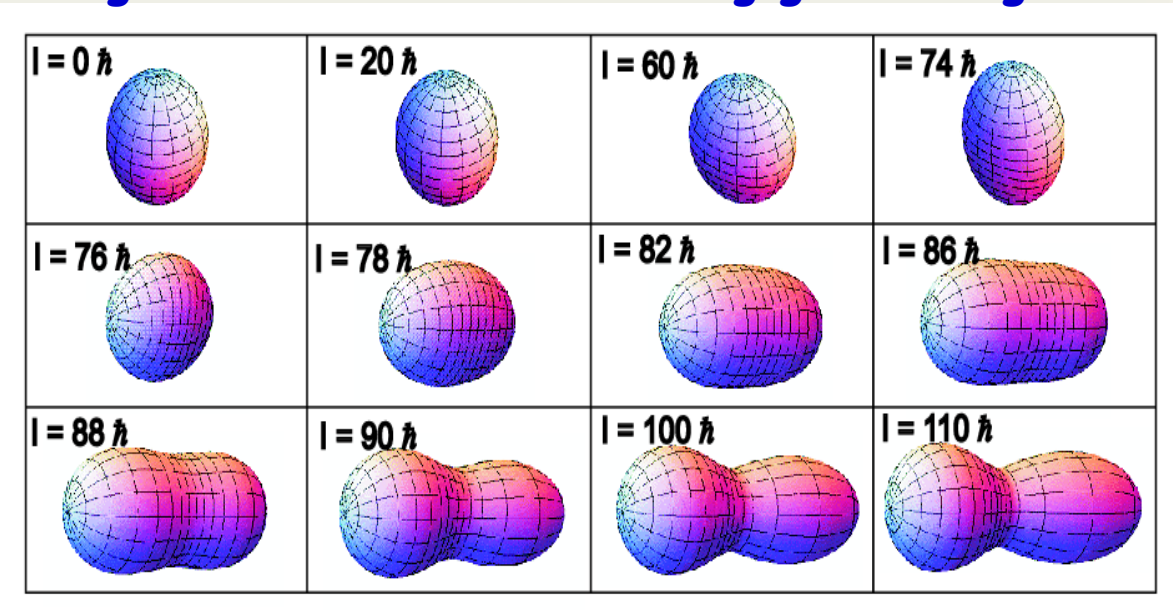
and the PARIS-EXOGAM-AGATA collaborations

[a] The Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland;
[b] Università degli Studi e INFN sezione di Milano, Via Celoria 16, 20133, Milano, Italy;
[c] GANIL, France; [d]IPN Orsay, France; [f]IPHC Strasbourg, France
[g] TIFR and BARC, Mumbai, India
[h] The Niels Bohr Institute, Copenhagen, Denmark
[i]Legnaro National Laboratory, INFN, Italy; [l]University of Padova and INFN Milano, Italy;

Evolution of Nuclear Shapes of HOT nucleus at the Highest angular momenta

Lublin-Strasbourg liquid Drop (LSD) model
by K. Pomorski and J. Dudek, PRC67 (2003) 044316

Analogous effect in fast rotating gravitating bodies



A.Maj *et al.* Int. J. Mod. Phys. E19, 532 (2010);
K.Mazurek *et al.*, Acta Phys. Pol. B42, 471 (2011)

Oblate (MacLaurin)

↓

Elongated triaxial (Jacobi)
-> gateway to
Hyperdeformed shapes at T~ 0

↓

Octupole, left- right asymmetric (Poincarè)

Search for Jacobi-Poincarè Transitions

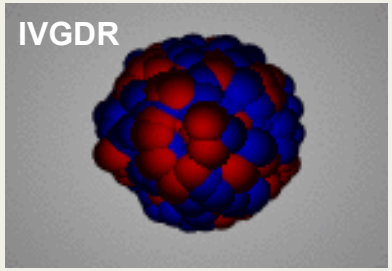
→ *Important for **FISSION** dynamics, search for **HyperDeformed** shapes at T≈0*

Search for Jacobi-Poincarè Transitions

Experimental Signature

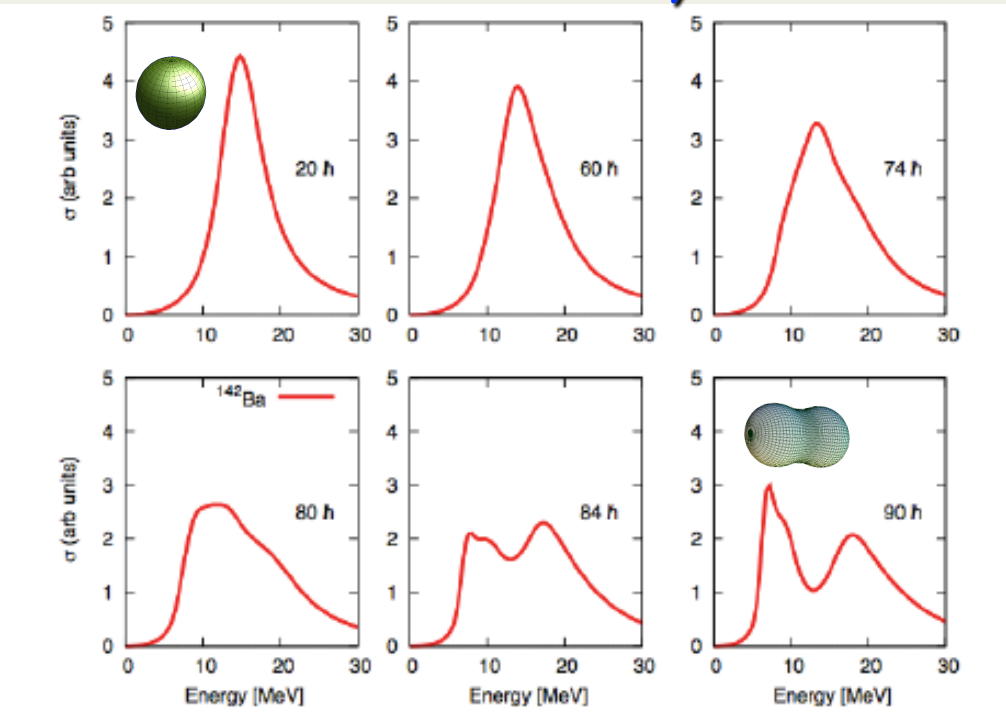
- **Fission:**
  - Symmetric (Jacobi)
  - Asymmetric (Poincarè)
- **Line Shape of Giant Dipole Resonance**
- **Warm Rotation** (Variation in moment of Inertia):
  - Giant Backbending
  - Ridge-Valley Structures in γ–γ spectra

1- Line Shape of Giant Dipole Resonance

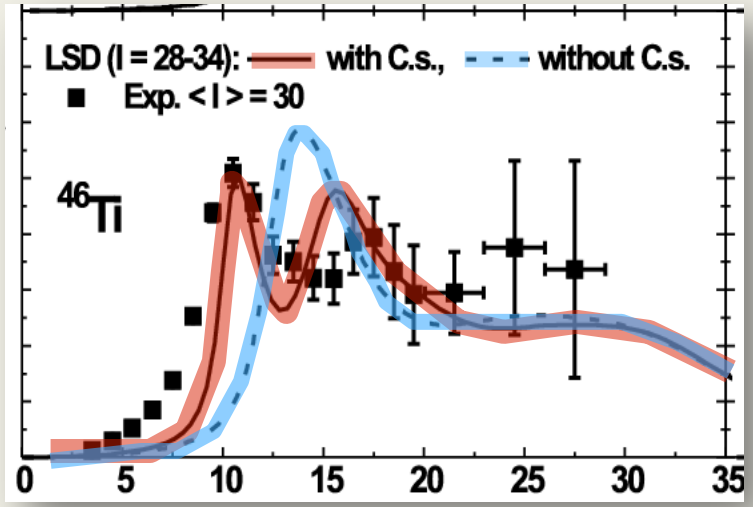


Evidence for
Jacobi shape transition in nuclei
(oblate -> very elongated prolate)
and for the Coriolis splitting

^{142}Ba-Theory



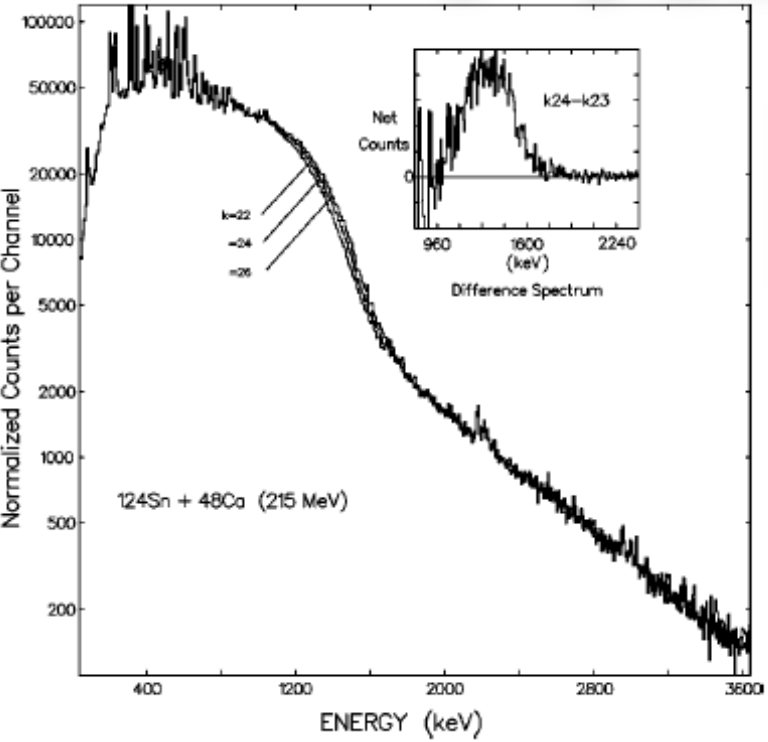
Euroball + HECTOR experiment in Strasbourg

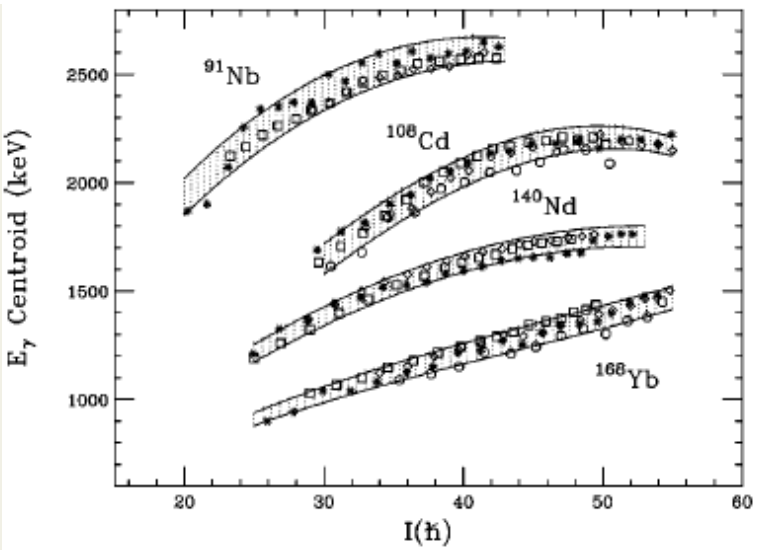


More on Jacobi transitions seen through GDR:
see talk of **Marysia Kmiecik** *during the Workshop*

A.Maj et al, Nucl. Phys. A731 (2004) 319 ;
M. Kmiecik et al., Acta Phys. Pol. B36, (2005) 1169

2- Giant backbending (T≈0)

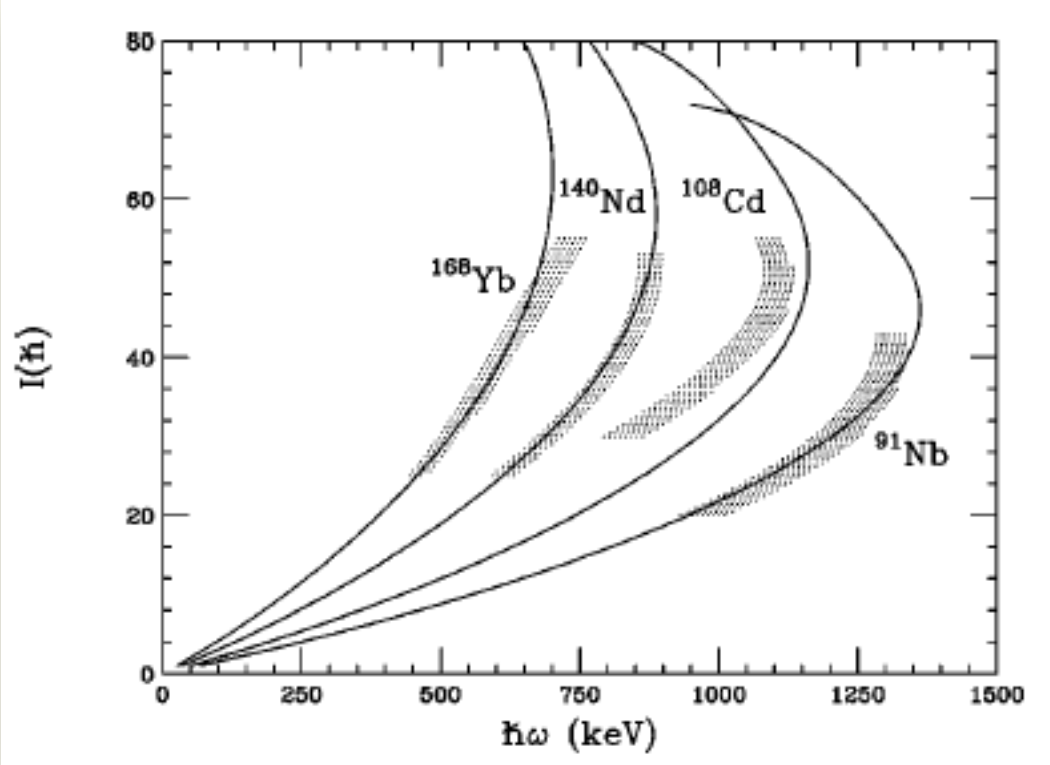




PHYSICAL REVIEW C 66, 024317 (2002)

Search for the Jacobi shape transition in rapidly rotating nuclei

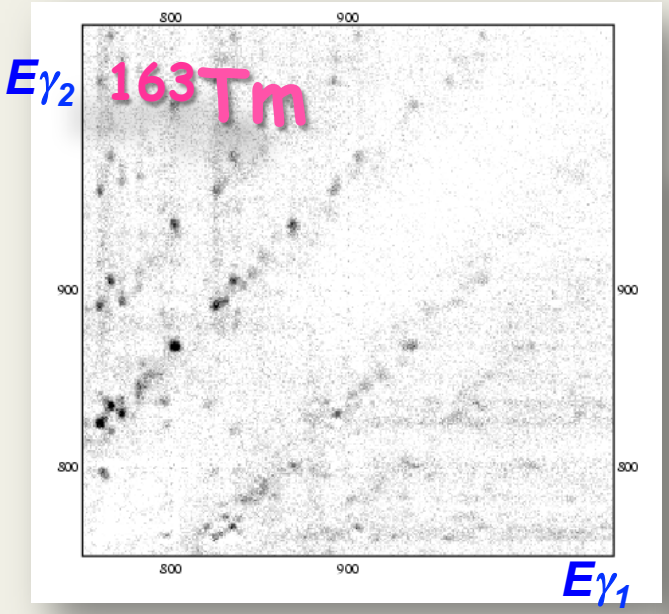
D. Ward,[1] R. M. Diamond,[1] W. J. Swiatecki,[1] R. M. Clark,[1] M. Cromaz,[1] M. A. Deleplanque,[1] P. Fallon,[1] A. Goergen,[1] G. J. Lane,[1,2] I. Y. Lee,[1] A. O. Macchiavelli,[1] W. Myers,[1] F. S. Stephens,[1] C. E. Svensson,[1,3] and K. Vetter[1,4]



Sudden change in moment of inertia of warm rotating nuclei

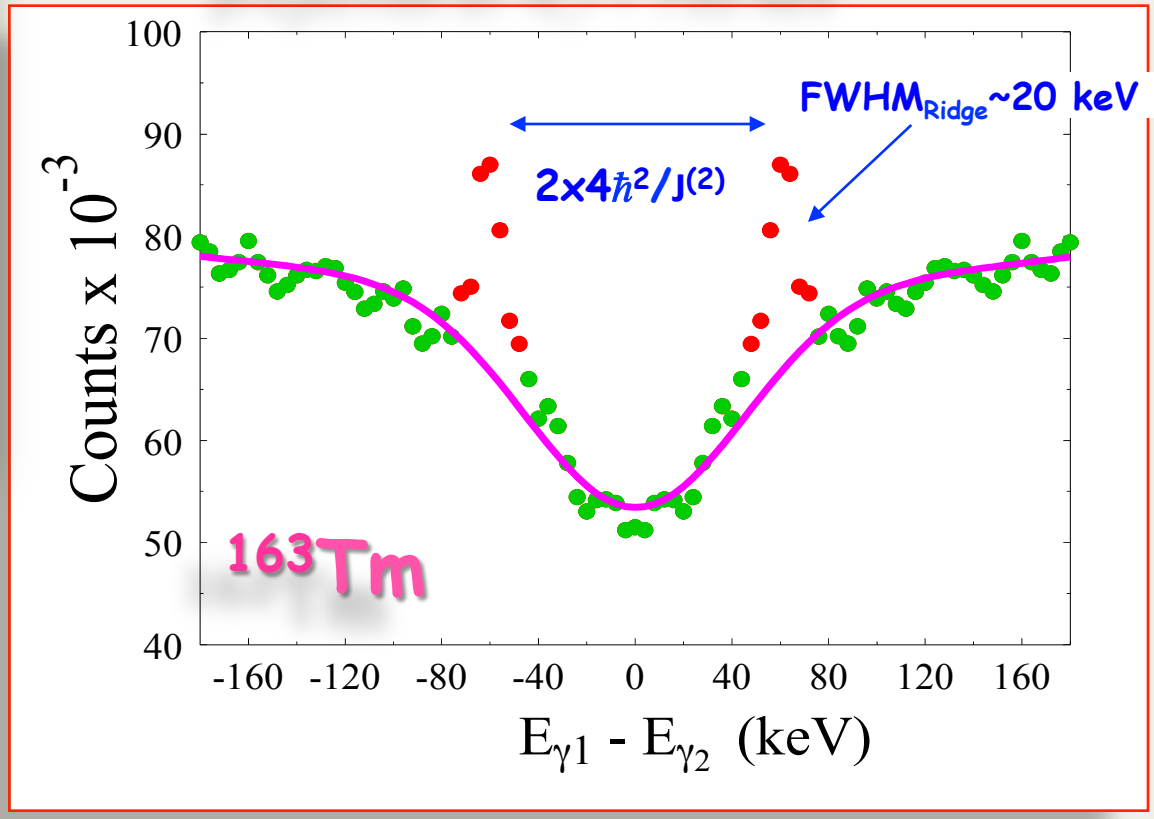
3- Ridge Valley Structure in γ–γ Spectra

clear signature of warm rotation



quasi-continuum γ–γ spectra

projection at $\langle E_\gamma \rangle$ = 750 keV



Superdeformed ^{152}Dy was FIRST observed as ridge structures !!!

Ridge spacing: Average Moment of Inertia $J^{(2)}$
Ridge FWHM: Spread in $J^{(2)}$

Best Candidates are expected in neutron-rich nuclei

New calculations based on the LSD model, allowing odd-rank deformation parameters (α_{30}, α_{50}, α_{70}) to be free:

K. Mazurek, J. Dudek, A.Maj, to be published

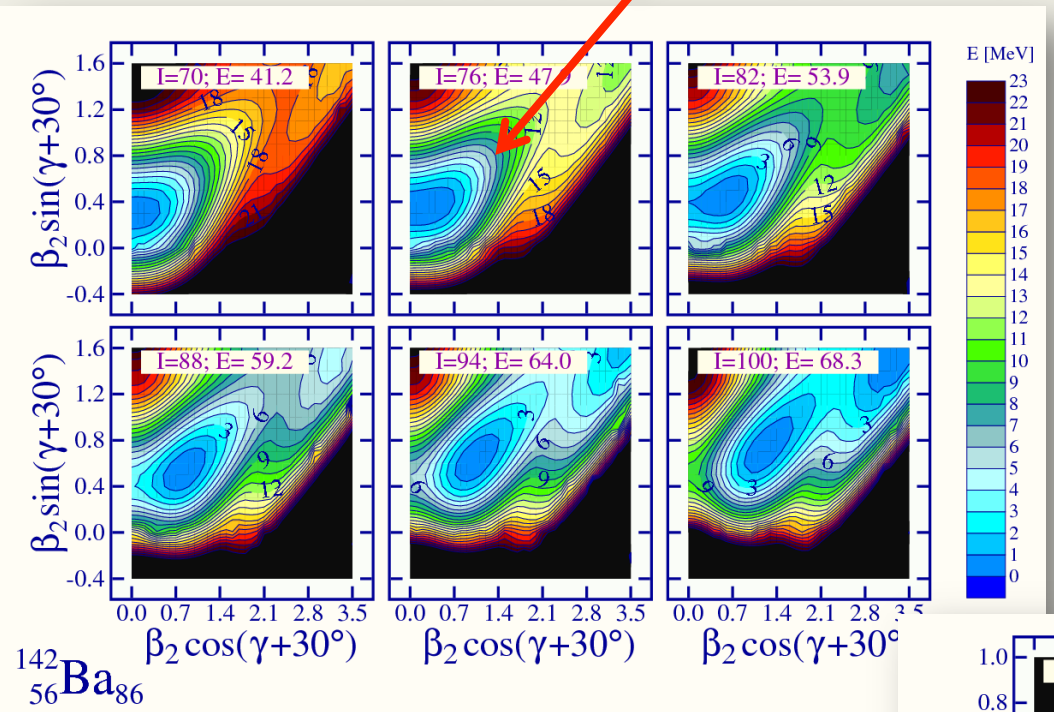
A.Maj, K. Mazurek, J. Dudek, M. Kmiecik, D. Rouvel
"Shape evolution at high spins and temperatures: nuclear Jacobi and Poincare transition", J. Mod. Phys. E19 (2010) 53

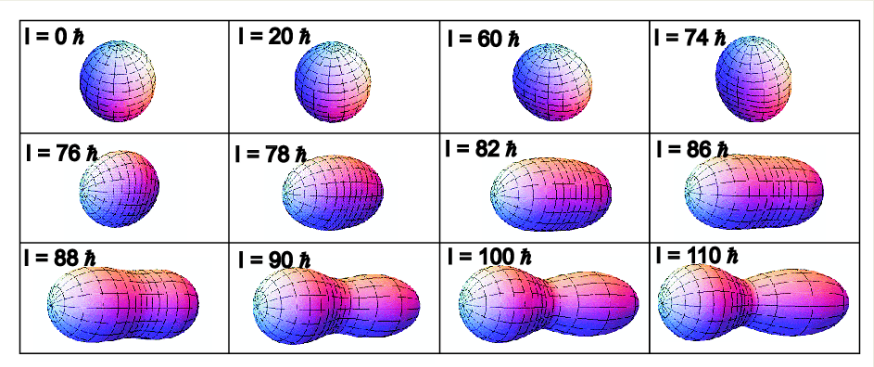
^{142}Ba (Z=56, N=86)

~430 MeV ^{94}Kr beam on ^{48}Ca target → ^{142}Ba*
SPIRAL2 beam with I~10^9 pps (@DAY1 I=1.3x10^7 pps)

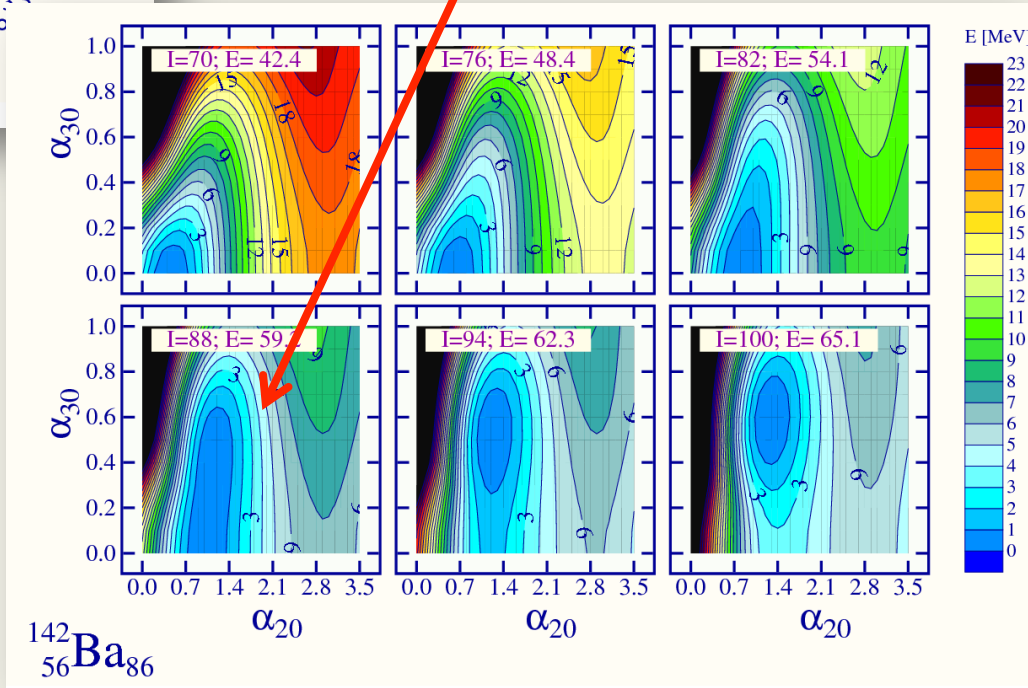
Lublin-Strasbourg liq.Drop (LSD) model by K. Pomorski and J. Dudek, PRC67 (2003) 044316

Jacobi shape transition sets in around I=76





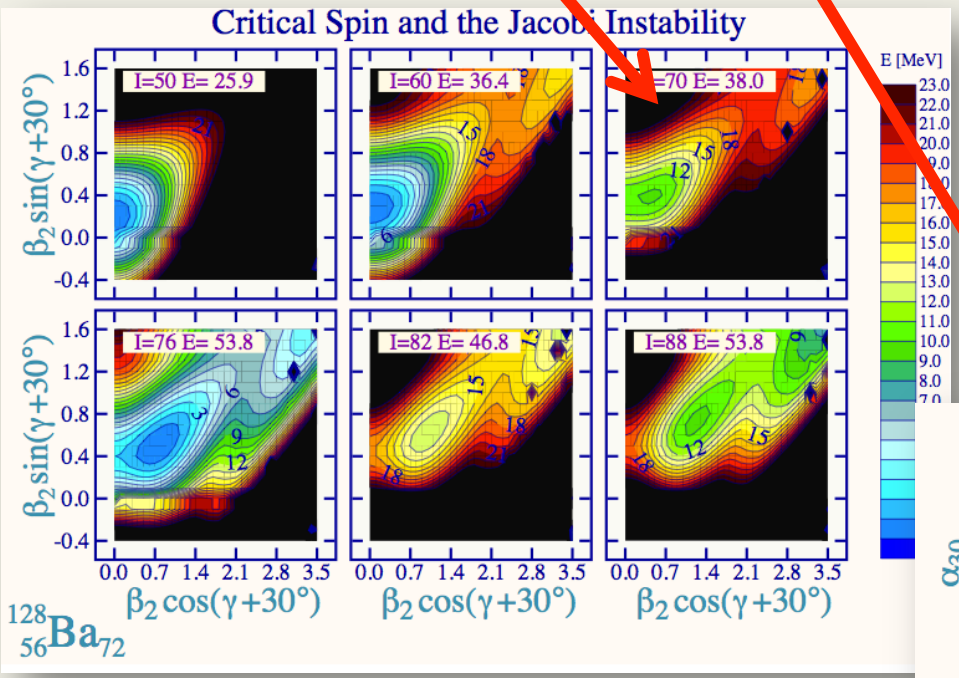
From I=88 octupole deformation sets in Poincare shape transition?

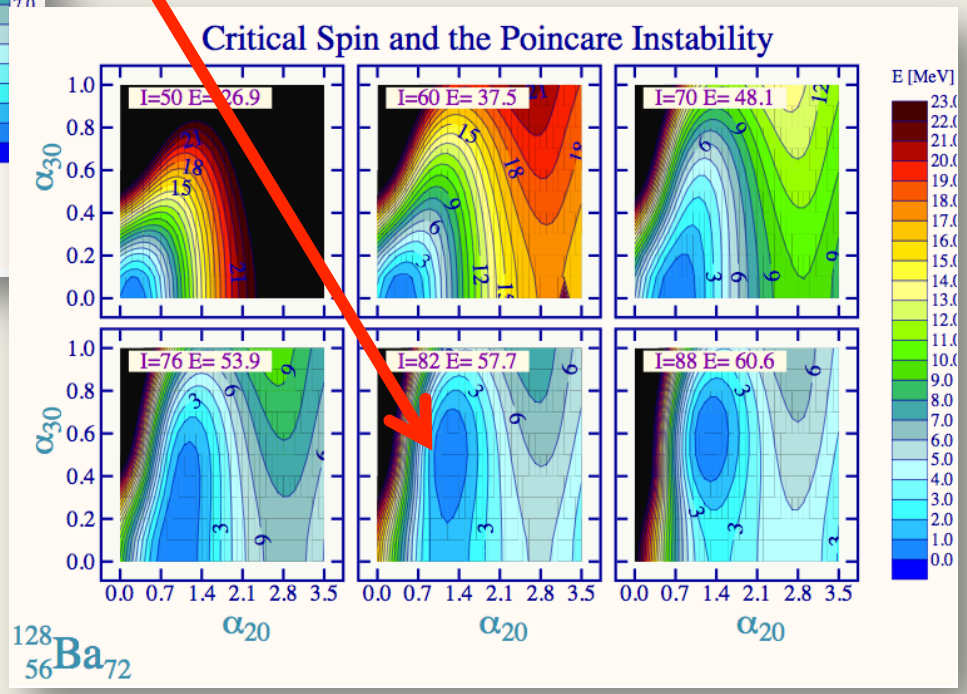


Similar behaviour is expected already for ^{128}Ba:

Oblate → Jacobi → Poincare → fission

I≈70 I≈82 I≈90





→ ***n-rich Ba nuclei are expected to exhibit Jacobi-Poincarè transitions***

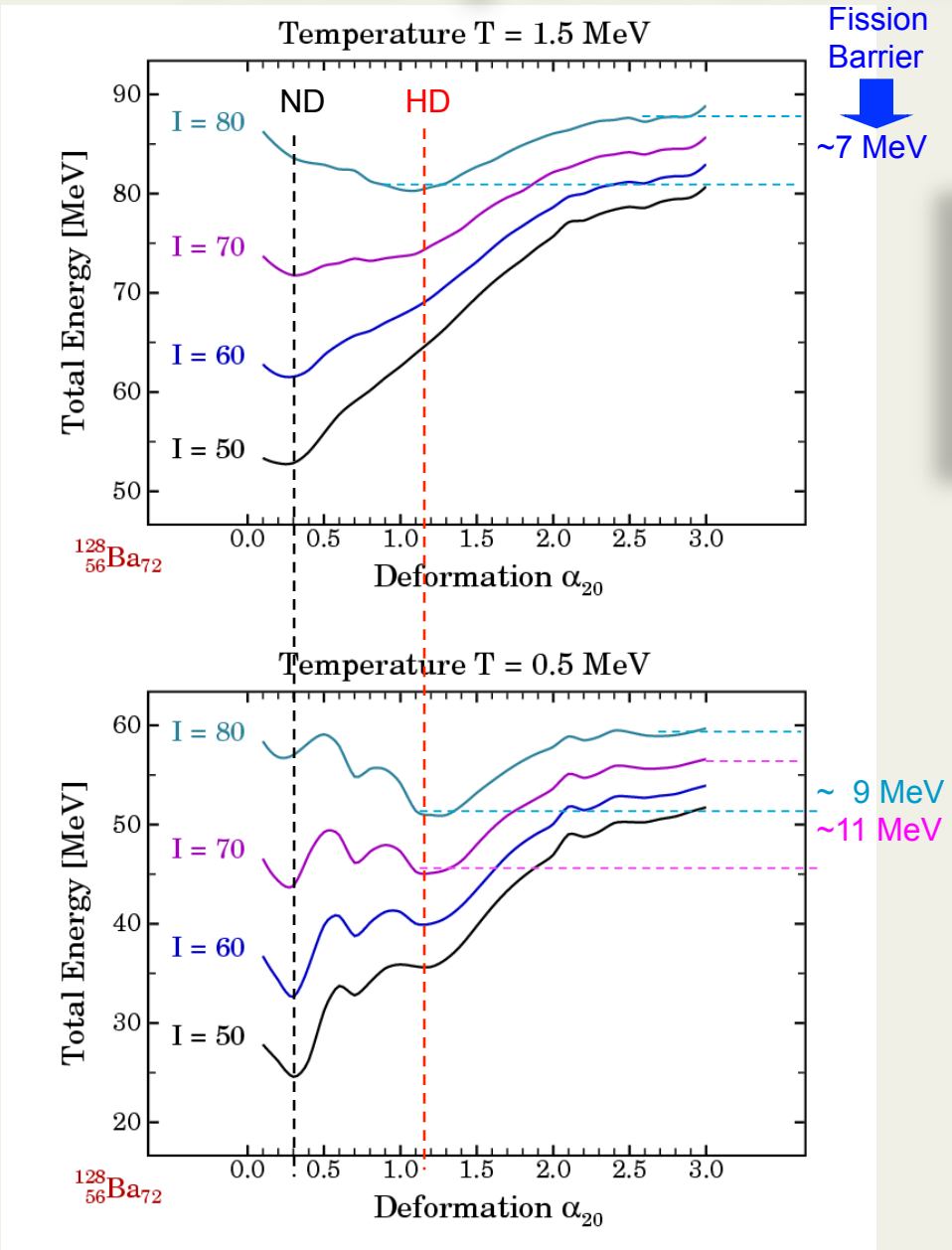
OUR EUROBALL IV+DIAMANT experiment,

B. Herskind et al.

$^{64}Ni + ^{64}Ni \rightarrow ^{128}Ba^*$, 255 and 261 MeV

Search for Discrete HyperDeformed Bands

Including Shell and Temperature Effects



The **Jacobi Transition** Effect is considered very important for the population of hyperdeformed states

Microscopic Calculations

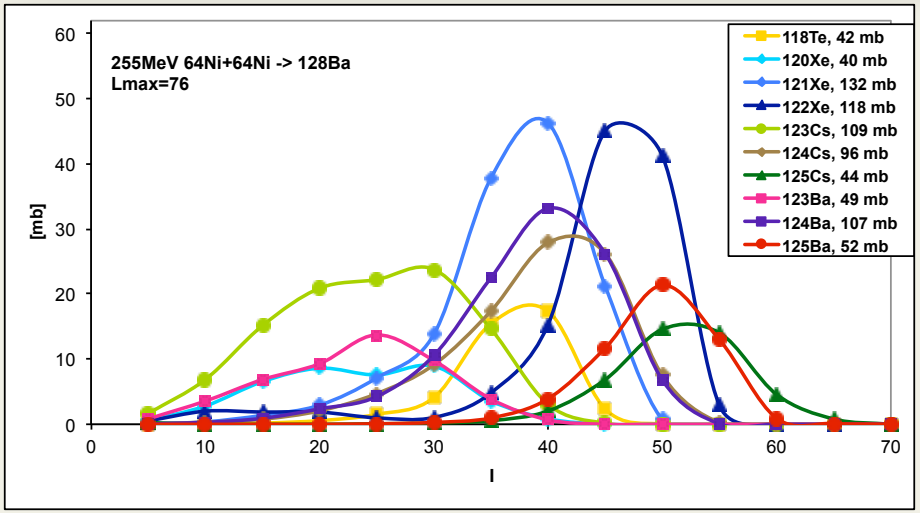
extented to include higher temperature regions

N. Schunck et al. PRC75(2007)054304

Results from EUROBALL experiment:

- NO discrete HyperDef bands
- Particle gated Ridge with very large $J^{(2)}$ in limited Spin Region

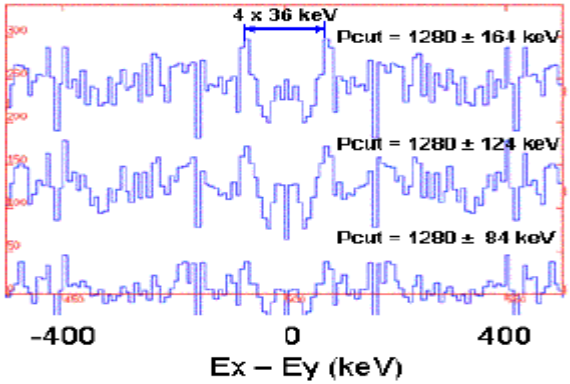
Particle gate	γ-gate	Nucleus	ΔE_γ (keV)	$J^{(2)}_{\text{exp}}$	$J^{(2)}_{\text{theory}}$	Probable shape
xn	$(2n)$	^{126}Ba	52	77	118	SD
α	(αn)	^{123}Xe	56	71		SD
α	$(\alpha 2n)$	^{122}Xe	52	77	108	SD
α	$(\alpha 3n)$	^{121}Xe	64	63		SD
2α	(2α)	^{120}Te	56	71		SD
2α	$(2\alpha 2n)$	^{118}Te	36	111	97	**HD**
p	$(p2n)$	^{125}Cs	40	100	106	**HD**
p	$(p3n)$	^{124}Cs	36	111		**HD**
$2p$	$(2p2n)$	^{124}Xe	36	111	111	**HD**
$\alpha + p$	(αpn)	^{122}I	56	71		SD
$\alpha + p$	$(\alpha p2n)$	^{121}I	52	77	102	SD



Several charged particle channels

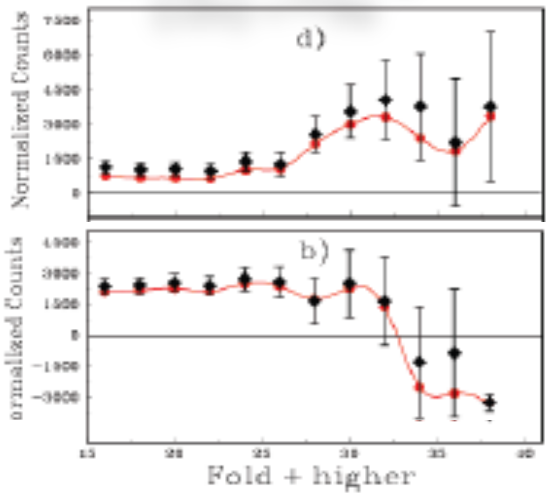
Rotational Planes γ–γ–γ

(2p2n)→^{124}Xe



Ridge intensity

(α2n)→^{122}Xe



HYPER NORMAL

SPIRAL2 Day1 experiment:
^{90}Kr (~ 10^9 pps) + ^{48}Ca → ^{138}Ba*

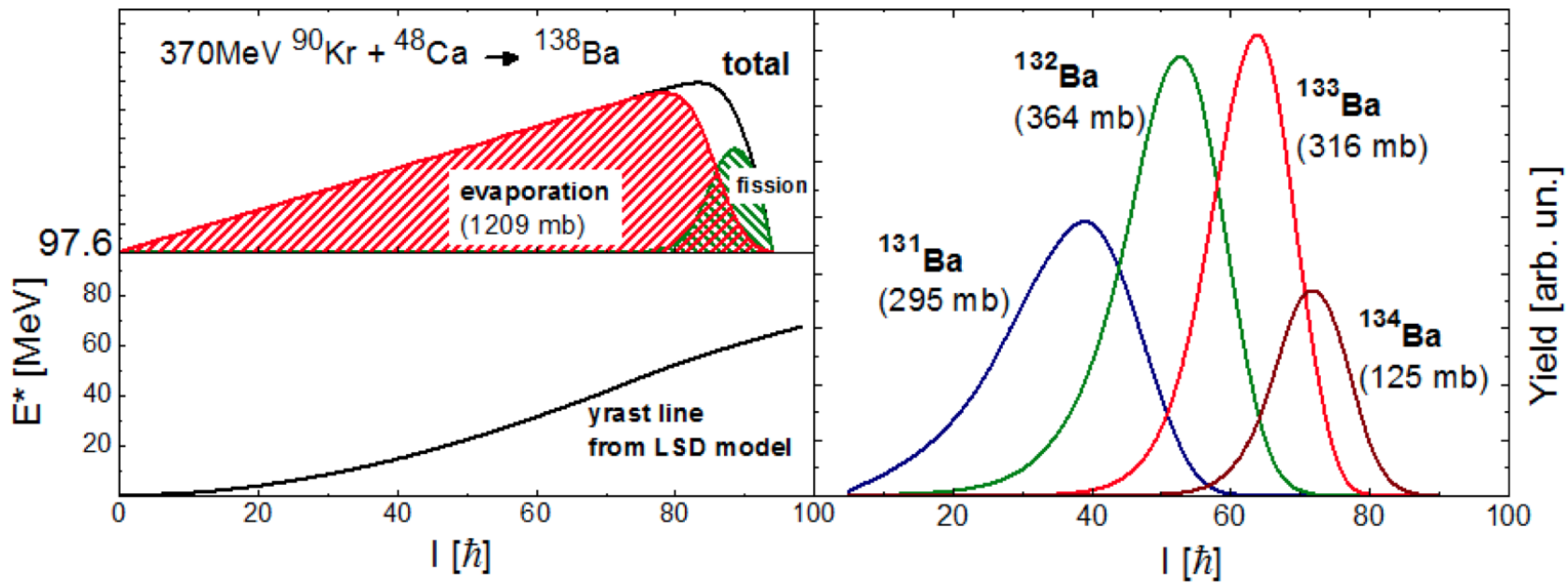


Figure 11. Left: Schematic illustration of the Excitation energy vs. Spin phase space for decay of the compound nucleus ^{138}Ba, populated by the fusion-evaporation reaction ^{90}Kr (at 370MeV) on ^{48}Ca. The total spin distribution is calculated by the GRAZING model, while the evaporation part, after fission, is estimated by CASCADE. The yields into the main neutron-evaporation channels are shown in the right part of the figure (see text for details). Integrated cross sections are also given for various channels.

LOI, A. Maj and S. Leoni

Experimental strategy: Step Approach

Day-0) LNL Legnaro: ^{86}Kr (stable) on ^{48}Ca leading to ^{134}Ba*:
TEST of inverse kinematic reaction with PARIS prototype, HECTOR+, GALILEO and RFD.
TEST competition with fission at extreme spins in neutron-rich region.

Day-1) At the first stage of SPIRAL2 the reaction **^{90}Kr** (with intensity of **5x10^{8} pps** and ~4 MeV/A) on **^{48}Ca** target will be used to populate the compound nucleus **^{138}Ba*** at maximum spin around 90 $\hbar$.

Day-2) At a later stages (Phase2-Day2) even more neutron-rich systems, as e.g. **^{142}Ba*** will be reached by the use of the **^{94}Kr** beam, with similar intensity.

Experimental Setup @ SPIRAL2

1π AGATA/EXOGAM2 + 1π PARIS + VAMOS/RFD + DIAMANT

Possible set-up :

PARIS (2π)	+	VAMOS/RFD	+	EXOGAM2/AGATA	+	DIAMANT
⬇		⬇		⬇		⬇
High-energy γ rays (GDR) γ-ray multiplicity (~ L)		Reject fission Measure of $(v, \vartheta)_{ER}$		Discrete γ lines Ridge structure		charged particles

High efficiency and selectivity

Recoil Filter Detector : see contribution of Mateusz Krzysiek

Thank You for the Attention

Proposed set-up at LNL:

GALILEO + LaBr3 (+ PARIS Prototype) + RFD

Discrete γ lines
Ridge structures/E2 bump

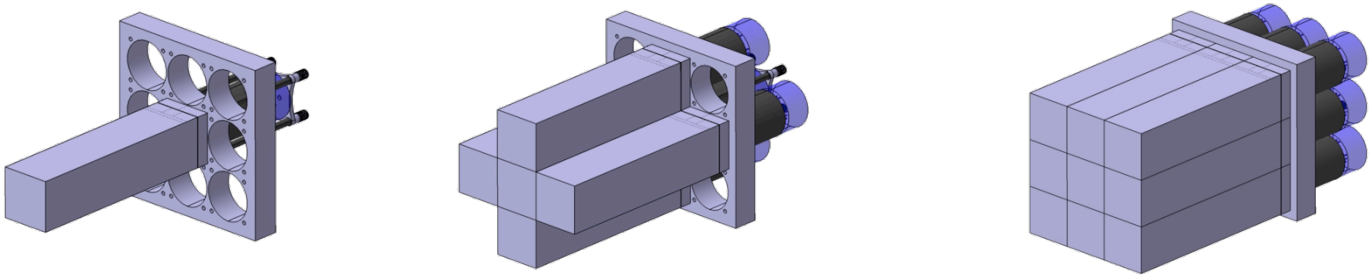
High-energy γ rays (GDR)

Reject fission
Measure of $(v, \vartheta)_{ER}$

High efficiency and selectivity

PARIS Prototype

9 phoswich (LaBr3+NaI) crystals

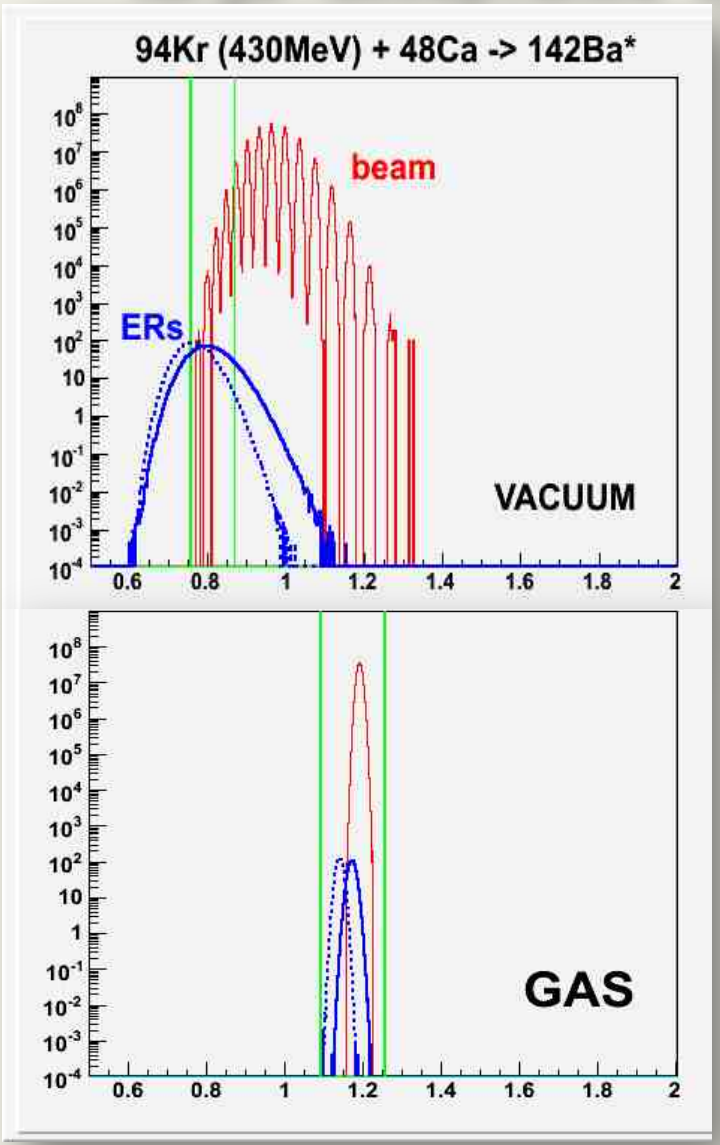


PARIS prototype: cluster of 9 phoswich crystals (LaBr3 2”x2”x2” +NaI 2”x2”x6”)
Dimension (without PMTs and holding structure): 6"x6"x8"

READY: beginning of 2012

October 2011: 5 phoswiches, to form a "clover" or "cross-like" cluster.

Heavy Ion detection:
large-acceptance spectrometer VAMOS @ 0°



- Vacuum VAMOS better for ^{94}Kr (430MeV) + ^{48}Ca
  (sufficient beam rejection if lower transmission)
- Available Doppler correction
- ^{88}Kr+^{40}Ca under study

Hyper- versus super-deformation: Expected differences in experimental approaches and suggested new strategies

- The discrete hyper-deformed bands are predicted to be much shorter than the super-deformed bands: 5–8 transitions typically, compared to 20 or more in the super-deformation case. Consequently, the experimental criteria based on the "picket-fence" like spectra must take this into account.

- The Jacobi transition seems a necessary condition: only nuclei that produce the Jacobi transitions, and therefore, the minima at high spins, high temperatures and at the same time at the hyper-deformed shapes can be populated through the fusion–evaporation reactions. Consequently, in contrast to the discussions existing so far in the literature, the first theoretical criterion should be "the nucleus of interest for the hyper-deformation studies must produce the Jabi transition". Only on top of that we must apply the shell-closure criteria, negative shell energies *etc.*

- As the result of the previous observation, one should seriously consider a drastic change in the experiment objectives: instead of hunting for the long discrete bands (that are anyway predicted to be absent) concentrate on the γ-γ-γ correlation analyses that give precious information at this time: the average length of the HD bands, the numbers of the excited bands in a given energy window *etc.*

Best Candidates (n-rich Ba): $^{94}Kr + ^{48}Ca \rightarrow ^{142}Ba^*$ (Z=56, N=86)

Fusion reactions with radioactive beams (SPIRAL2)

Study of collective modes of excitations in the neutron-rich Ba region via fusion-evaporation reactions

LOI SPIRAL2 *Spiral2 Day1-Phase2 LoI*

Adam Maj (Kraków), Silvia Leoni (Milano) - spokespersons
Christell Schmitt - GANIL Liaison

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A. Gadea[m], T.Hüyük[m] et al.,
J. Simpson[n] et al.,
W. Korten[o] et al., A. Goergen[p] et al.,
D. Jenkins[q], R. Wadsworth[q] et al.,
M. Palacz[r], G. Jaworski[r], K. Hadynska-Klek[r], P. Napiorkowski[r], K. Wrzosek-Lipska[r] et al.,
A. Atac[s] et al.,

and the PARIS-EXOGAM-AGATA collaborations

Experimental setup: **AGATA/EXOGAM2** array + 2π **PARIS** scintillator array
+ detection system for selection of the evaporation residues (**RFD: Recoil Filter Detector**)