PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

PARIS - status, perspectives for installation in Poland and studies of hot rotating nuclei

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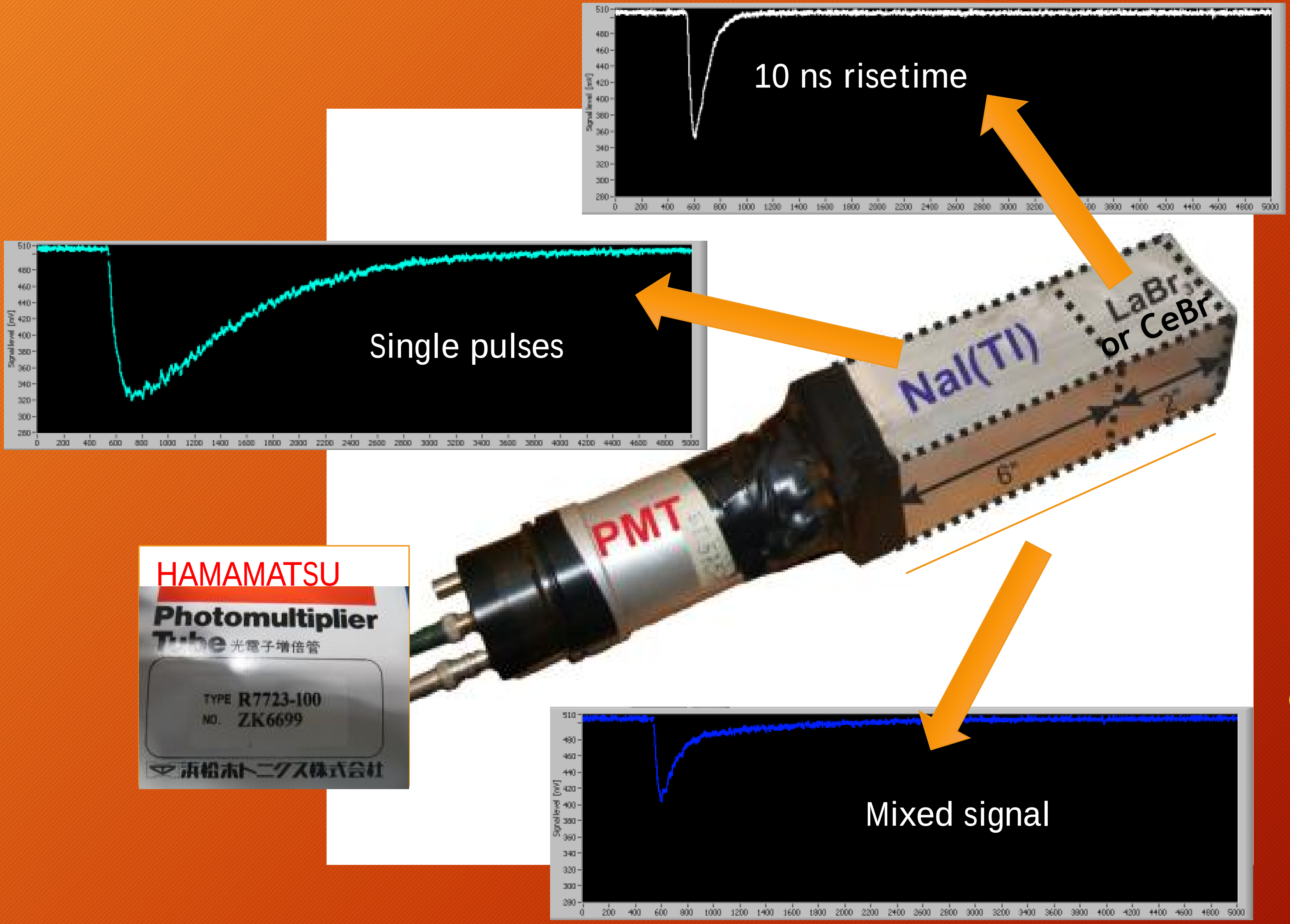
and the PARIS Collaboration

Warszawa, 15.01.2019

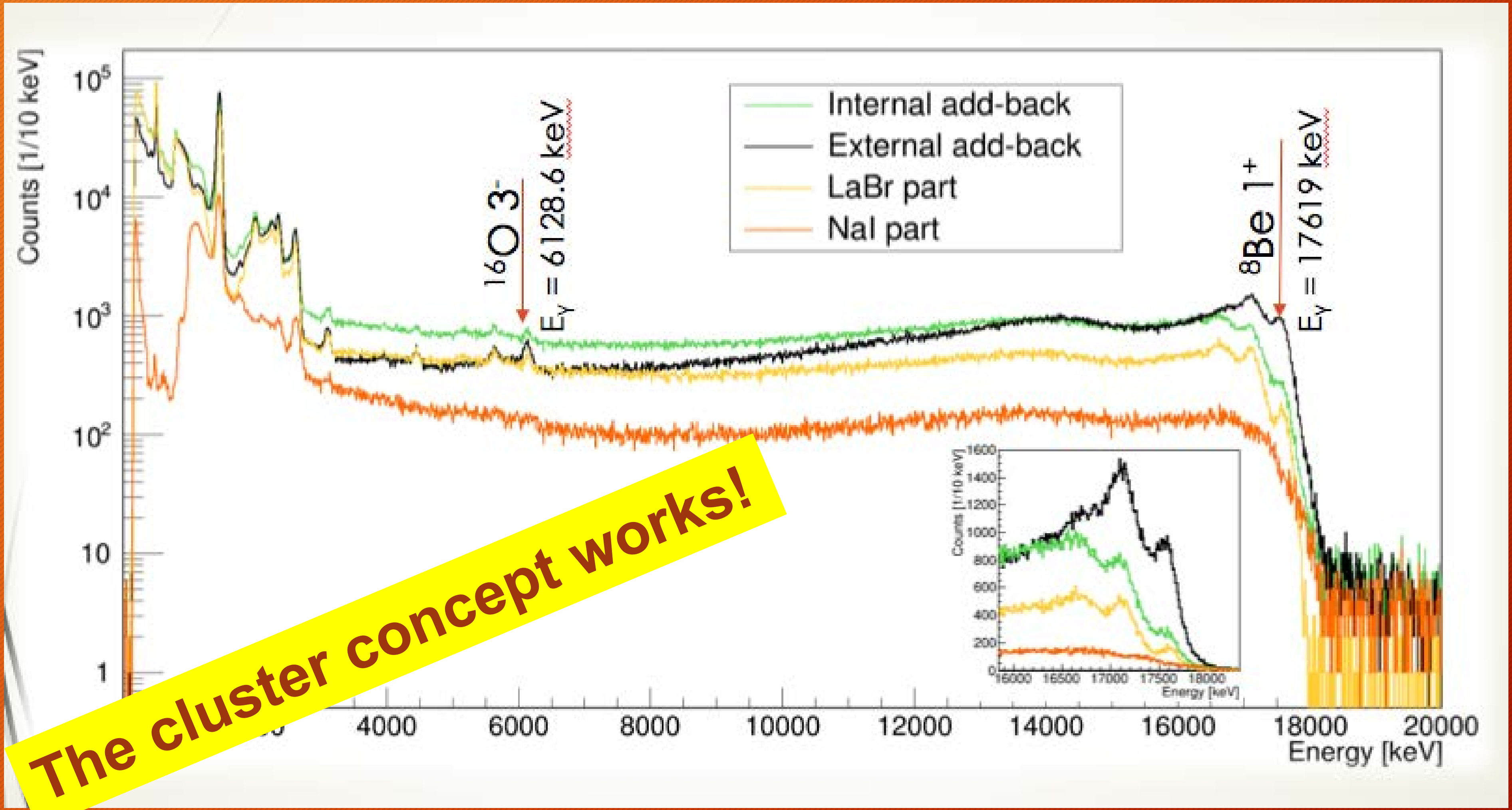
The PARIS PHOSWICH at work



PARIS:
- Good time resolution,
- Very good Energy resolution,
- Good efficiency for high Energy (10-30 MeV) gamma-rays.

$LaBr_3$ resolution (seen through 6” long NaI): ca. 4%

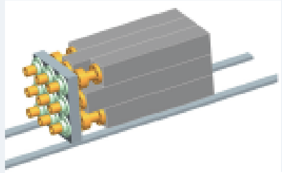
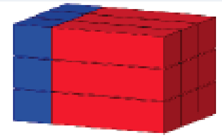
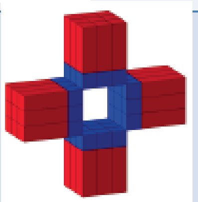
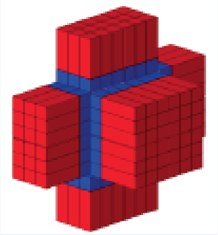
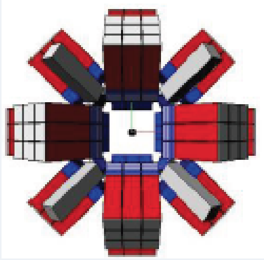
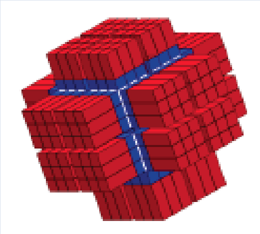
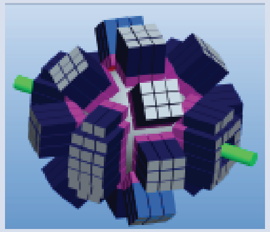
Exp. in ATOMKI Debrecen – March 2017
(p,gamma) – reaction on LiBO target
Testing PARIS cluster add-back with high-energy gamma-rays



PARIS Demonstrator MoU (2011-2015…) and PARIS phases

MoU on PARIS Demonstrator (Phase 2) was prepared and agreed to be signed by IN2P3 (France), COPIN (Poland), GANIL/SPIRAL2 (France), TIFR/BARC/VECC (India), IFIN HH (Romania), INFN (Italy), UK, Turkey

PARIS phases and cost estimates

Phase 1 **2011/2012** PARIS cluster	1 cluster: 9 phoswiches	 	250 k€	**Decided** Funds: SP2PP, ANR, Orsay, Strasbourg, Kraków, Mumbai Tests in-beam and with sources
Phase 2 **2017** **PARIS Demonstrator**	**4 clusters:** **36 phoswiches**		1100 k€	**Only if Phase1 validated** Funds: MoU Ph1Day1 exp@S3
Phase 3 **2022** **PARIS 2π**	12 clusters: 108 phoswiches	 	≈ 2 M€	**Only if Phase2 validated** Funds: MoU, PARIS consortium Ph2Day1 exp. wit AGATA and GASPARD Other exp.
Phase 4 **2025?** **PARIS 4π**	≥24 clusters: :216 phoswiches	 	≈ 4 M€	**Only if Phase3 validated** Funds: PARIS consortium Regular experimen in various labs

IPN Orsay
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AGATA@GANIL
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.
S3@GANIL
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CCB Krakow
.
.
LNL/SPES
.
.
SPIRAL2 phase2
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Presently PARIS collaboration has 4 clusters:
3 LaBr3_NaI clusters (produced by Saint Gobain)
1 CeBr3_NaI cluster (produced by Scionix)
The goal of the original MoU on PARIS Demonstrator was achieved

Recently PSC decided to extend the PARIS Demonstrator MoU until 2021
with the goal to reach at least 8 clusters (33% of 4π)
(process of signing is ongoing – 3 partners signed)
Total cost: ≈1.9 M€

New partners:
JINR Dubna and GSI

Installation in Poland

Already used in IFJ PAN CCB facility and in HIL Warsaw

- **M. Kmiecik, F. Crespi, B. Wasilewska et al. „Studies of resonance states in nuclei usi… …oton beam in p,p' reactions at forward angles with HECTOR, PARIS, KRATTA (2017, t… 2018/2019)**
- **K. Hadyńska-Klęk et al., „**Coulomb excitation in ^{40}Ar**" (2015)**

Accepted to be performed at IFJ PAN CCB

- **S. Leoni, B. Fornal, N. Cieplicka et al., „Study of M4…**
- **A. Bracco, B. Fornal „Investigations of (p,2p) r… …entify deep single-particle proton-hole states"**
- **Ch. Schmidt, D. Mancusi, B. Kamys et al., „Invest… …proton induced spallation with HECTOR, PARIS, KRATTA"**

Later today talks by:
B. Wasilewska
N. Cieplicka
M. Krzysiek

PARIS@HIL with new cyclotron
studies of hot rotating nuclei

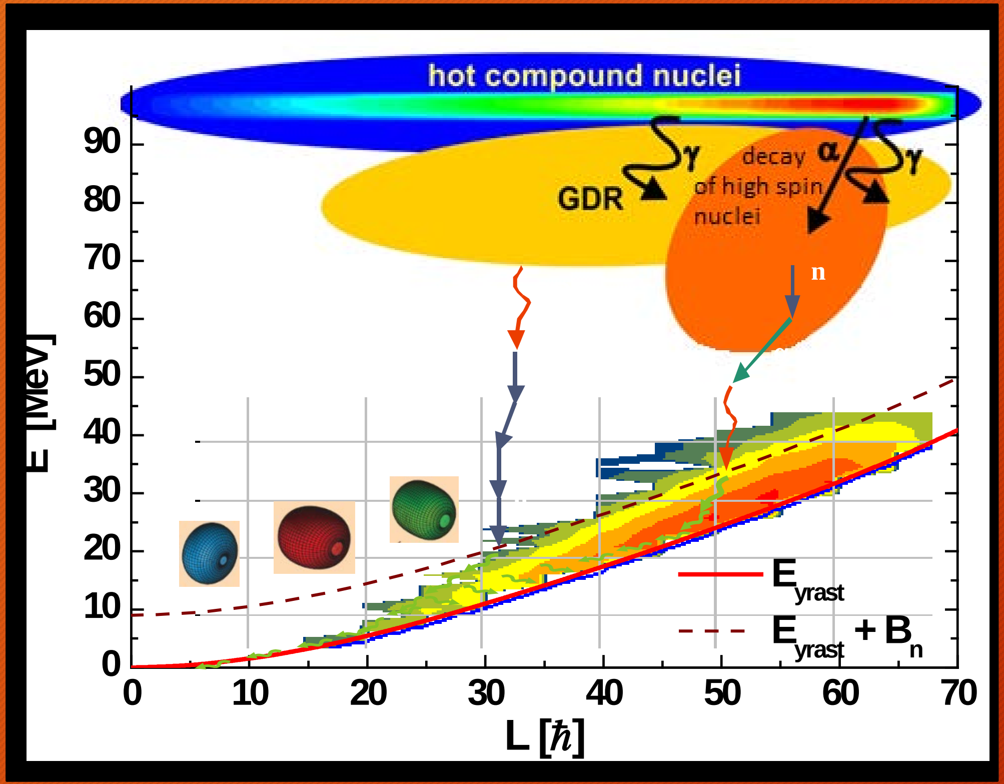
PJN presentation, Kazimierz, 2018

- Available ions: from alpha up to ^{209}Bi
- beam current 10 pμA for A=50
- Energy ≤10 MeVA

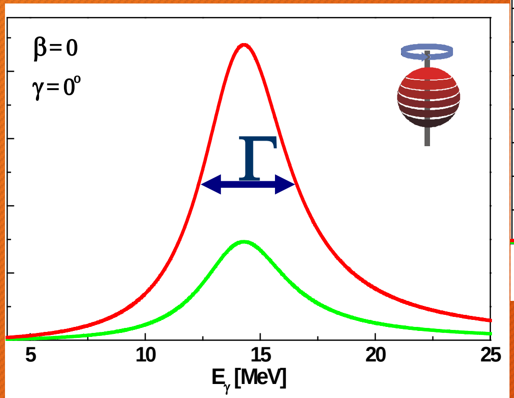
- Nuclear deformation evolution in function of temperature and angular momentum (for example Jacobi shape transition) – use of PARIS coupled to residue/charge particles detector (FAZIA or equivalent).
- Studies of the properties of the GDR decaying to isomeric states with PARIS and HPGe (AGATA, EAGLE or equivalent) detectors.
- Study of isospin mixing with use of GDR (PARIS and AGATA/EAGLE or FAZIA).
- Pre-fission GDR measurements in super heavy isotopes with PARIS and fission fragment detectors (FAZIA).

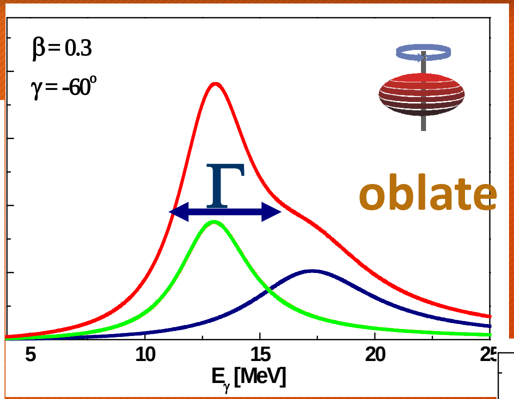
At least 8 PARIS clusters should be available (72 phoswiches) soon.

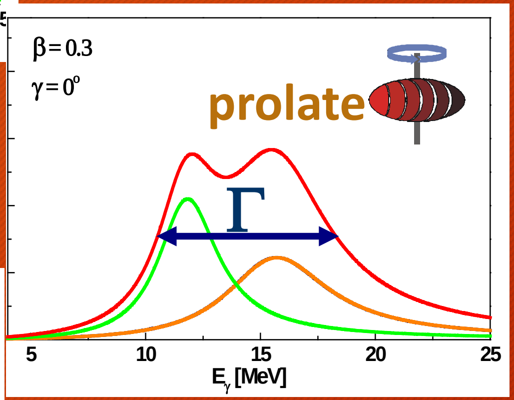
Hot rotating nuclei - formation in fusion reactions

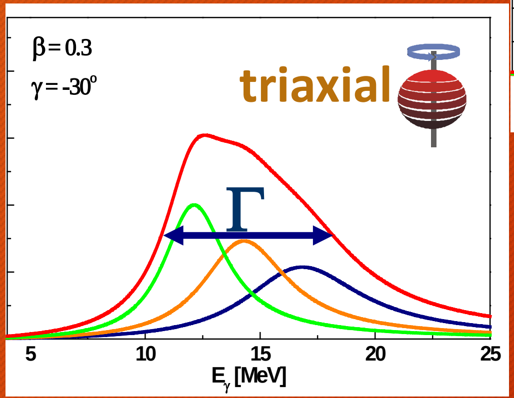


Nuclear deformation evolution in function of temperature and angular momentum









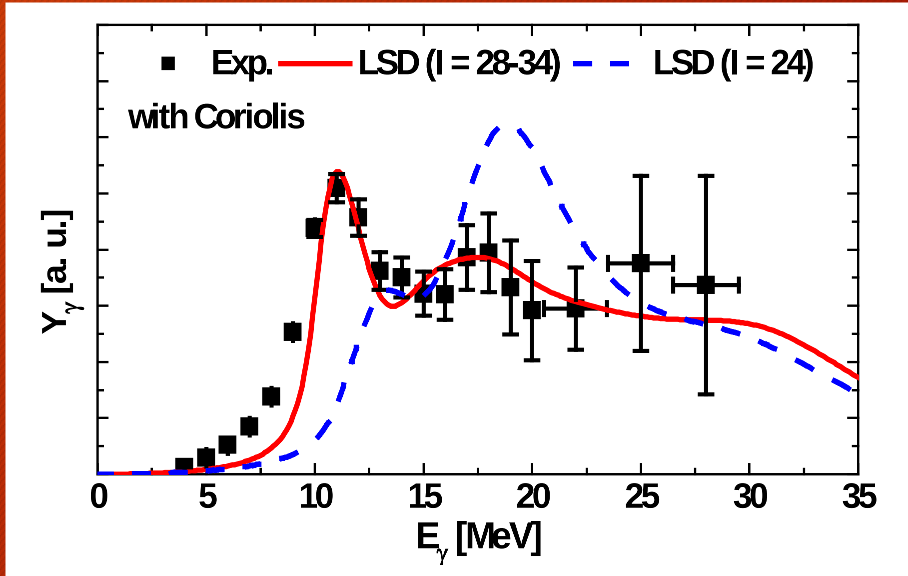
$$E_k = E_0 \exp\left[-\sqrt{\frac{5}{4\pi}}\beta\cos\left(\gamma - \frac{2\pi k}{3}\right)\right]$$

$$E_0 = 18A^{-\frac{1}{3}} + 25A^{-\frac{1}{6}}$$

$$Y(E_\gamma) = Y_1(E_\gamma) + Y_2(E_\gamma) + Y_3(E_\gamma)$$

$$Y_k(E_\gamma) = \frac{S_k \Gamma_k E_\gamma^2}{\left(E_\gamma^2 - E_{GDR\,k}^2\right) + \Gamma_k^2 E_\gamma^2}$$

$$\Gamma_k = \Gamma_{GDR}\left(\frac{E_k}{E_{GDR}}\right)^\delta$$



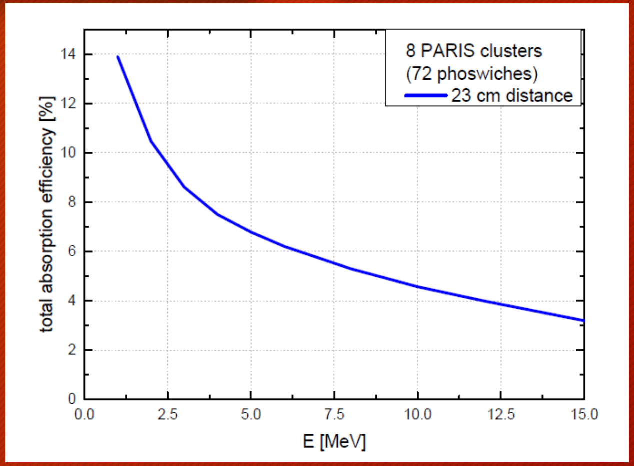
A. Maj et al., Nucl. Phys. A731, 319c (2004)

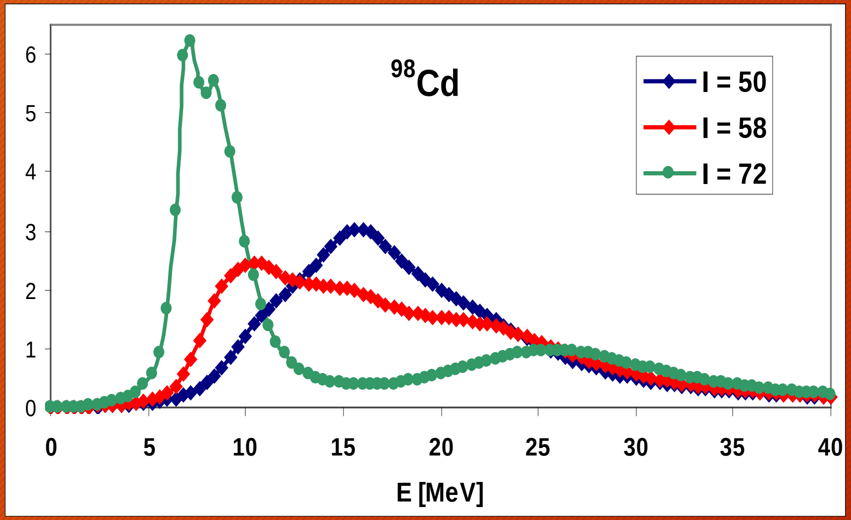
Jacobi shape transition and seen for the first time Coriolis effect

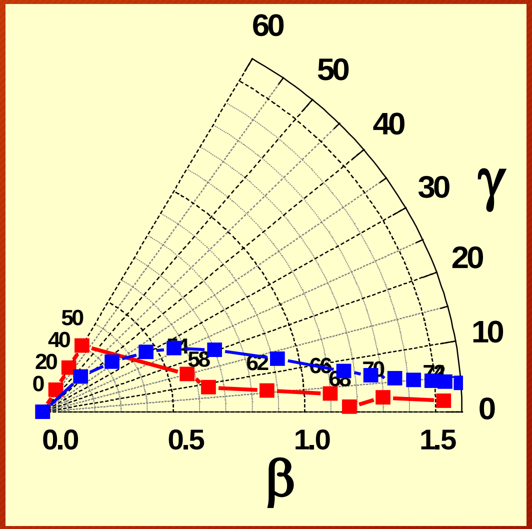
Nuclear deformation evolution in function of temperature and angular momentum

- PARIS (gamma GDR) coupled to FAZIA (residues and fission fragments)

- Reaction (for example): **^{40}Ca@250 MeV on ^{58}Ni ->^{98}Cd***



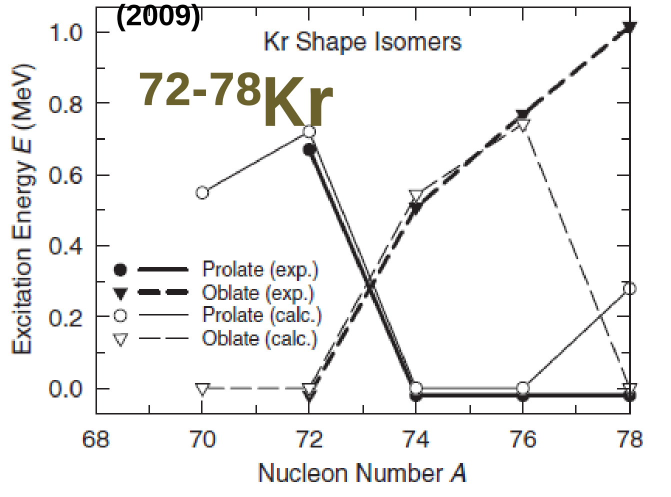




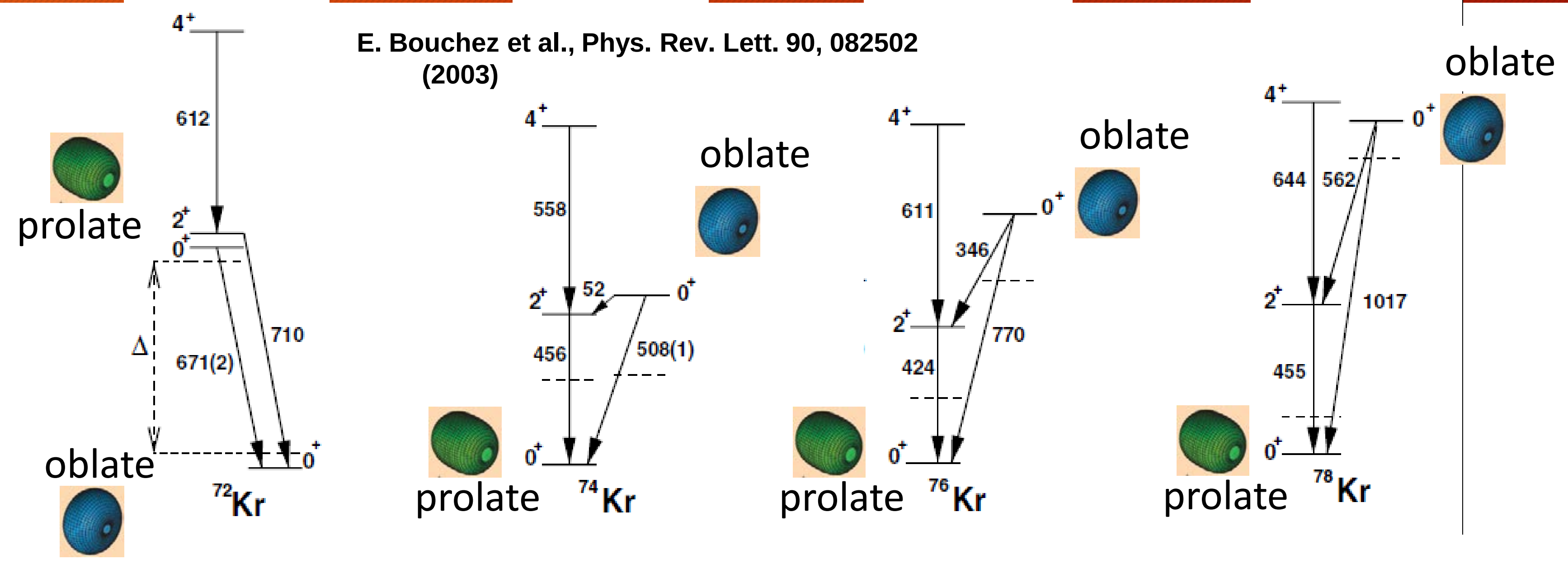
Studies of the properties of the GDR decaying to isomeric states - Idea

- GDR high energy γ rays – hot nucleus shape
- Low energy transitions – shape of excited residue
- Link between deformation in hot CN and cold evaporation residue

P. Möller et al., Phys. Rev. Lett. 103, 212501 (2009)



E. Bouchez et al., Phys. Rev. Lett. 90, 082502 (2003)



Studies of the properties of the GDR decaying to isomeric states - Idea

- PARIS (gamma GDR) coupled to HPGe detectors souch as EAGLE or AGATA arrays (discrete transitions in residue).

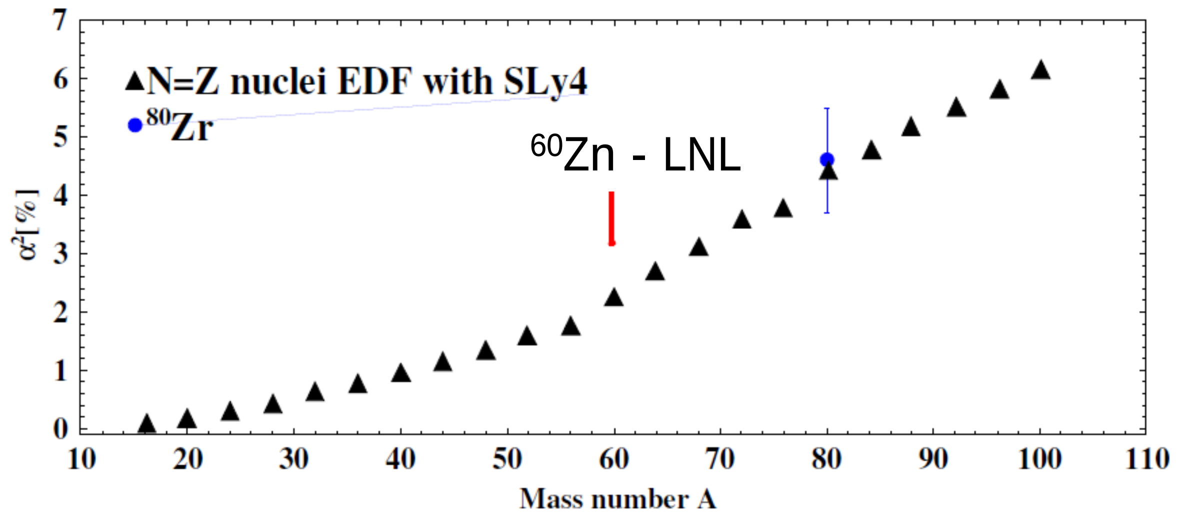
- Reactions (by example):

^{16}O @ 90 MeV on ^{66}Zn,^{64}Zn → $^{80}Sr^*$,$^{82}Sr^*$ → ^{76}Kr, ^{78}Kr

^{32}S @ 144 MeV on ^{46}Ti → $^{78}Sr^*$ → ^{74}Kr

Study of isospin mixing with use of GDR - Idea

- PARIS (gamma GDR) coupled to HPGe detectors souch as EAGLE or AGATA arrays (discrete transitions in residue) or FAZIA (A,Z of residues).



Calc from W. Satuła et al. PRL, 103 (2009); Data: S. Ceruti, F. Camera et al. PRL, 115 (2015)

Using a combination of N=Z projectile and target it is possible to produce a CN in I=0 channel.
The E1 gamma decay from I=0 to another I=0 is forbidden and only the decay to the I=1 states is open.
If we consider the isospin mixing effect, the initial state is a superposition of I=0 and I=1 states and therefore it can also decay to I=0 states.

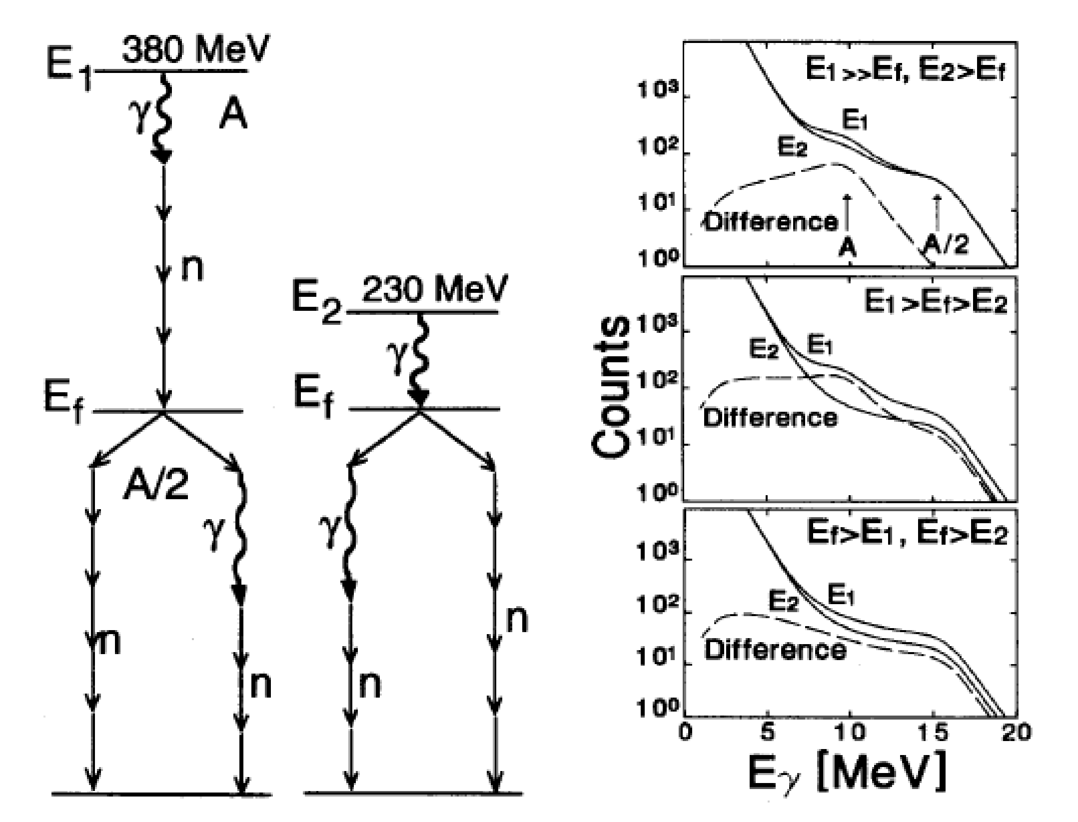
Pre-fission GDR measurements in super heavy isotopes – Method and motivation

To investigate the properties of superheavy nuclei throught gamma GDR Decay in hot compound nucleus prior to fission.

1. Measure gamma GDR spectrum emitted from CN formed at E_1 and E_2 excitation energy ($E_1>E_2$)
2. E_F is Energy at which fission occurs. If $E_1 > E_2 > E_F$ (slow fission compared to gamma emission) then post-fission difference should be 0, pre-fission difference should be visible.
3. If fission occurs very fast ($E_F>E_2>E_1$) differentia gamma spectrum is dominated by emissions from fission fragments. Measure gamma GDR emitted from CN formed at E_1 and E_2 excitation Energy ($E_1> E_2$)

Allows to extract time scale of fission proces for the super heavy nuclei, and possibility to determine theirs deformations at high temperature.

Investigated for ^{272}Hs:
A. Maj et al., Acta Phys. Pol. B 26(2-3) 1995.
A. Bracco et al., Nucl. Phys. A583(1995) 83-92



A. Maj et al., Acta Phys. Pol. B 26(2-3) 1995.

Pre-fission GDR measurements in super heavy isotopes - Idea

Allows to look into superheavy elements fission dynamics as well as their deformation at high temperatures

- Use of PARIS (measurement of high Energy gamma-rays from GDR Decay) coupled to FAZIA detectors (fission fragments).
- Intense A ≈ 50 beam to populate super heavy **hot** Compound Systems – ideally suited for new HIL cyclotron
- Reactions (for example):

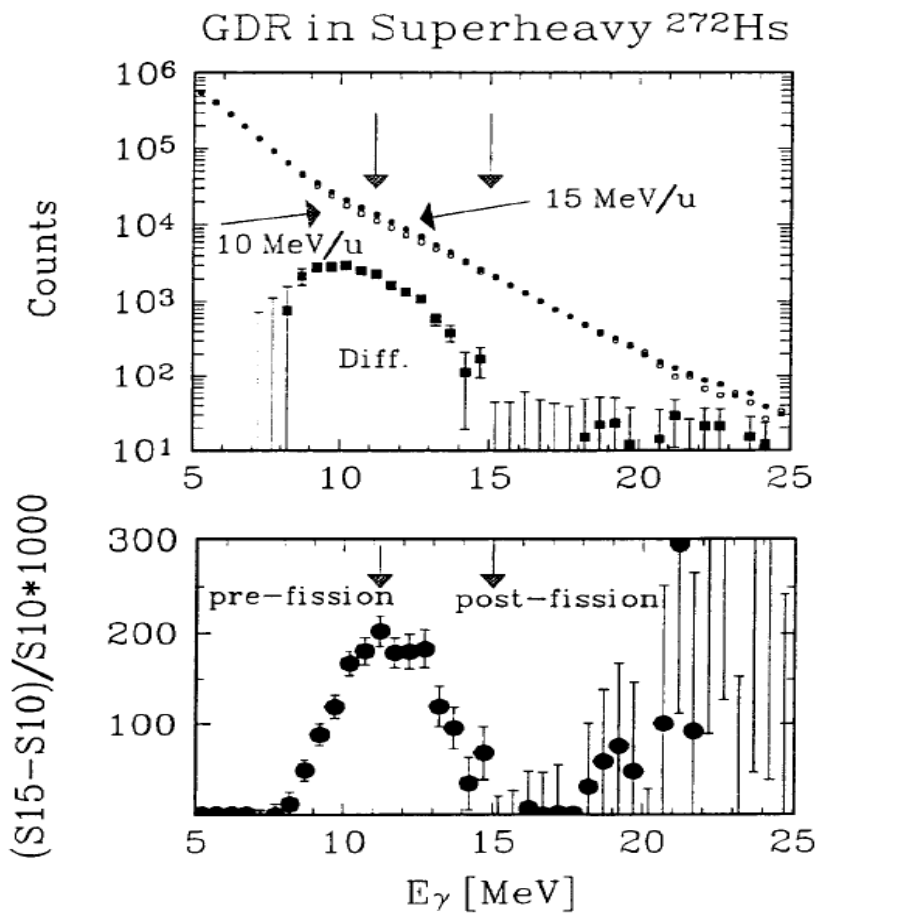
^{56}Fe@400 and 560 MeV on ^{238}U -> ^{294}Og*

(E* = 115 MeV, E* = 244 MeV)

^{56}Fe@400 and 560 MeV on ^{232}Th -> ^{288}Lv*

(E* = 118 MeV, E* = 247 MeV)

and others – possible systematic study in superheavy elements region



T. S. Tveter, J.J. Gaardhcje ,A. Maj, et al., Phys. Rev. Lett. 76(7), 1996.

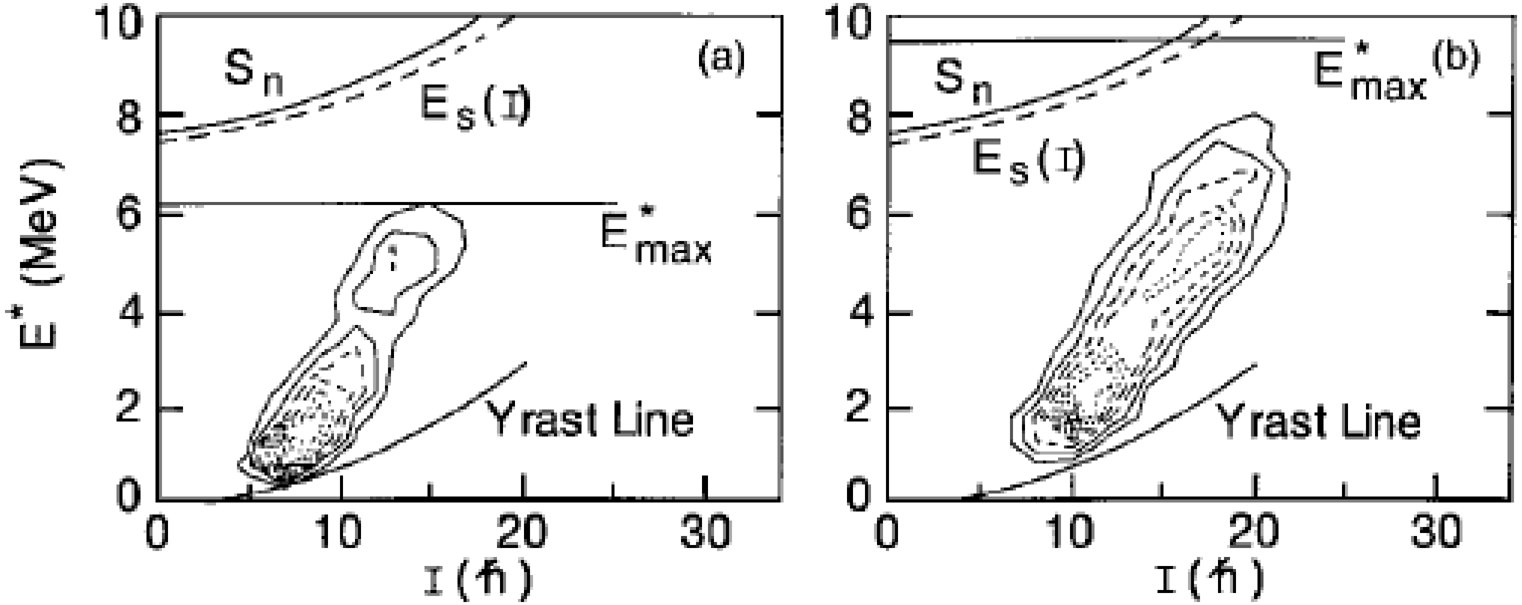
Study of the fission barier height vs angular momentum dependence in heavy and superheavy nuclei

VOLUME 84, NUMBER 16 PHYSICAL REVIEW LETTERS 17 APRIL 2000

Entry Distribution, Fission Barrier, and Formation Mechanism of $^{254}_{102}$No

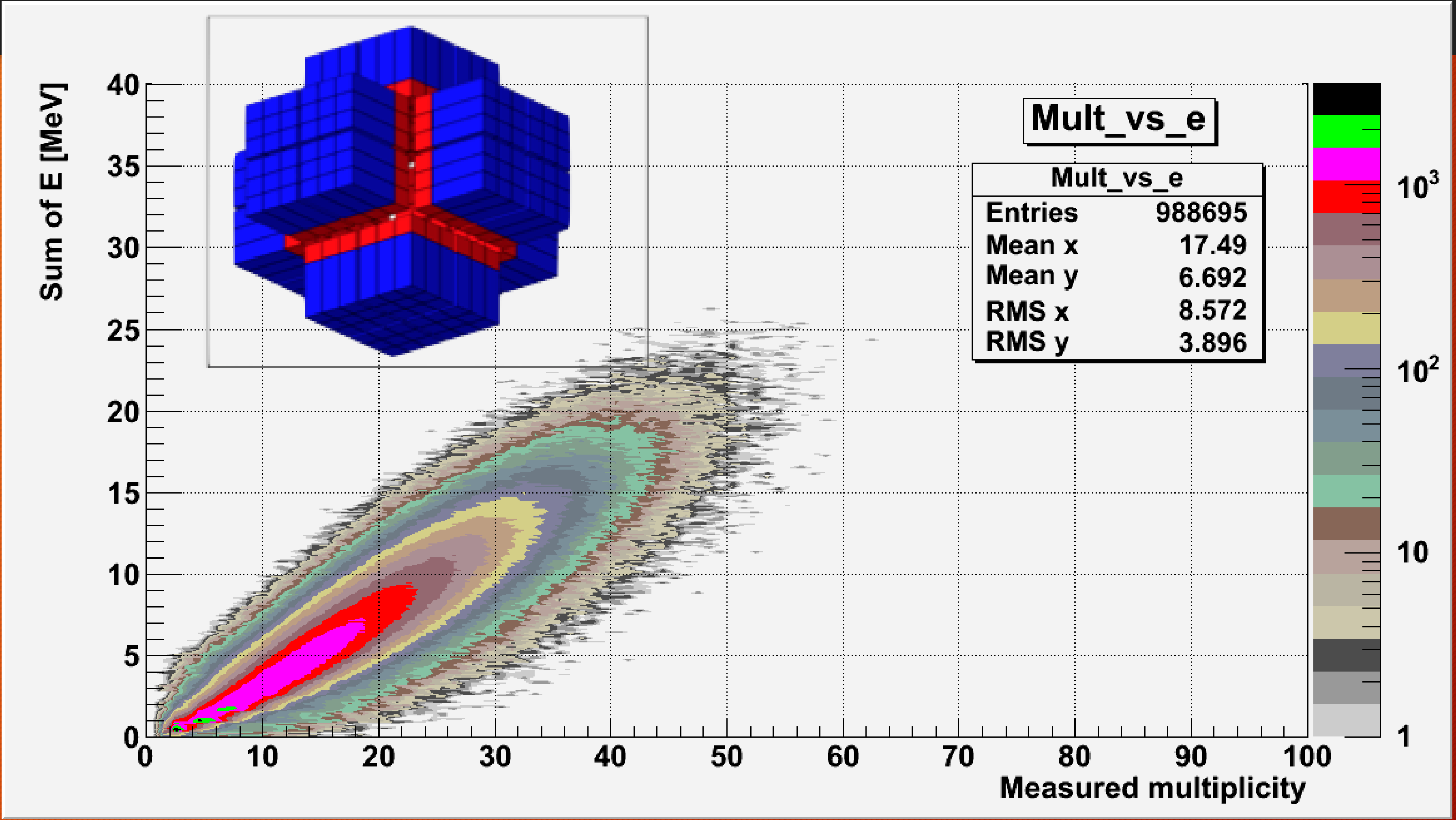
P. Reiter,[1,2] T. L. Khoo,[1] T. Lauritsen,[1] C. J. Lister,[1] D. Seweryniak,[1] A. A. Sonzogni,[1] I. Ahmad,[1] N. Amzal,[3] P. Bhattacharyya,[4] P. A. Butler,[3] M. P. Carpenter,[1] A. J. Chewter,[3] J. A. Cizewski,[1,5] C. N. Davids,[1] K. Y. Ding,[5] N. Fotiades,[5] J. P. Greene,[1] P. T. Greenlees,[3] A. Heinz,[1] W. F. Henning,[1] R.-D. Herzberg,[3] R. V. F. Janssens,[1] G. D. Jones,[3] H. Kankaanpää,[7] F. G. Kondev,[1] W. Korten,[6] M. Leino,[7] S. Siem,[1,8] J. Uusitalo,[1] K. Vetter,[9] and I. Wiedenhöver[1]

ANL-P-22,616



In summary, we have measured the entry distribution for a shell-stabilized nucleus. The limiting angular momentum and excitation energy are deduced for excited states in ^{254}No after the ^{208}Pb(^{48}Ca, $2n$) reaction. The data provide direct information on the fission barrier and on the shell-correction energy, based on a novel experimental technique to determine a lower bound of the barrier height. In

H-K matrix response for full PARIS



SUMMARY

- The concepts of PARIS phoswich ($LaBr_3$+NaI, $CeBr_3$+NaI) and PARIS cluster of 9 phoswiches, were proved to work very well.
- In the near future at least 8 clusters of PARIS (72 phoswiches) should be available
- PARIS can be used in broad area of experiments in CCB proton facility at IFJ PAN, as well as at planned HIL new cyclotron:
- **Pre-fission GDR measurements in super heavy isotopes** *(case unique for HIL with new cyclotron)*
- Studies of the properties of the GDR built on isomeric states *(at HIL, but is being done elsewhere too)*
- Nuclear deformation evolution in function of temperature and angular momentum *(HIL, but is being done elsewhere too)*
- Study of isospin mixing with use of GDR (HIL and being done elsewhere too)