

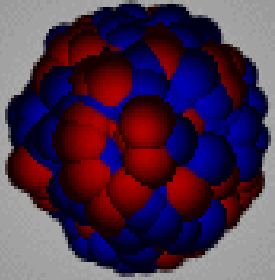
FRANCO CAMERA: THE MAN BEHIND THE HECTOR, PARIS AND OTHER SCINTILLATOR ARRAYS

Adam Maj
IFJ PAN Krakow



Multifaceted aspects of
collaborative research on nuclear structure
at UNIMI and INFN-MI

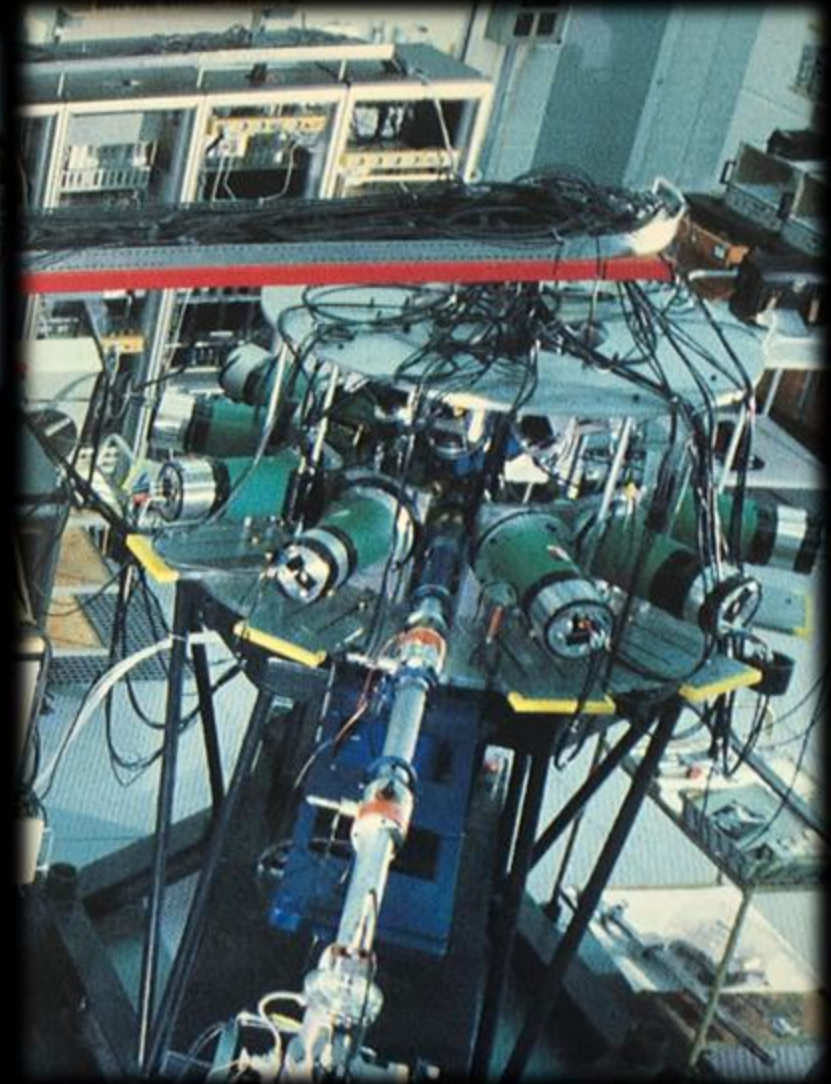
Celebrating F.Camera's, G.Colò's and S.Leoni's 60th birthday
Milano, October 17-18, 2024



INTRODUCTION

- The research on the **giant dipole resonances** (GDR) built on excited states is relevant for the understanding of the properties of nuclear matter at finite temperature and of the evolution of the damping mechanisms of this collective vibration with temperature and angular momentum. Extensive experimental and theoretical work was done to address these topics.
- In particular, the **nuclear shapes of hot nuclei** are probed by the GDR and the nuclear deformations and their fluctuations affect the damping mechanisms.
- Experimentally these effects are studied in exclusive measurements of the **g-decay of the GDR**, for which **large arrays of scintillator detectors** are used.
- In my talk I will present 2 of such arrays, **HECTOR** and **PARIS**, the examples of the research highlights obtained with them, and the role played by **Franco Camera** in all of this.

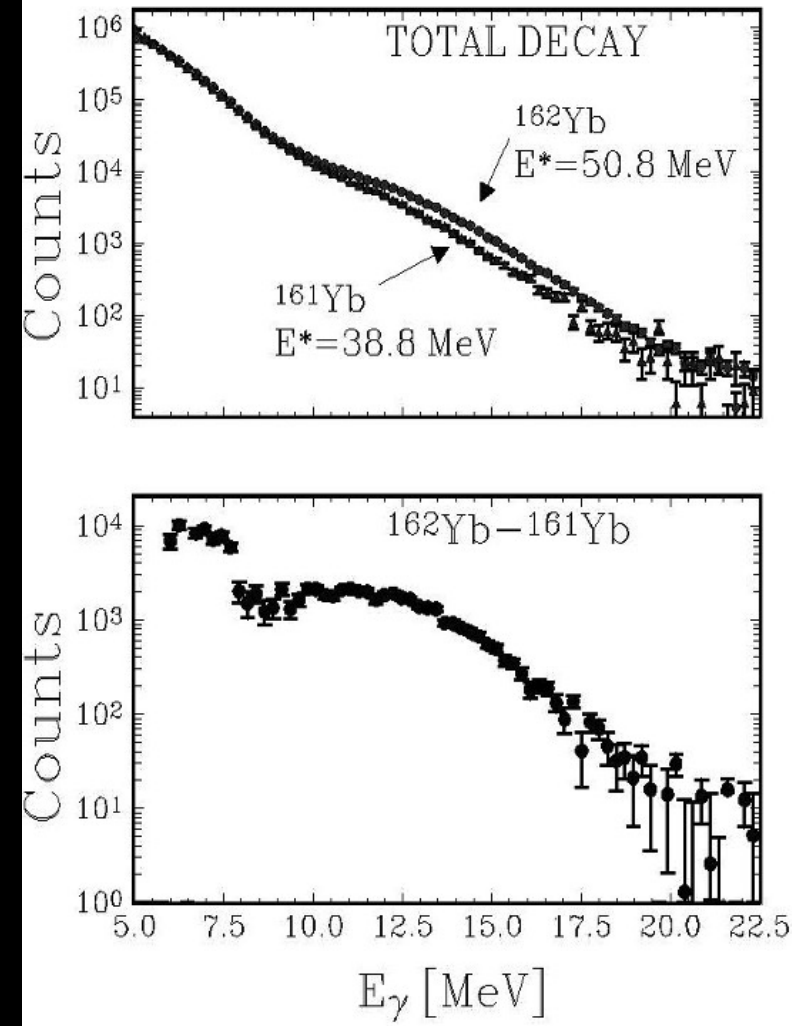
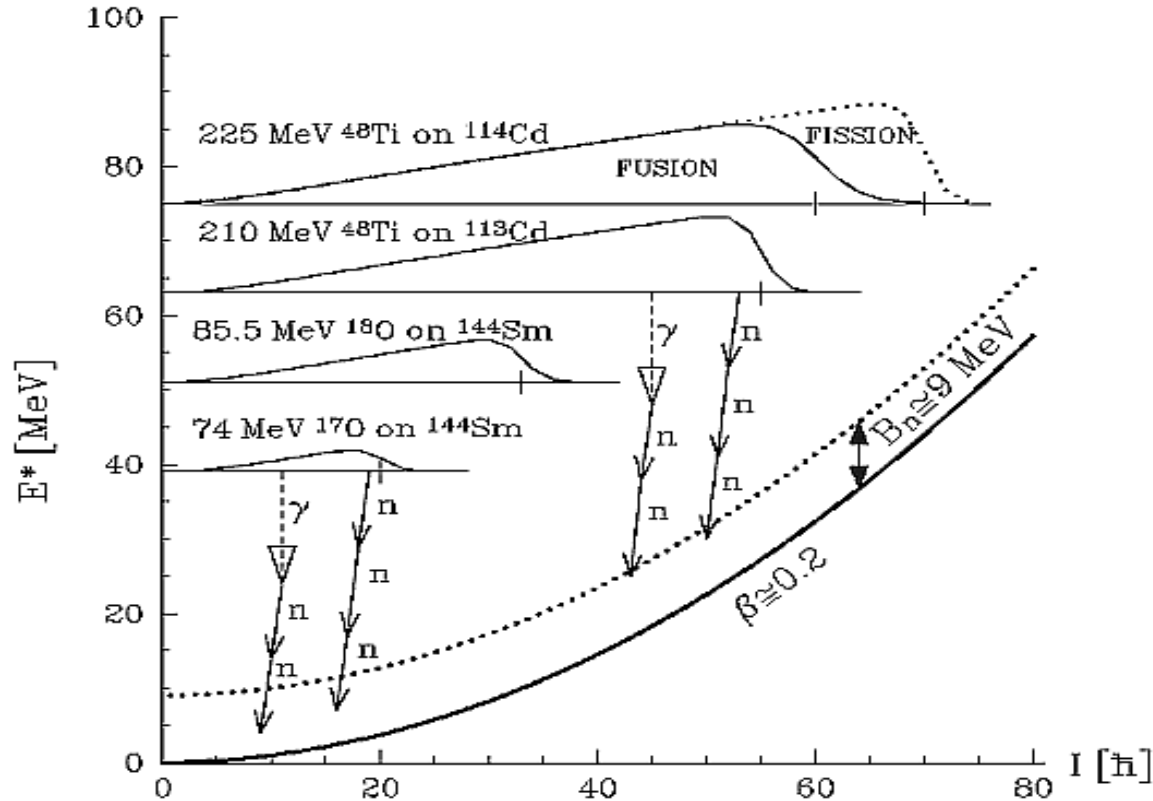
NBI-TAL RISØ



Early spring 1989 I arrived to the Tandem Accelerator Laboratory of NBI in Risø (near Roskilde) in Denmark for a post-doc position, with the aim to work in the **group of Jens Jørgen Gaardhøje** on γ -decay of GDR from hot rotating nuclei, and especially to employ the new **HECTOR array**, just constructed by the **Copenhagen-Milano collaboration**. The Milano group, visiting frequently NBI-TAL, was lead by **Angela Bracco**, and consisted that time of **Benedicte Million**, **Marcello Pignanelii**, Ph.D. student **Silvia Leoni** (partly) and Ph.D. student, who was just taken for the army service, **Franco Camera**.

Phase-space selection of the GDR gamma ray emission from hot ^{162}Yb nuclei ☆

A. Maj ^{a,1}, J.J. Gaardhøje ^a, B. Herskind ^a, G. Sletten ^a, J. Nyberg ^a, A. Bracco ^b, B. Million ^b,
M. Pignanelli ^b



Result:
By applying the **differential technique** the spectrum associated only with the CN γ -decay (first step) can be extracted

FRANCO ENTERS INTO THE GAME



UNIVERSITÀ DEGLI STUDI DI MILANO
Facoltà di Scienze Matematiche, Fisiche e Naturali
Dottorato di Ricerca in Fisica

LE FLUTTUAZIONI DI FORMA E DI ORIENTAMENTO
IN NUCLEI CALDI E LA DISTRIBUZIONE ANGOLARE
DEI γ DELLA RISONANZA GIGANTE DI DIPOLO

Franco CAMERA

Dicembre 1992

To Alan
Thank you for your
help and advice
with friendship
Franco

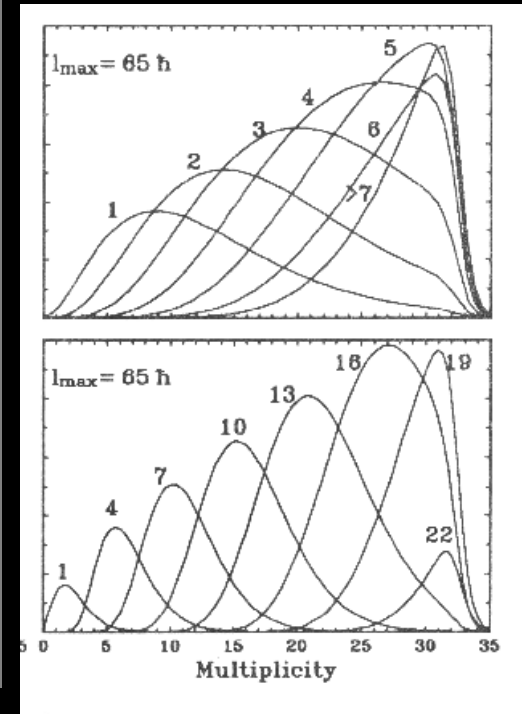
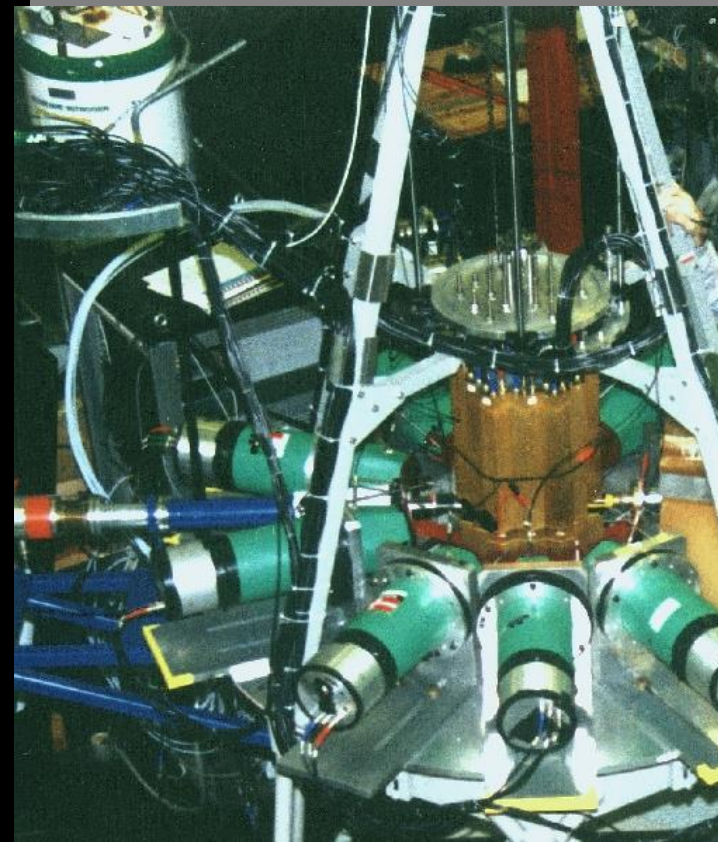
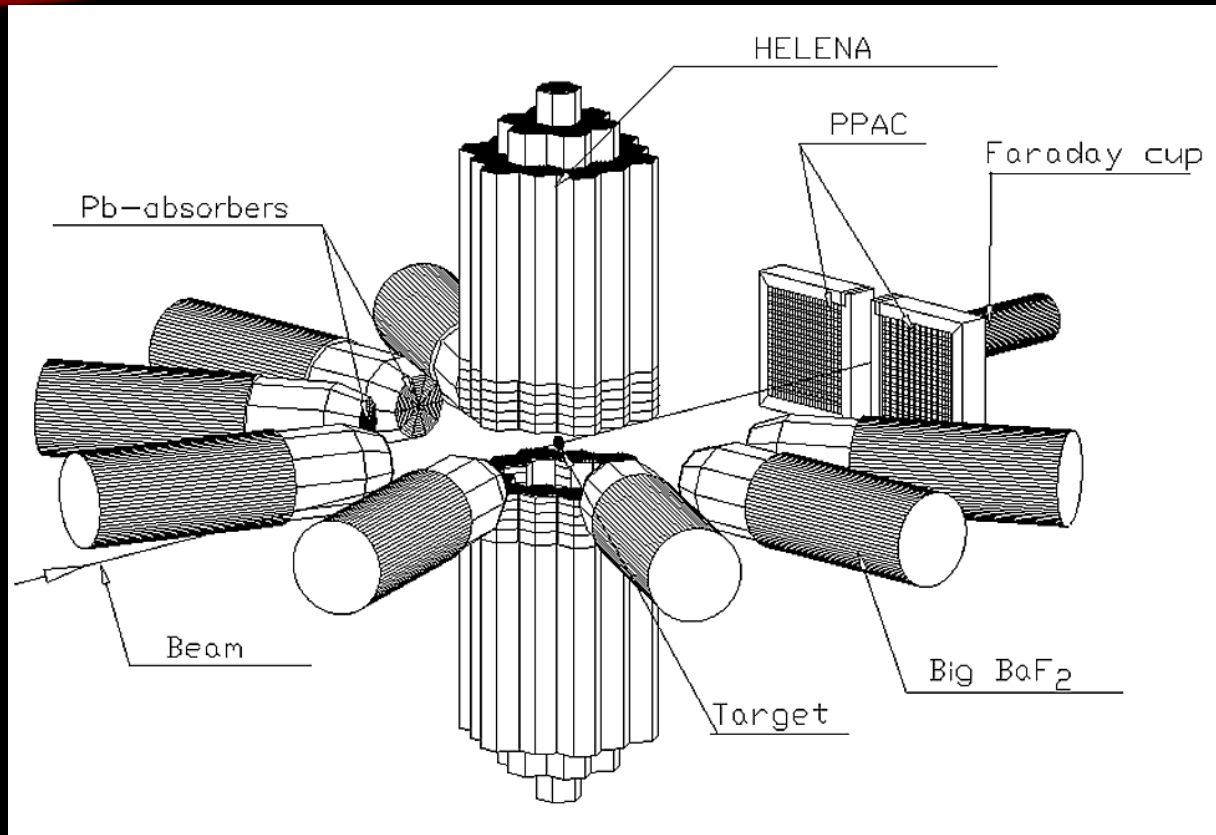
156

Ringraziamenti

Vorrei infine ringraziare tutte le persone che mi hanno aiutato durante questi tre anni di lavoro. Prima di tutto il mio tutore, la dott. Angela Bracco, che mi ha introdotto alle problematiche della Risonanza Gigante di Dipolo e che mi ha seguito durante la tesi di laurea e di dottorato.

Inoltre desidero ringraziare il prof. R.A. Broglia dell'Università degli studi di Milano ed il Dott. E. Ormand del Caltech (Los Angeles) per la consulenza e l'aiuto datomi nello sviluppo e nella comprensione della teoria della GDR, il Prof M. Pignanelli, la dott. B. Million dell'Università degli studi e della sezione I.N.F.N. di Milano, il Prof. J.J. Gaardhøje del Niels Bohr Institute (Copenhagen) e il Prof. A. Maj del Niewodniczinki Institute of Physics (Cracovia) per l'aiuto datomi durante lo sviluppo e la costruzione di HECTOR e durante la fase di analisi dei dati.

FURTHER DEVELOPMENT OF HECTOR IN NBI-TAL



Adding

- 1) highly efficient **HELENA multiplicity filter**, for better measurement of angular momentum (Franco and Milano group took the responsibility for this);
- 2) **2 PPACs** to measure recoiling nuclei, thus selecting only fusion-evaporation reactions.

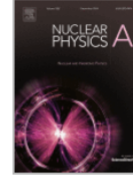
NEXT HECTOR EXPERIMENTS



ELSEVIER

Nuclear Physics A

Volume 571, Issue 1, 18 April 1994, Pages 185-220

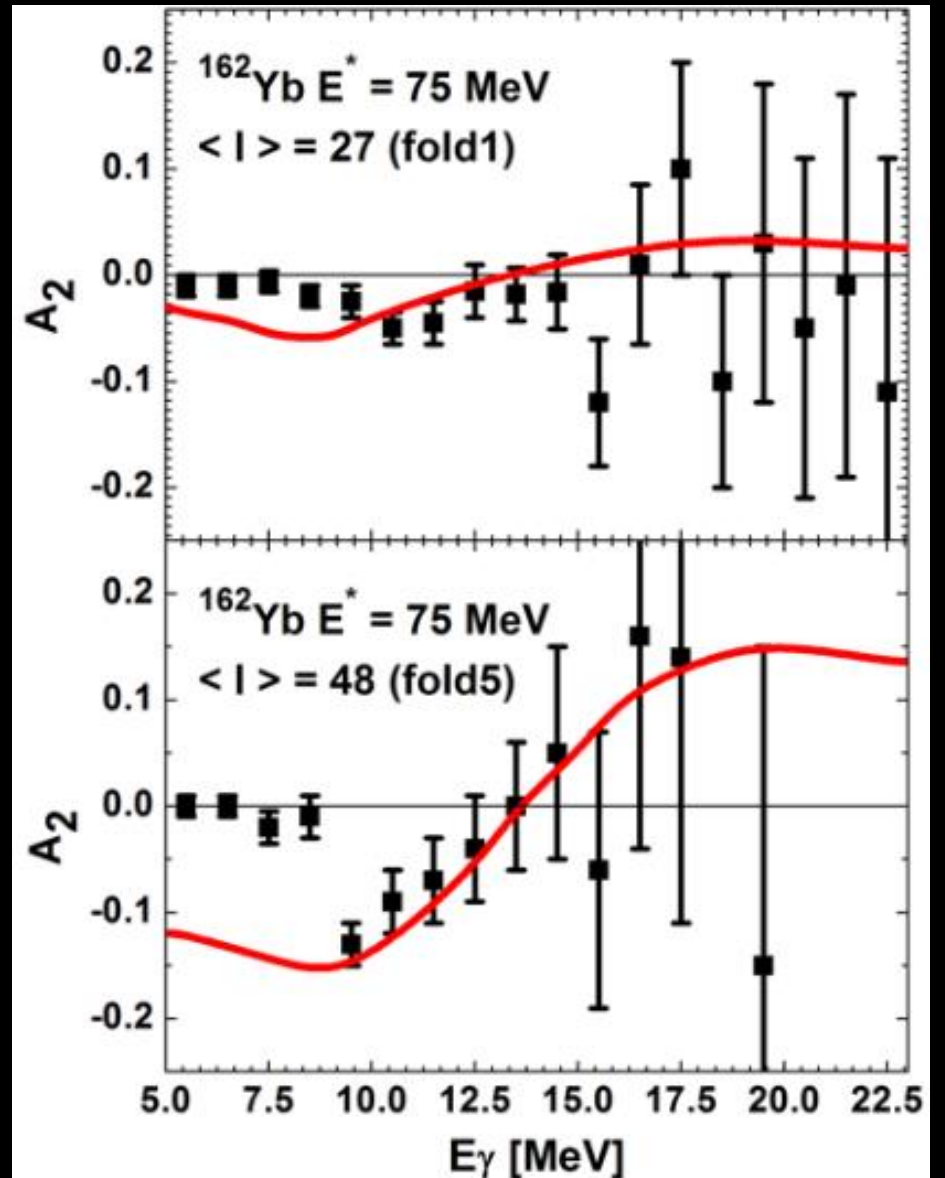


Angular distribution of photons from the decay of the GDR in hot and rotating light Yb nuclei from exclusive experiments

A. Maj¹, J.J. Gaardhøje, A. Ataç², S. Mitarai³, J. Nyberg⁴, A. Virtanen⁵, A. Bracco, F. Camera, B. Million, M. Pignanelli

Result:

For lower spins, where the deformation is small, the amplitudes of the absolute A_2 values are also small. At higher spins, where the prolate deformation becomes larger, the A_2 magnitude increases significantly.

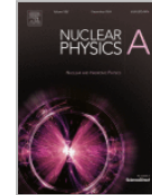


NEXT EXPERIMENTS



Nuclear Physics A

Volume 572, Issue 2, 23 May 1994, Pages 401-416



Large effects of orientation fluctuations in the angular distribution of the GDR photons

F. Camera, A. Bracco, B. Million, M. Pignanelli, J.J. Gaardhøje, Z. Zelazny, T. Ramsøy, A. Maj^{a b}

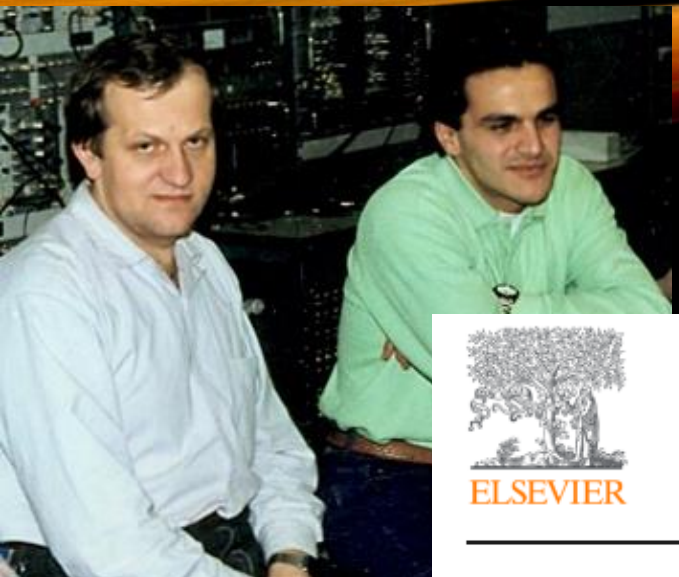
Result:

Measurements of the angular distribution of high energy γ rays emitted in the decay of compound nuclei $^{165-167}\text{Er}$, $^{175,176}\text{Hf}$, ^{110}Sn are presented.

In all cases the **measured anisotropies** as a function of the gamma transition energy **are small**.

A comparison between the data and model predictions shows that **both shape and orientation fluctuations are very important and must be taken into account** to reproduce the experimental results.

The dominant role played by **orientation fluctuations** on the GDR lineshape and the effective induced nuclear deformations are discussed.



New member of Milano group: Marco Mattiuzzi

NEXT EXPERIMENTS



Nuclear Physics A

Volume 612, Issue 2, 13 January 1997, Pages 262-278

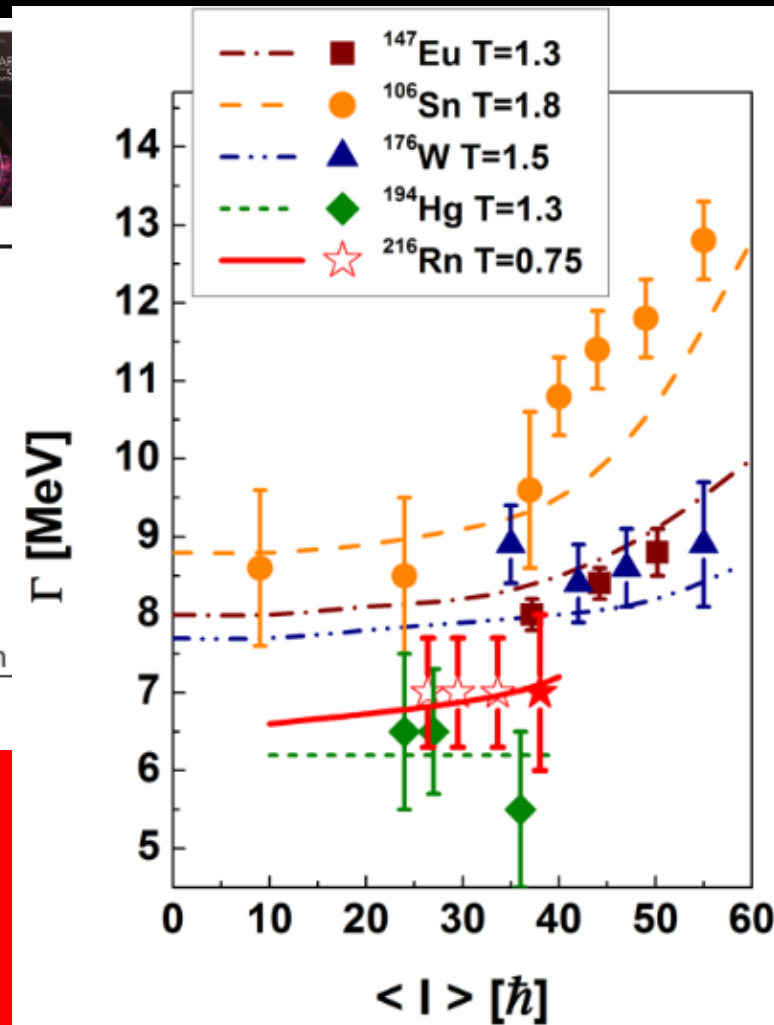


Heavy ions

Angular momentum dependence of the GDR width in Sn nuclei at fixed excitation energy

M. Mattiuzzi ^a, A. Bracco ^a, F. Camera ^{a,1}, W.E. Ormand ^{a,b}, J.J. Gaardhøje ^c, A. Maj ^{c,d}, B. Million M. Pignanelli ^a, T. Tveter ^{c,e}

Result:
The most probable deformation increases with the spin of the nucleus and thus, due to the splitting of the GDR strength function (resulting from the oscillations along different axes of symmetry), also the **width of the GDR in a deformed nucleus becomes larger.**



HECTOR IN GRENOBLE: SEARCH FOR GDR IN SHE

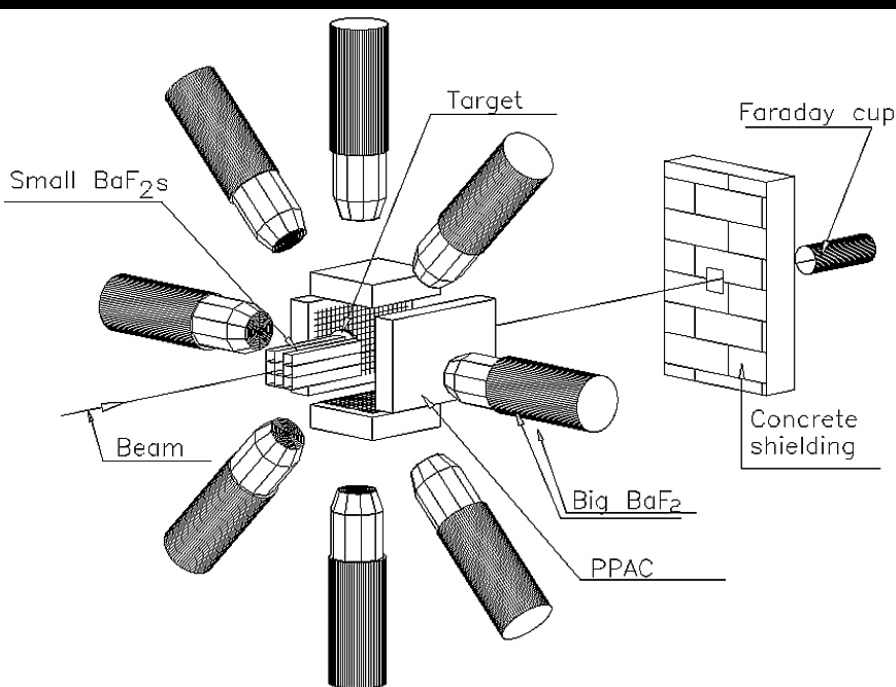
VOLUME 76, NUMBER 7

PHYSICAL REVIEW LETTERS

12 FEBRUARY 1996

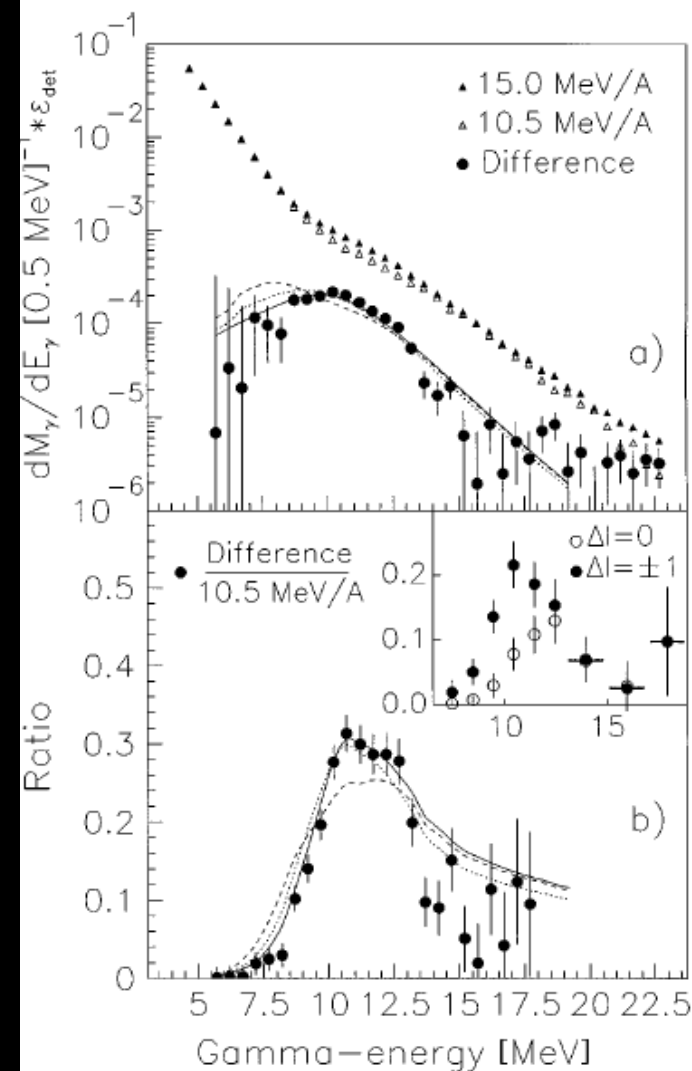
Collective Dipole Motion in Highly Excited ^{272}Hs ($Z = 108$) Nuclei

T. S. Tveter,^{1,2} J. J. Gaardhøje,¹ A. Maj,^{1,3} T. Ramsøy,^{1,4} A. Ataç,⁵ J. Bacelar,⁶ A. Bracco,⁷ A. Buda,⁶ F. Camera,⁷ B. Herskind,¹ W. Korten,^{1,8} W. Królas,³ A. Menthe,⁹ B. Million,⁷ H. Nifenecker,⁹ M. Pignanelli,⁷ J. A. Pinston,⁹ H. v. d. Ploeg,⁶ F. Schussler,⁹ and G. Sletten¹



Beam: ^{40}Ar @ 6.8, 10.5, 15 MeV/A
Target: ^{232}Th

Result:
Difference between the two
gamma spectra in coincidence
with fission fragments shows a
bump in the range of the GDR
energy predicted for the
composite system
 ^{272}Hs ($E_{\text{GDR}} = 12.2$ MeV)



HECTOR IN SEARCH FOR JACOBI SHAPE TRANSITIONS

Carl Gustav Jacob Jacobi (1834, Prussia):

At certain angular velocity gravitating mass rotating synchronously may change abruptly the shape from oblate **to elongated triaxial (Jacobi shape transition)**

R. Beringer, W.K. Knox, *Phys. Rev.* 121 (1961) 1195: Jacobi shape transition might be expected in nuclei at highest spins

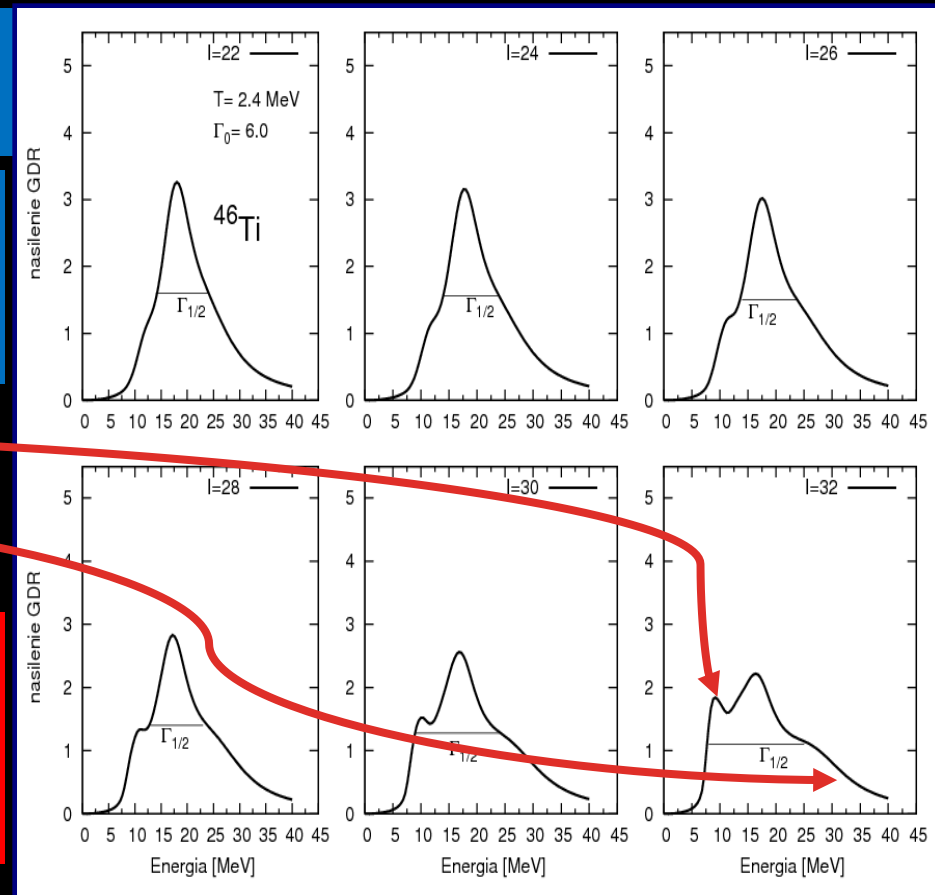
S. Cohen, F. Plasil, W.J. Swiatecki, *Ann. Phys. (N. Y.)* 82 (1974) 557: Rotating liquid drop model confirms predictions for Jacobi transition

strong low-energy component

broad high-energy shoulder

K. Pomorski, J. Dudek, *Phys. Rev. C* 67 (2003) 044316: **LSD (Lublin-Strasbourg Drop) Model + very userfriendly code**

E.g.: LSD predicts in ^{46}Ti Jacobi shapes above $I = 28 \hbar$



HECTOR IN SEARCH FOR JACOBI SHAPE TRANSITIONS

Around 1991 the Seattle group claimed to observe **a sign for the Jacobi shape transition in ^{45}Sc** (a broad high-energy component) in **inclusive** experiment

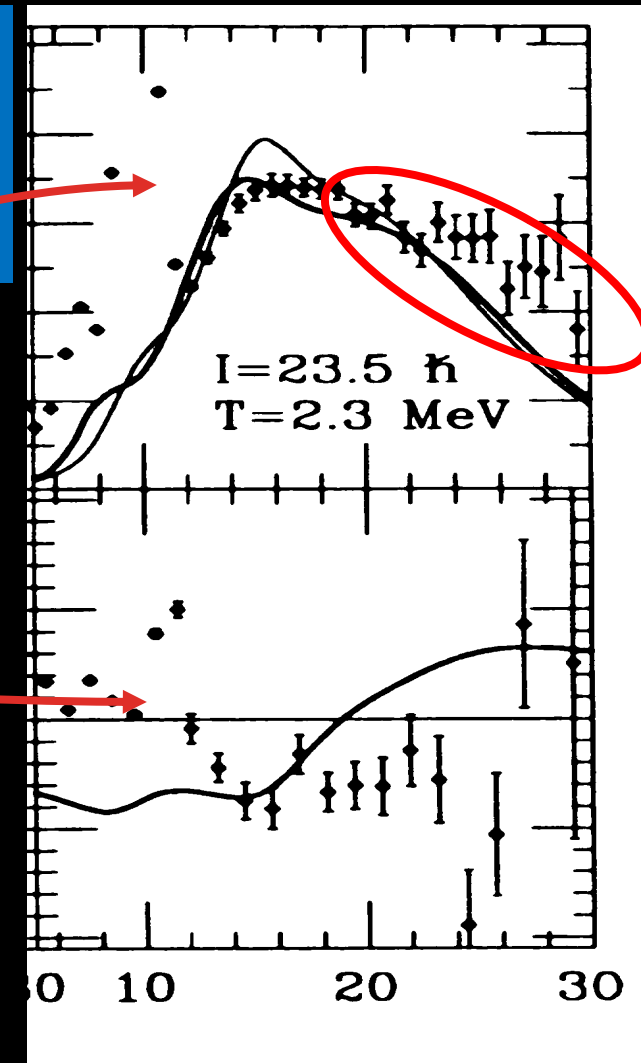
M. Kicińska-Habior, K. Snover et al., Phys.Lett. B308 (1993) 225

There were some doubts:

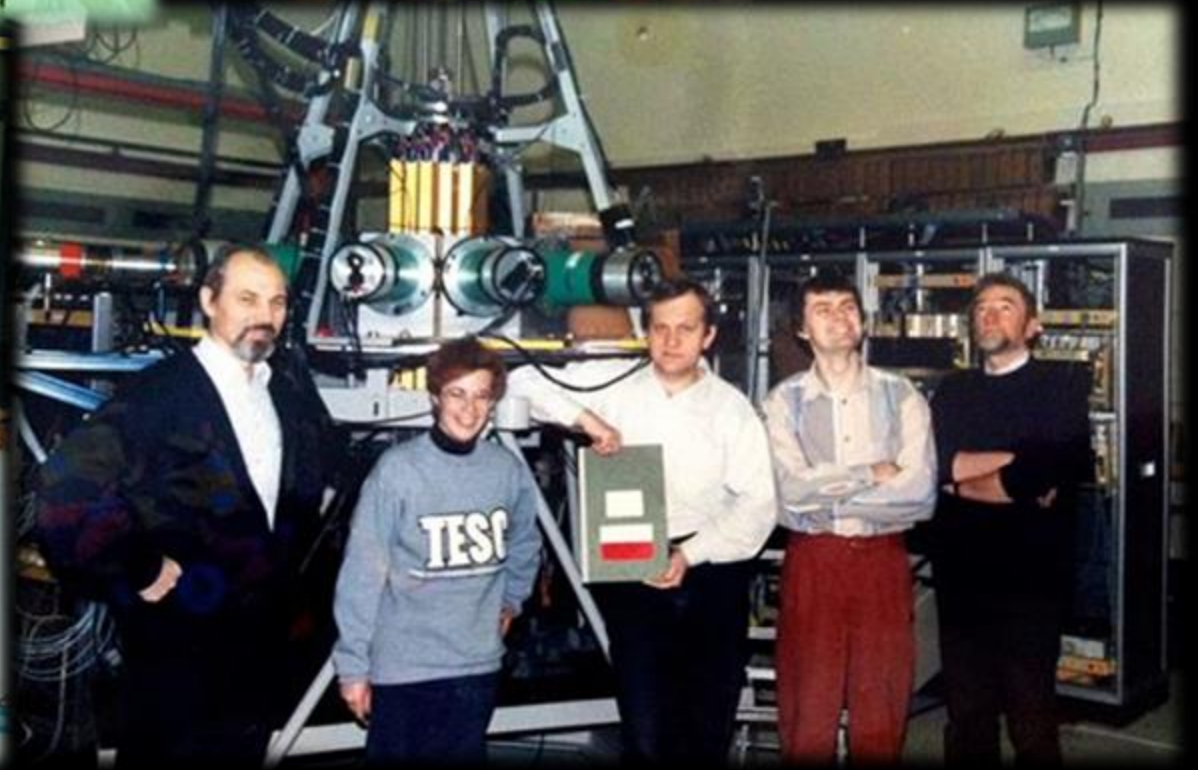
No low-energy component evident
(because of the strong background line)

Wrong angular distribution pattern
for prolate rotating nuclei

Conclusion: we shall perform an exclusive experiment
with HECTOR and HELENA



HECTOR IN SEARCH FOR JACOBI SHAPE TRANSITIONS



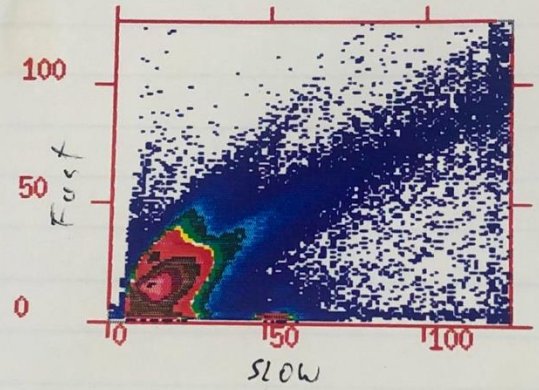
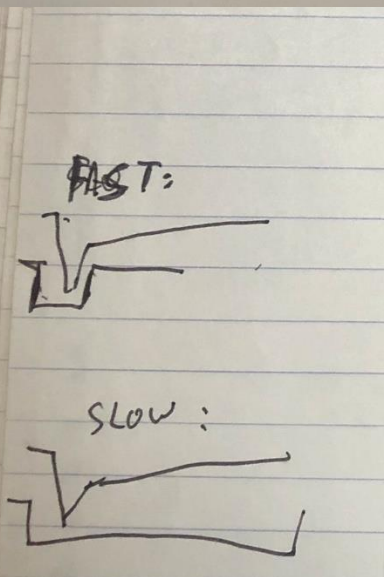
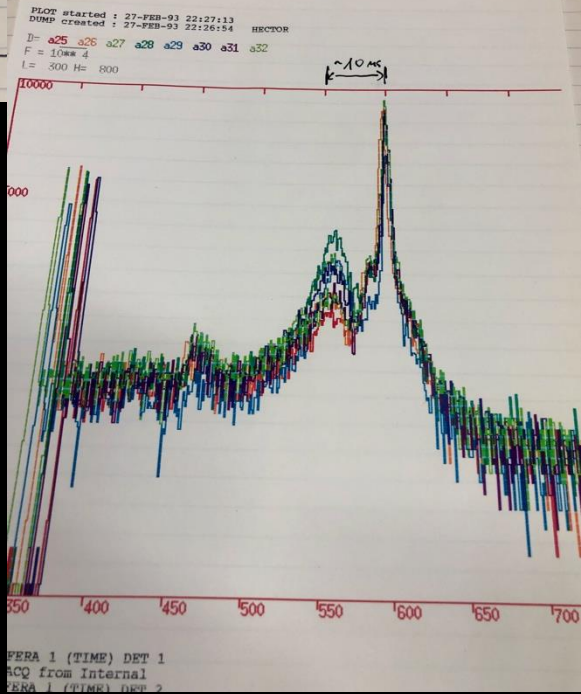
The "Polish" HECTOR experiment:

GDR in $^{48}\text{Ti}^*$

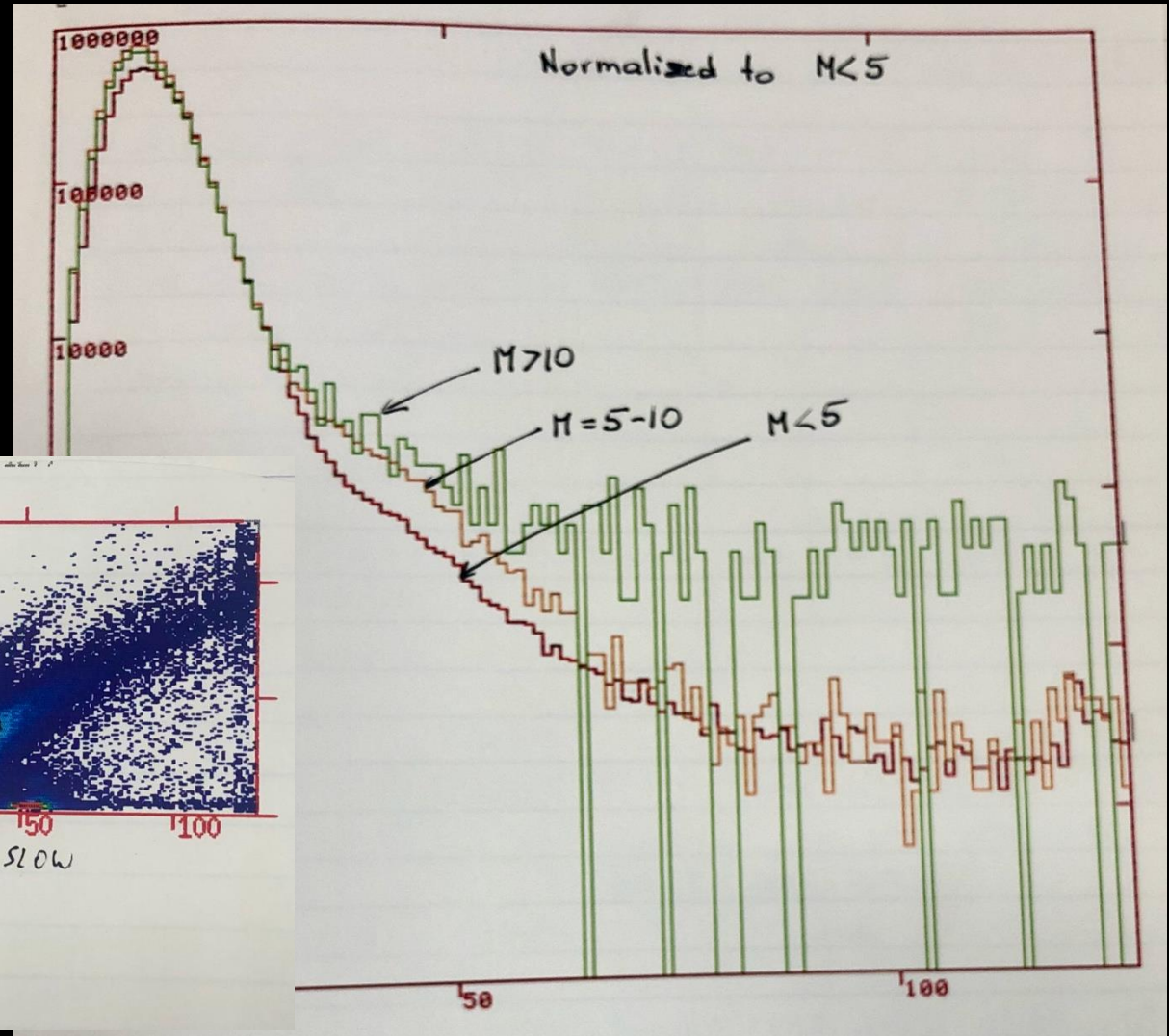
26/02/1993 — 5/03/1993

Participants:

<u>Kraków</u>	<u>Warsawa</u>	<u>Klostermann</u>	<u>Milano</u>
Jan Strycharz	Marta Kicińska-Helias	Janusz Jędrzejewski	Marco Mattiuzzi
Wojtek Królak	Jan Kowuadi	Zbyszek Żelazny	Franco Casareto
Adam Maj		Trine Tveten	



HECTOR IN SEARCH FOR JACOBI SHAPE TRANSITIONS



HECTOR+HELENA exp.

NBI-TAL 1993

$94 \text{ MeV } ^{18}\text{O} + ^{28}\text{Si} \Rightarrow ^{46}\text{Ti}^*$,

$I_{\text{max}} \approx 30\hbar, E^* = 80 \text{ MeV}$

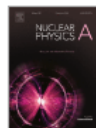
HECTOR IN SEARCH FOR JACOBI SHAPE TRANSITIONS

Both low-energy component and high-energy shoulder evident at high spins

Correct angular distribution pattern for prolate rotating nuclei

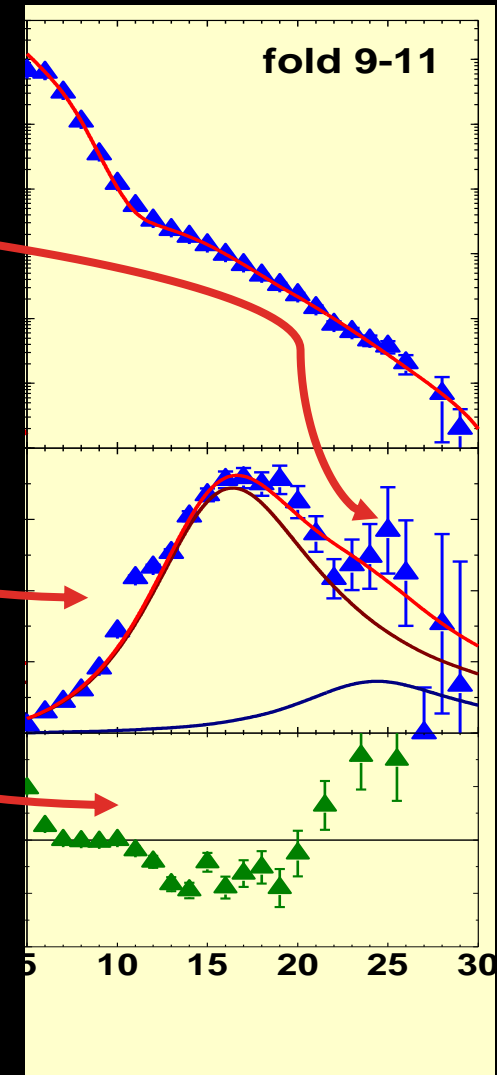


Nuclear Physics A
Volume 687, Issues 1-2, 23 April 2001, Pages 192-197



Search for exotic shapes of hot nuclei at critical angular momenta

A. Maj, M. Kmiecik, W. Królas, W. Męczyński, J. Styczeń, M. Ziębliński, B. Million, A. Bracco, F. Camera, S. Leoni, O. Wieland, B. Herskind, M. Kicińska-Habior



Is this final evidence of Jacobi shapes in hot rotating ^{46}Ti ?
Do we have only fusion-evaporation events?

**HECTOR+HELENA+EUROBALL
+EUCLIDES exp.**

IRES Strasbourg 2002

$105 \text{ MeV } ^{18}\text{O} + ^{28}\text{Si} \Rightarrow ^{46}\text{Ti}^*$,

$I_{\text{max}} \approx 35 \text{ h}$, $E^* = 88 \text{ MeV}$

**HECTOR IN SEARCH FOR
JACOBI SHAPE TRANSITIONS**

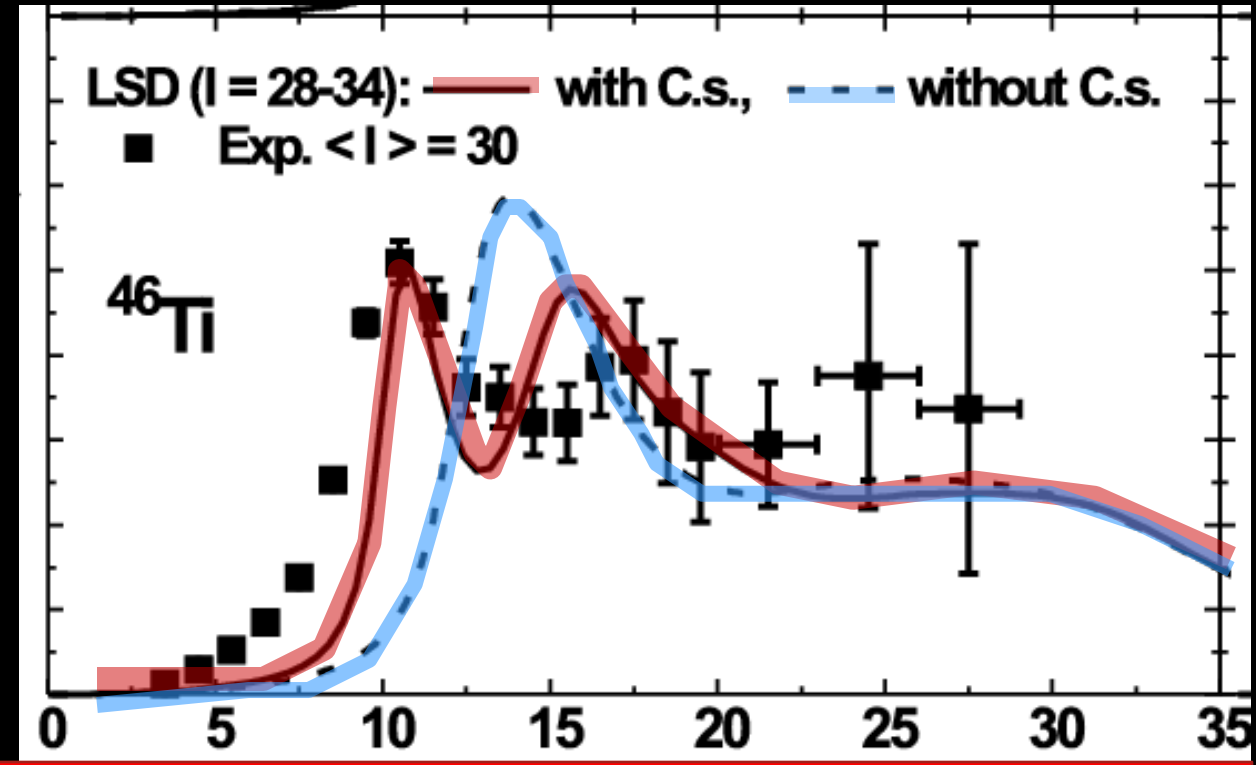
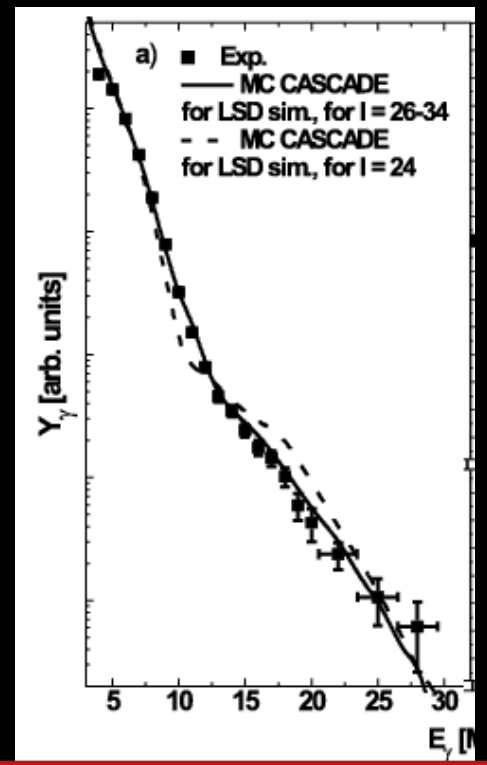


HECTOR IN SEARCH FOR JACOBI SHAPE TRANSITIONS



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

HECTOR IN SEARCH FOR JACOBI SHAPE TRANSITIONS



Evidence of

- the „Jacobi shapes” in ^{46}Ti at high spins
- the Coriolis splitting of the GDR
- preferential feeding of the SD band in ^{42}Ca by GDR low-energy component

HECTOR LNL LEGNARO

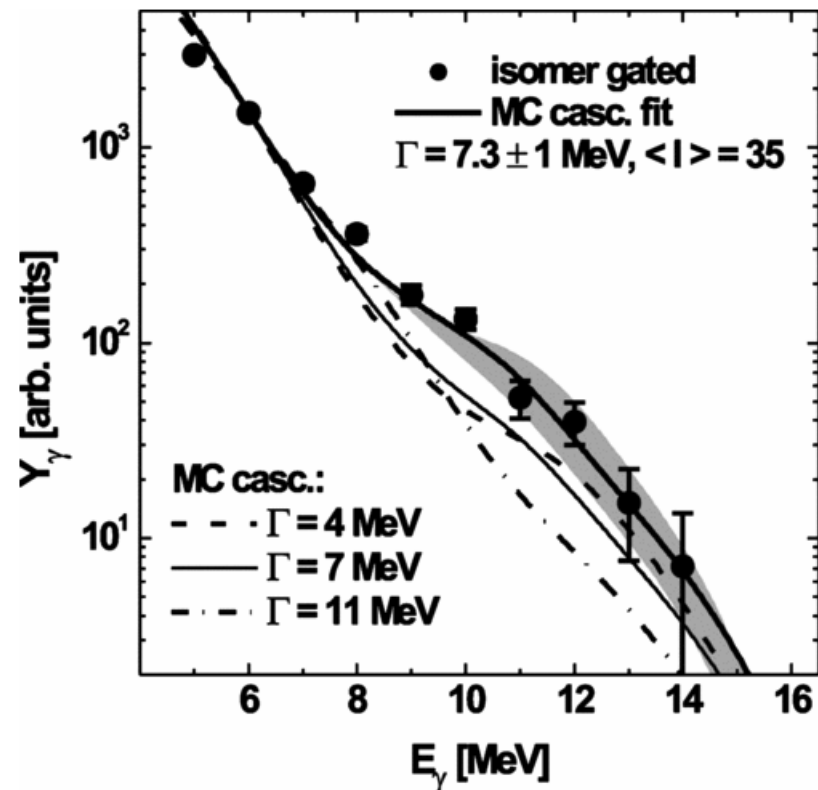


HECTOR LNL LEGNARO

Probing nuclear shapes close to the fission limit with the giant dipole resonance in ^{216}Rn

M. Kmiecik, A. Maj, B. Million, M. Brekiesz, W. Królas, W. Męczyński, J. Styczeń, M. Ziębliński, A. Bracco, F. Camera, G. Benzoni, S. Leoni, O. Wieland, S. Brambilla, B. Herskind, M. Kicińska-Habior, N. Dubray, J. Dudek, and N. Schunck

Phys. Rev. C **70**, 064317 – Published 17 December 2004



First measurement of the GDR feeding the 30+ isomeric state, very close to the fission limit

HECTOR + AGATA IN LNL LEGNARO



Physics Letters B

Volume 540, Issues 3–4, 1 August 2002, Pages 199–206

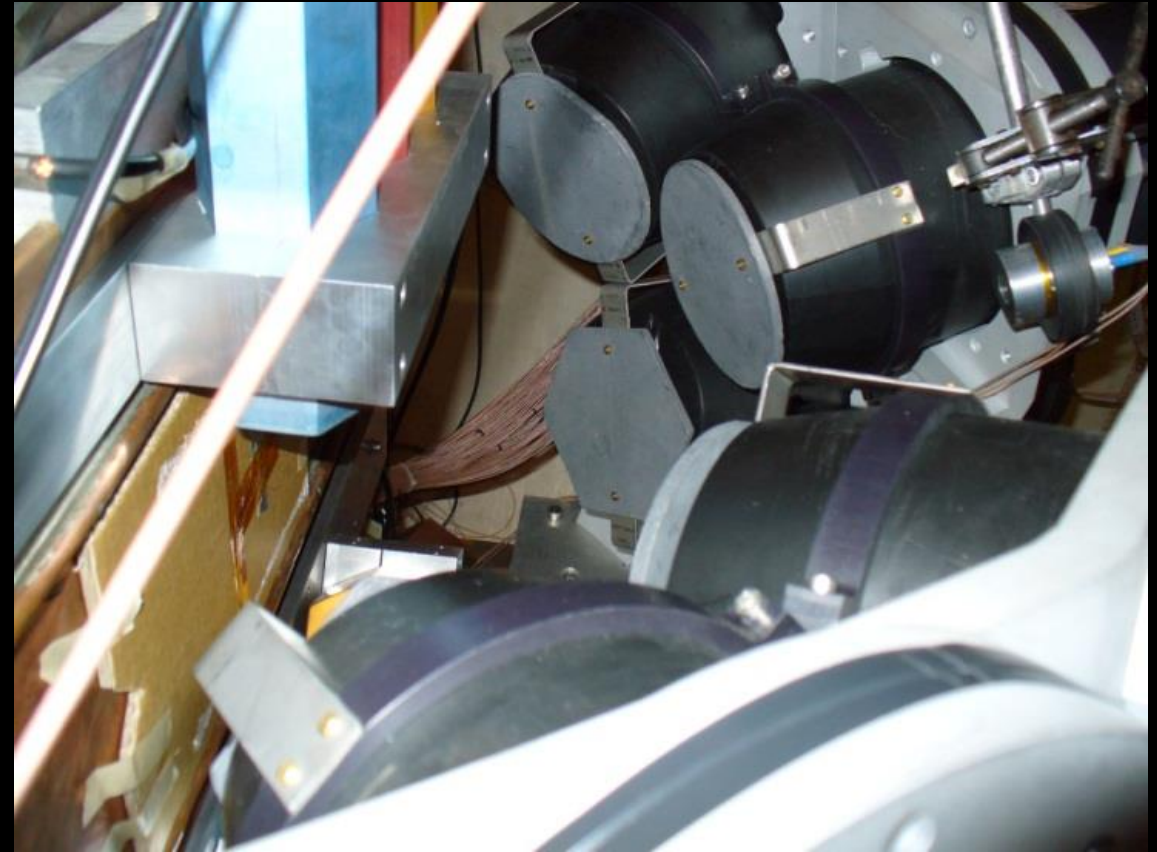
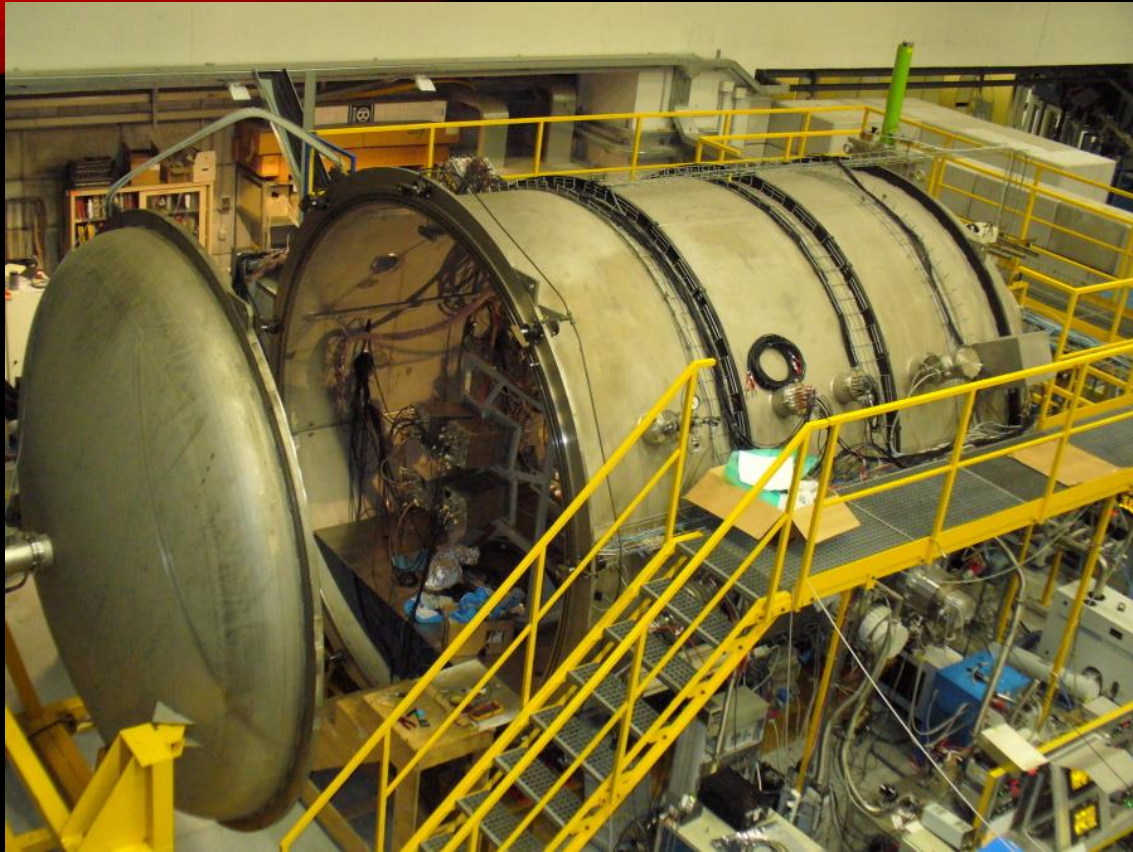


Effect of E1 decay in the population of superdeformed structures

G. Benzoni^a, A. Bracco^a, F. Camera^a, S. Leoni^a✉, B. Million^a, A. Maj^b, A. Algora^c, A. Axelsson^d,
M. Bergström^e, N. Blasi^a, M. Castoldi^f, S. Frattini^a, A. Gadea^c, B. Herskind^e, M. Kmiecik^b,
G. Lo Bianco^g, J. Nyberg^d, M. Pignanelli^a, J. Styczen^b, O. Wieland^a...A. Zucchiatti^f

A sign of direct feeding of the SD band in ^{143}Eu by GDR low-energy component

HECTOR + GARFIELD IN LNL LEGNARO



Giant Dipole Resonance in the Hot and Thermalized ^{132}Ce Nucleus:
Damping of Collective Modes at Finite Temperature

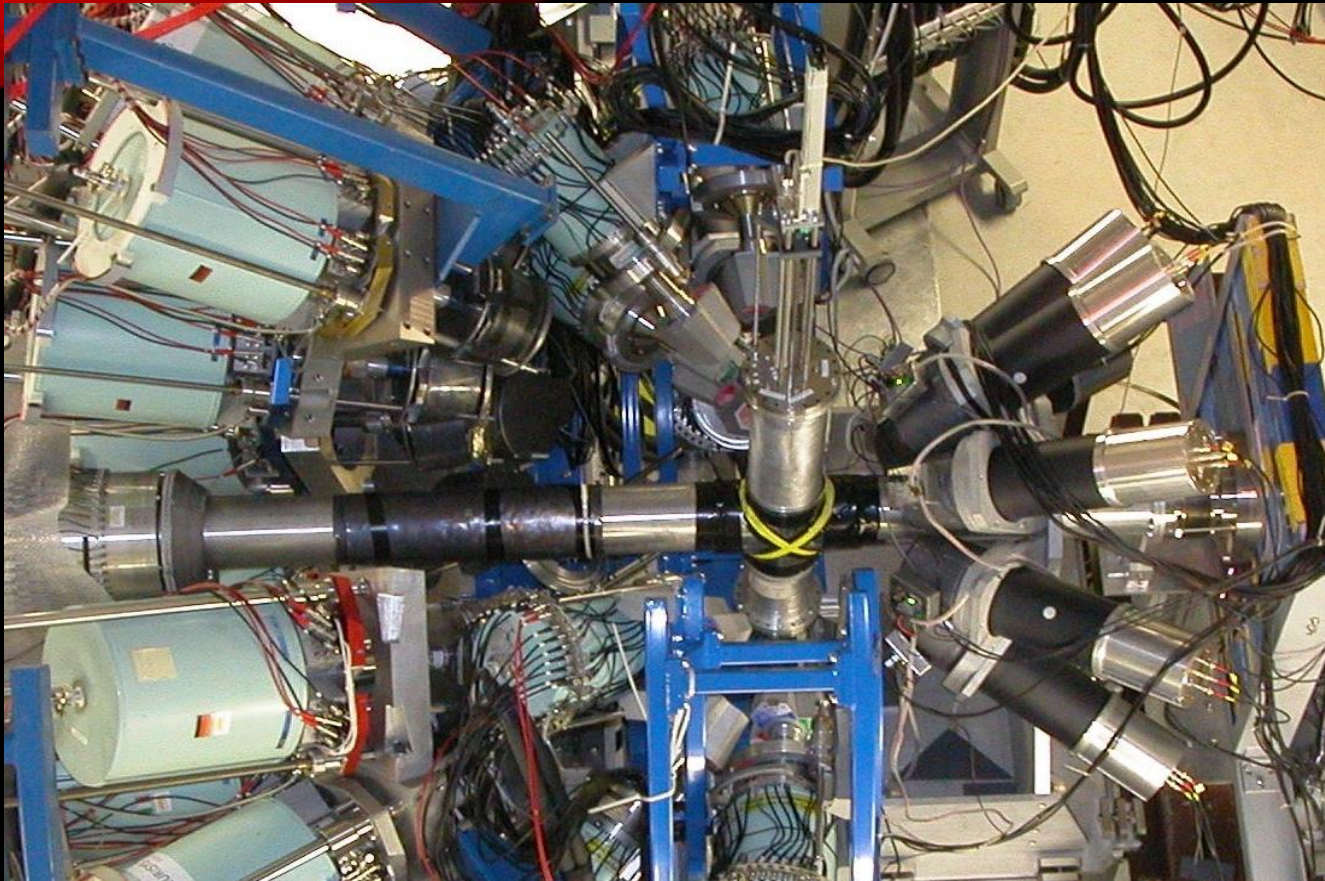
O. Wieland *et al.*
Phys. Rev. Lett. **97**, 012501 – Published 7 July 2006

Giant dipole resonance built on hot rotating nuclei produced
during evaporation of light particles from the ^{88}Mo compound
nucleus

M. Ciemala *et al.*
Phys. Rev. C **91**, 054313 – Published 13 May 2015

HECTOR + RISING IN GSI

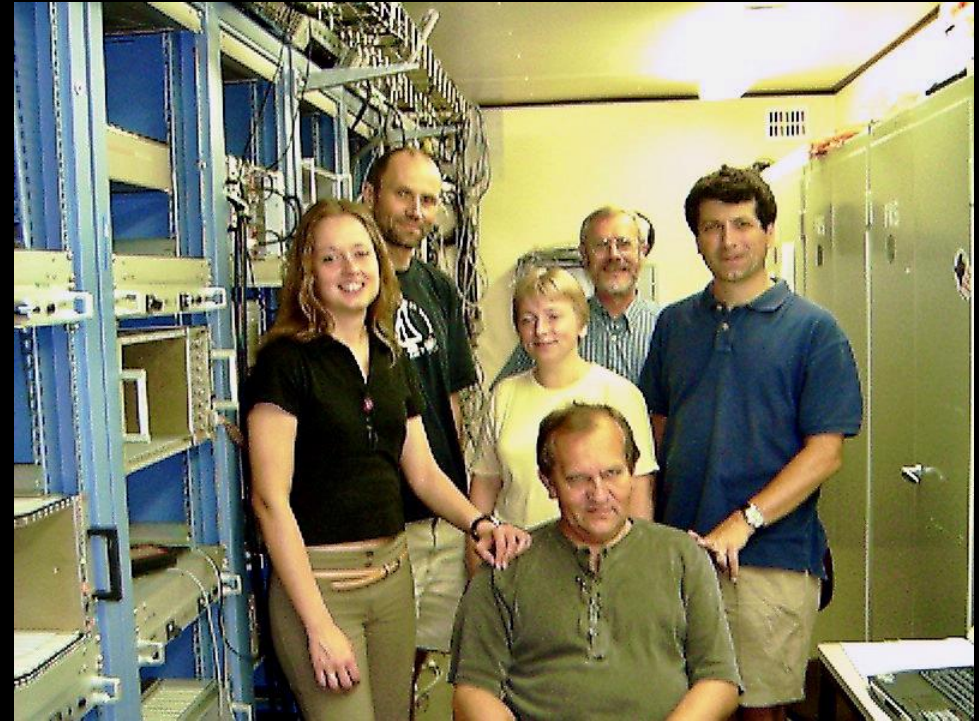
2010-2014



Search for the Pygmy Dipole Resonance in ^{68}Ni at
600 MeV/nucleon

O. Wieland *et al.*

Phys. Rev. Lett. **102**, 092502 – Published 4 March 2009



HECTOR AT CCB KRAKOW SINCE 2014



cf. talk of Marysia Kmiecik later today

PARIS PROJECT

4-5-6th October, 2005 „Future prospects for high resolution gamma spectroscopy at GANIL”

Convenors : Bob Wadsworth and Wolfram Korten

WG „Collective modes in continuum” – convenors: **Silvia Leoni** & Adam Maj;

M. Kmiecik: talk on possible Jacobi shapes in exotic nuclei

Title: High-energy γ -rays as a probe of hot nuclei and reaction mechanisms

Spokesperson(s) (max. 3 names, laboratory, e-mail - please underline among them one corresponding spokesperson):

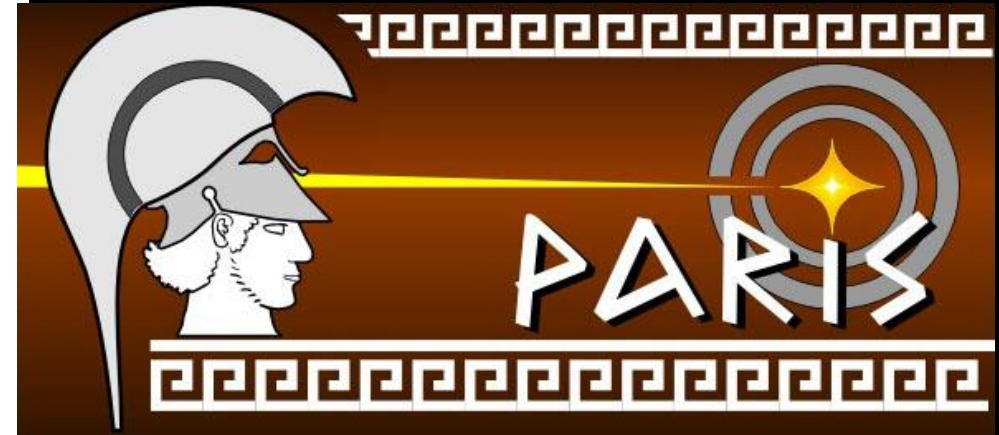
Adam Maj, IFJ PAN Krakow, Adam.Maj@ifj.edu.pl

Jean-Antoine Scarpaci, IPN Orsay, scarpaci@ipno.in2p3.fr (EXL and R3B contact)

David Jenkins, University of York (UK), dj4@york.ac.uk

GANIL contact person

Jean-Pierre Wieleczko, GANIL, wieleczko@ganil.fr



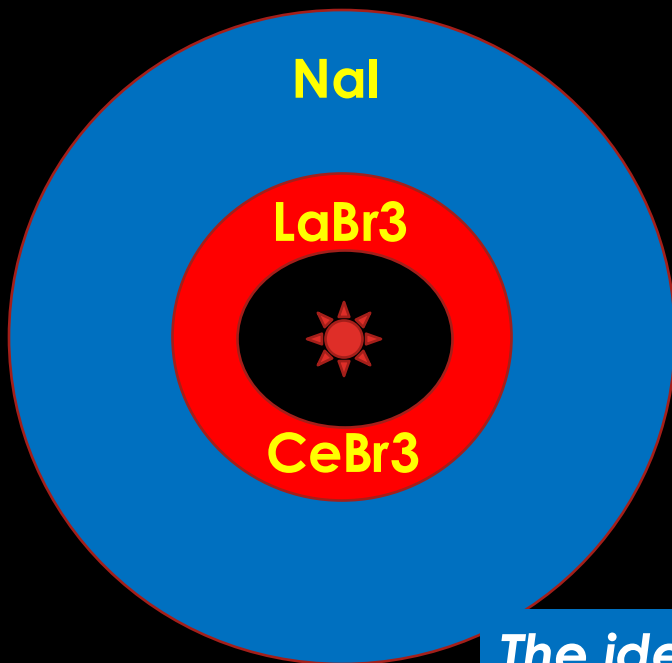
Aim: to design and construct novel scintillator array – later named **PARIS**



PARIS PROJECT

PARIS design assumptions:

High efficiency ($\approx 4\pi$) gamma detector, based on new scintillation materials, consisting of 2 shells for medium resolution spectroscopy and calorimetry of γ -rays in large energy range



Inner sphere, highly granular, made of new crystals (LaBr3 or CeBr3), to be used as a gamma multiplicity filter, sum-energy detector (calorimeter), detector for the gamma-transition up to 10 MeV with medium energy resolution, fast timing.

Outer sphere, high volume conventional crystals (NaI), for high-energy photons, active shield for the inner shell.

2-shell concept, in addition to being more economic, shall help to distinguish a high-energy photon from a cascade of low energy gamma transitions in fusion evaporation reactions

The idea of PARIS was proposed by the Krakow group and developed jointly by physicists from Poland, France, India, UK and Italy

PARIS PROJECT

Some of the physics cases in the Lol

HOT ROTATING NUCLEI

- Jacobi and Poincare shape transitions
- Studies of shape phase diagrams of hot nuclei
- Hot GDR in neutron-rich nuclei
- Isospin mixing at finite temperatures
- Links between GDR emission and SD/HD structure
- GDR and PDR built on isomeric states
- Onset of chaotic regime (+AGATA)

A.Maj, J. Dudek, K. Mazurek, M. Kmiecik, M. Ciemala

A. Bracco, F. Camera, S. Leoni, I. Mazumdar, D.R.

Chakrabarty, V. Nanal, M. Kicinska-Habior, M. Harakeh, P.

Bednarczyk

COLLECTIVE MODES

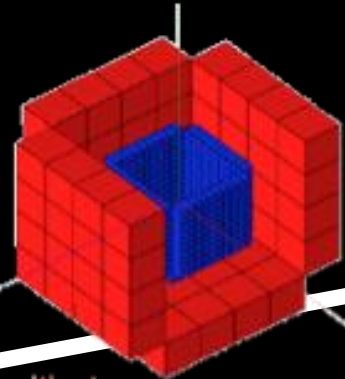
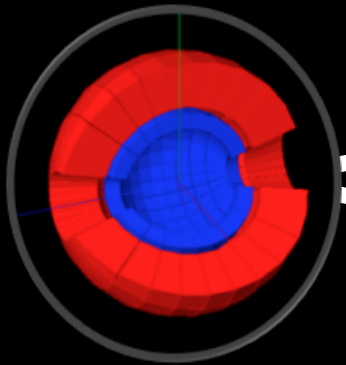
- PDR in neutron-rich and proton-rich nuclei
- Gamma-decay of GDR and GQR built on ground states
- GDR built on isomeric states

*A.Bracco, A. Maj, D. Beaumel, I. Matea, F. Camera, F. Crespi,
M. Kmiecik, M. Lewitowicz, M. Harakeh,*

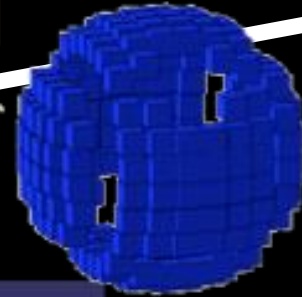
PARIS PROJECT

Design studies

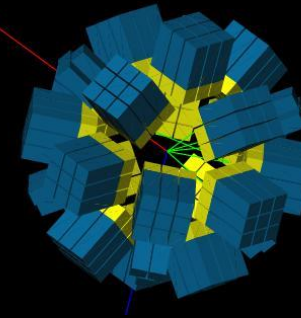
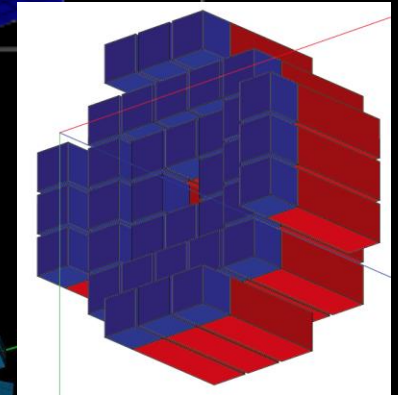
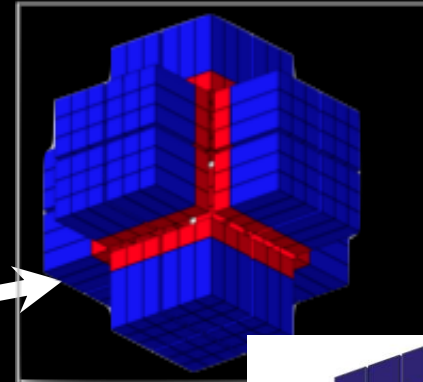
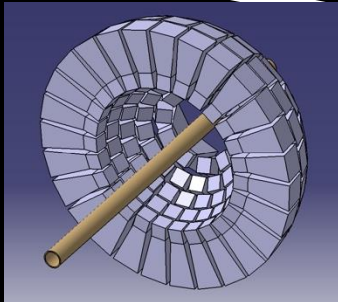
'Ideal' - spherical



'cubic'-like

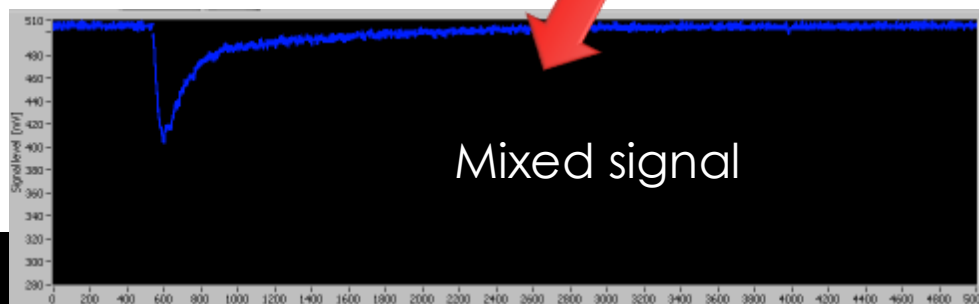
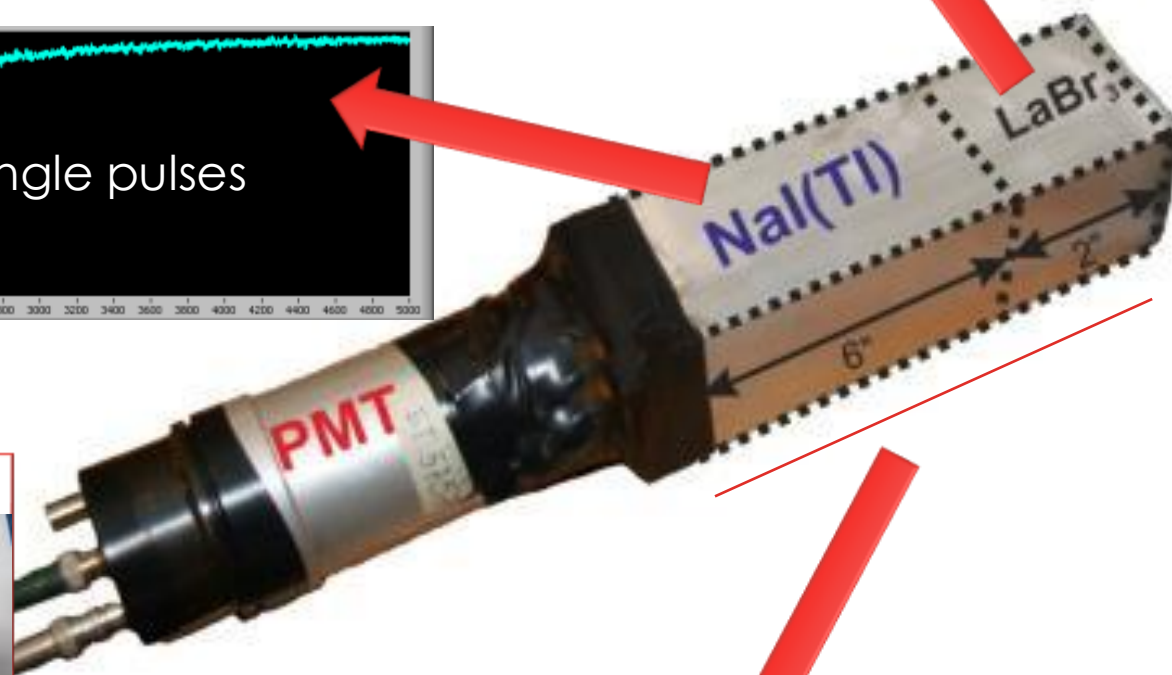
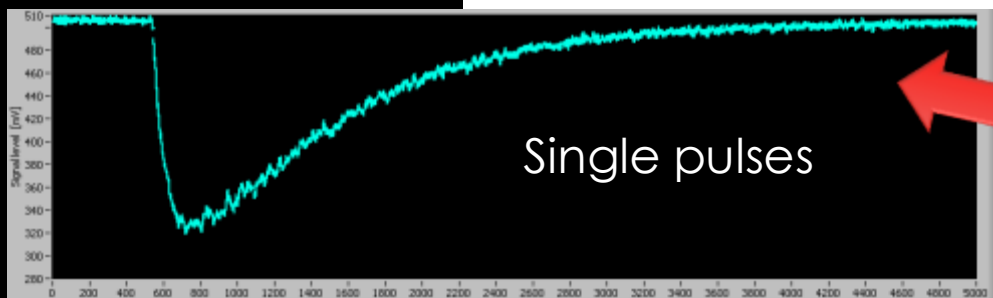
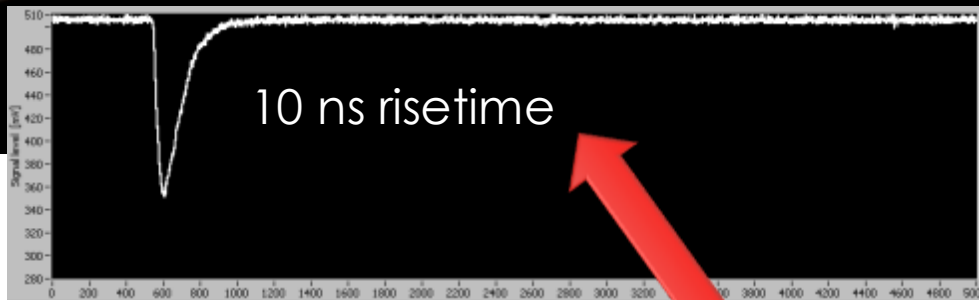


'radial'-like



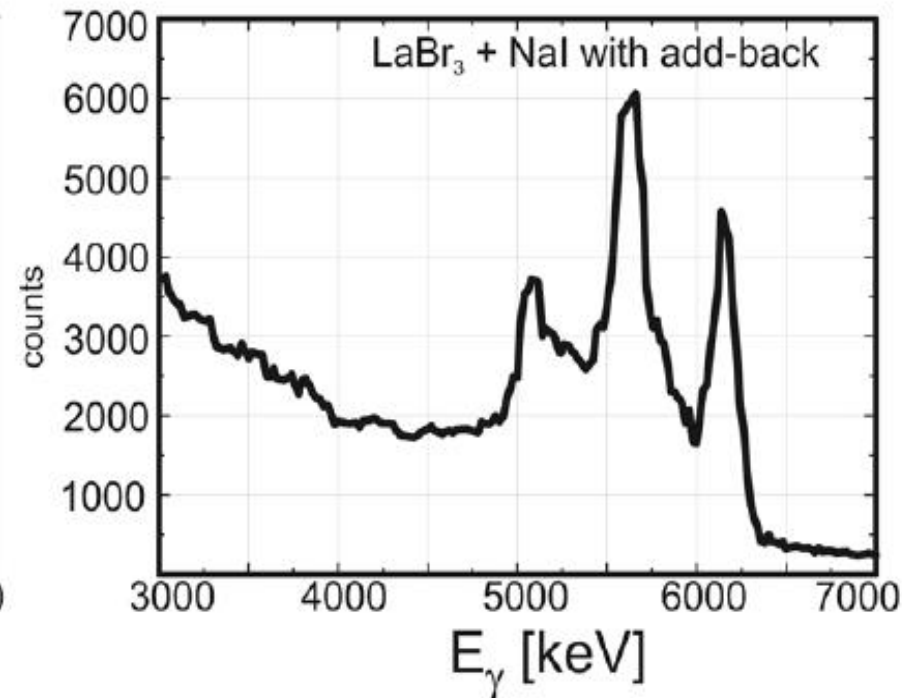
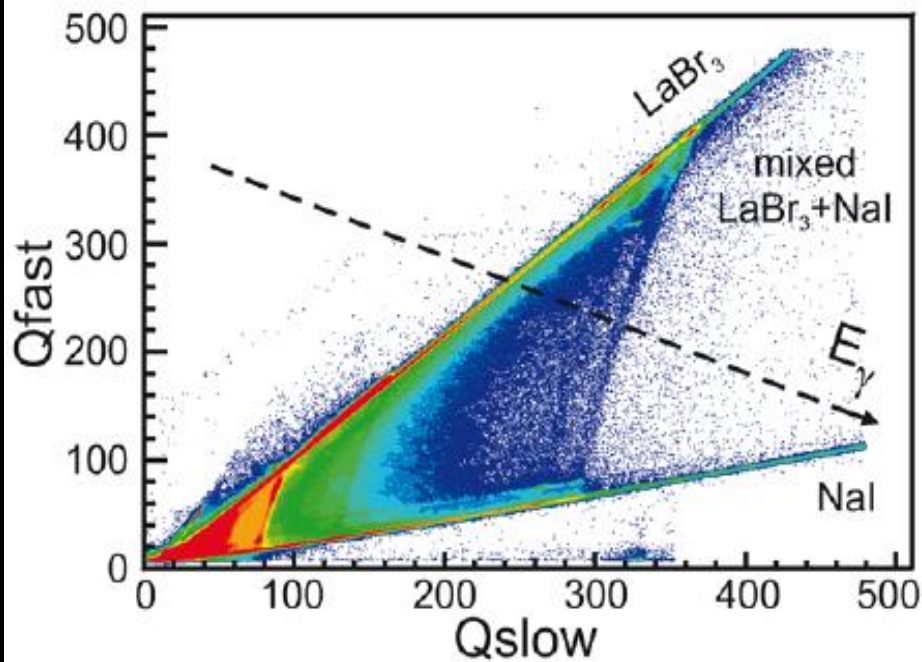
Conclusion: PARIS will be made of rectangular phoswiches
Arranged in clusters (9 phoswiches each)
This allows *cubic*, *wall* or *semi-spherical* geometry with
24 clusters (216 phoswiches)

PARIS PROJECT



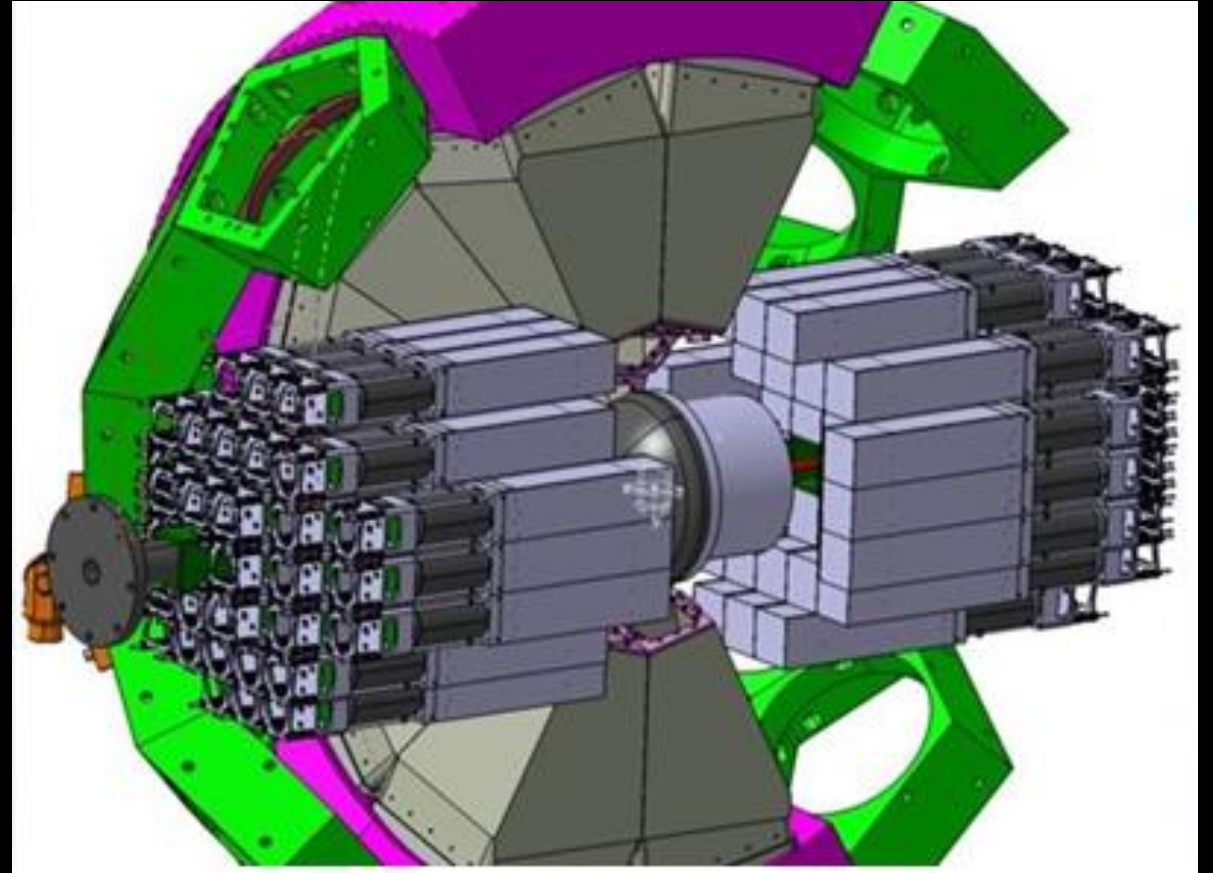
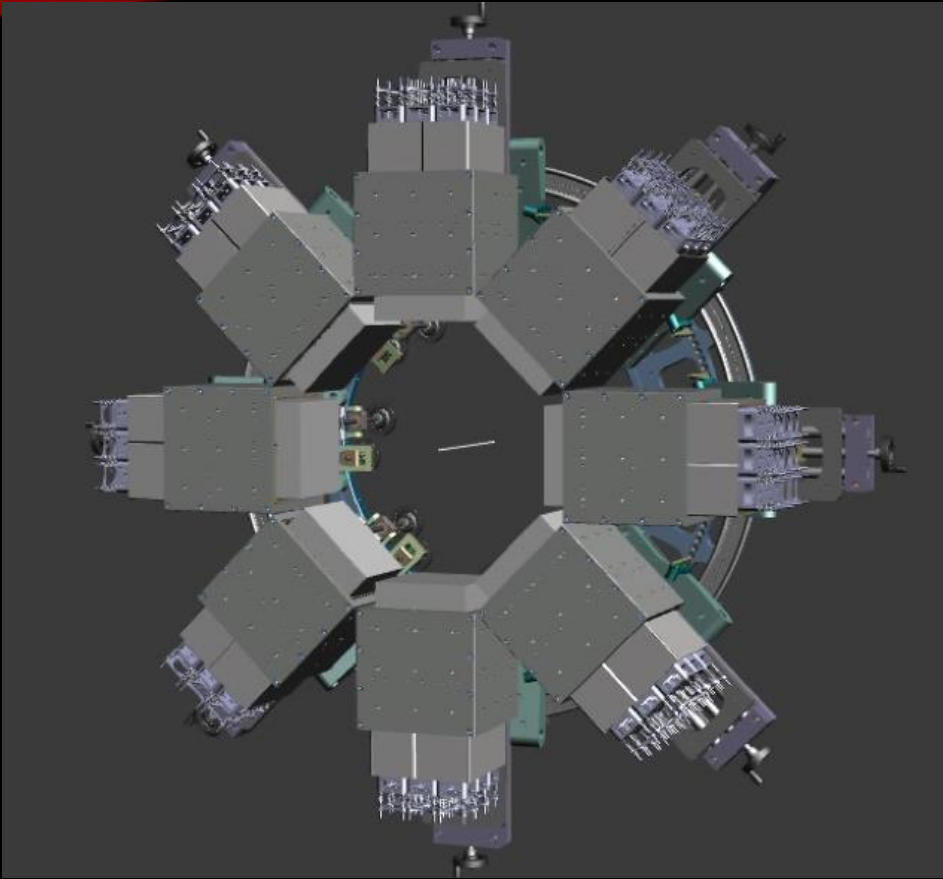
PARIS PROJECT

Milano group (F. Camera, S. Brambilla and others)
Krakow group (M. Ziębliński, P. Bednarczyk, M. Kmiecik, AM and others)
and other groups
started an intensive R7D program to make the PARIS phoswich work.
This was successful!



PARIS PROJECT

As for today the PARIS collaboration owns ca. 100 phiswiches (11 clusters)



They were used in many campaigns in GANIL (VAMOS, LISE, NFS, AGATA), IJC LAB Orsay (nuBall1&2, Licorne, standalone), CCB Krakow. Data aer being analyzed.

AGATA@LNL (2026?)

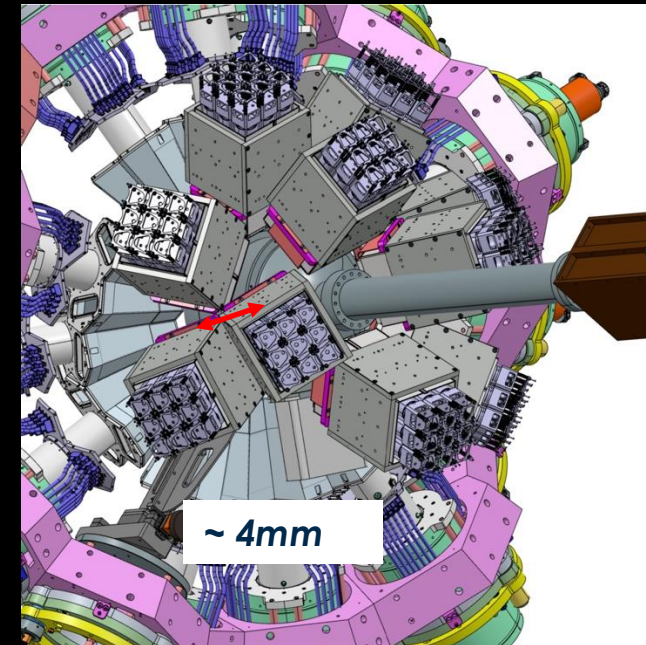
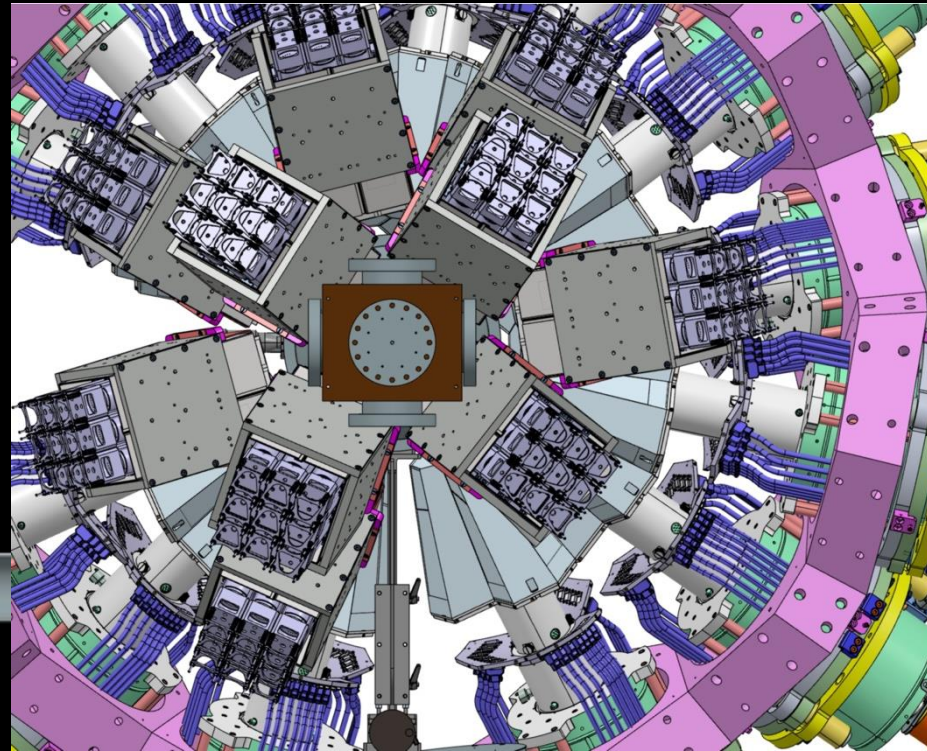
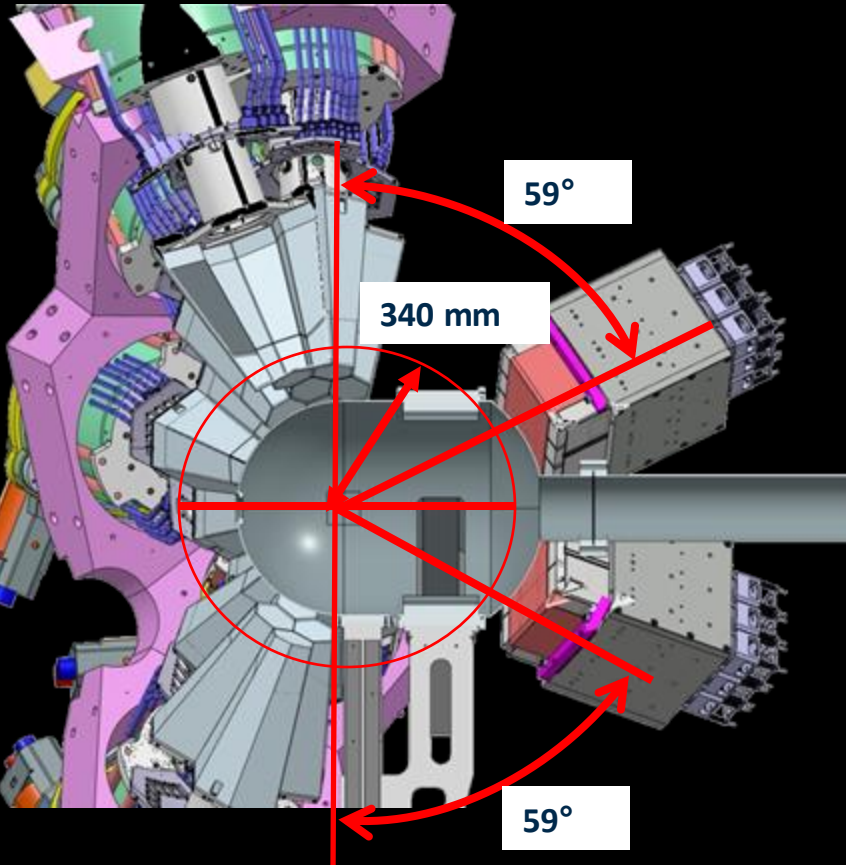
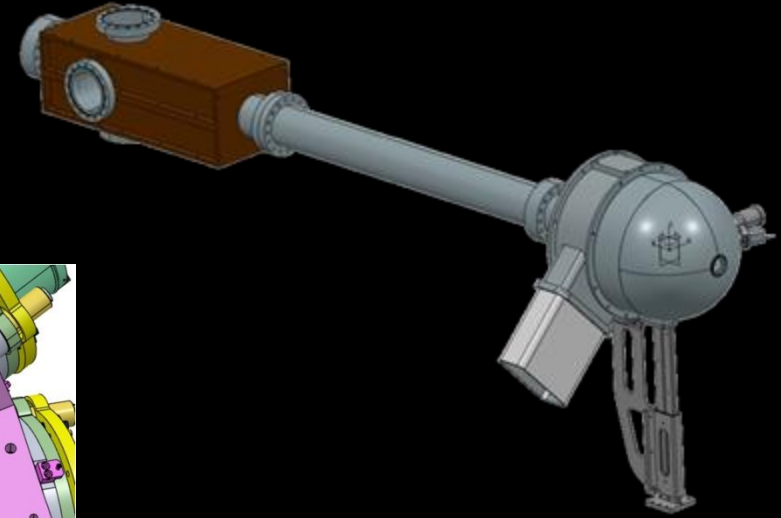
Preliminary list of Lols AGATA+PARIS in LNL:

- Measurement of Isospin Mixing (F. Camera et al.,)
- GDR feeding of SD states (G. Benzoni)
- Gamma and Particle Decay of Giant Resonances Excited by Inelastic Scattering of ^{17}O ions at 20 MeV/A (F Crespi et al.)
- Onset of collectivization/clusterization in Oxygen neutron-nuclei (S. Leoni, B. Fornal et al.)
- Lifetime measurements of excited states in neutron-rich C isotopes: a test of the three-body forces (M. Ciemala, B. Fornal, S. Leoni et al.)
- The search for Jacobi shape transitions in hot rotating nuclei from the Mo-Ba region (M. Kmiecik, A. Maj, S. Leoni et al.)
- Investigation of a high spin structure in the vicinity of ^{44}Ti via discrete and continuum γ -spectroscopy with AGATA+EUCLIDES+PARIS detectors (P. Bednarczyk et al.)
- Coulomb excitation of the super-deformed structures in $A \sim 40$ mass region (AGATA+SPIDER+PARIS) (K. Hadynska-Klek et al.)

PREPARATIONS FOR PARIS@AGATA IN LNL LEGNARO

4th test : New chamber design - 2^d Clustes Ring

Courtesy of Christine LE GALLIARD (IJC Lab, Orsay)



PARIS Whitebook

(concept, physics case, outlook)

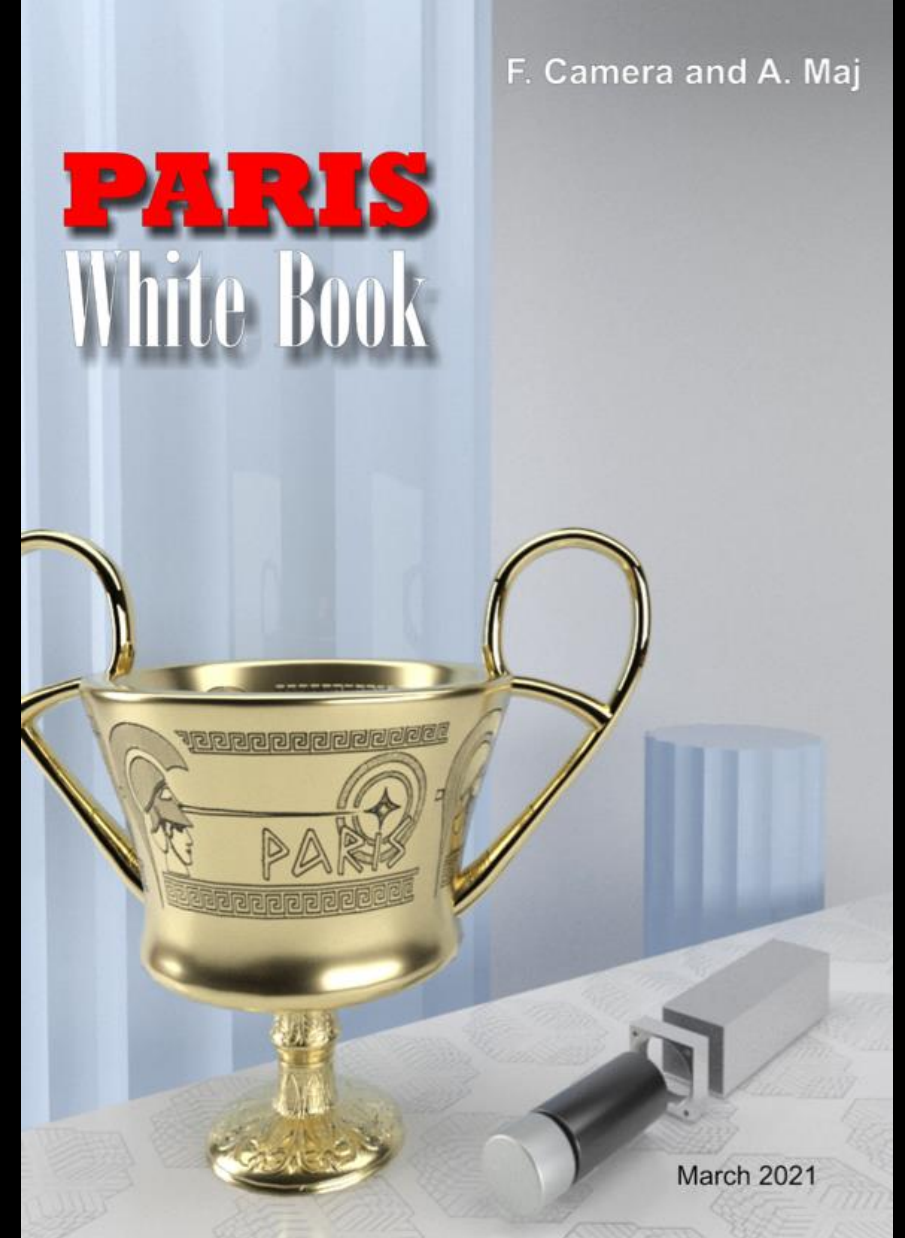
Editorial Board:

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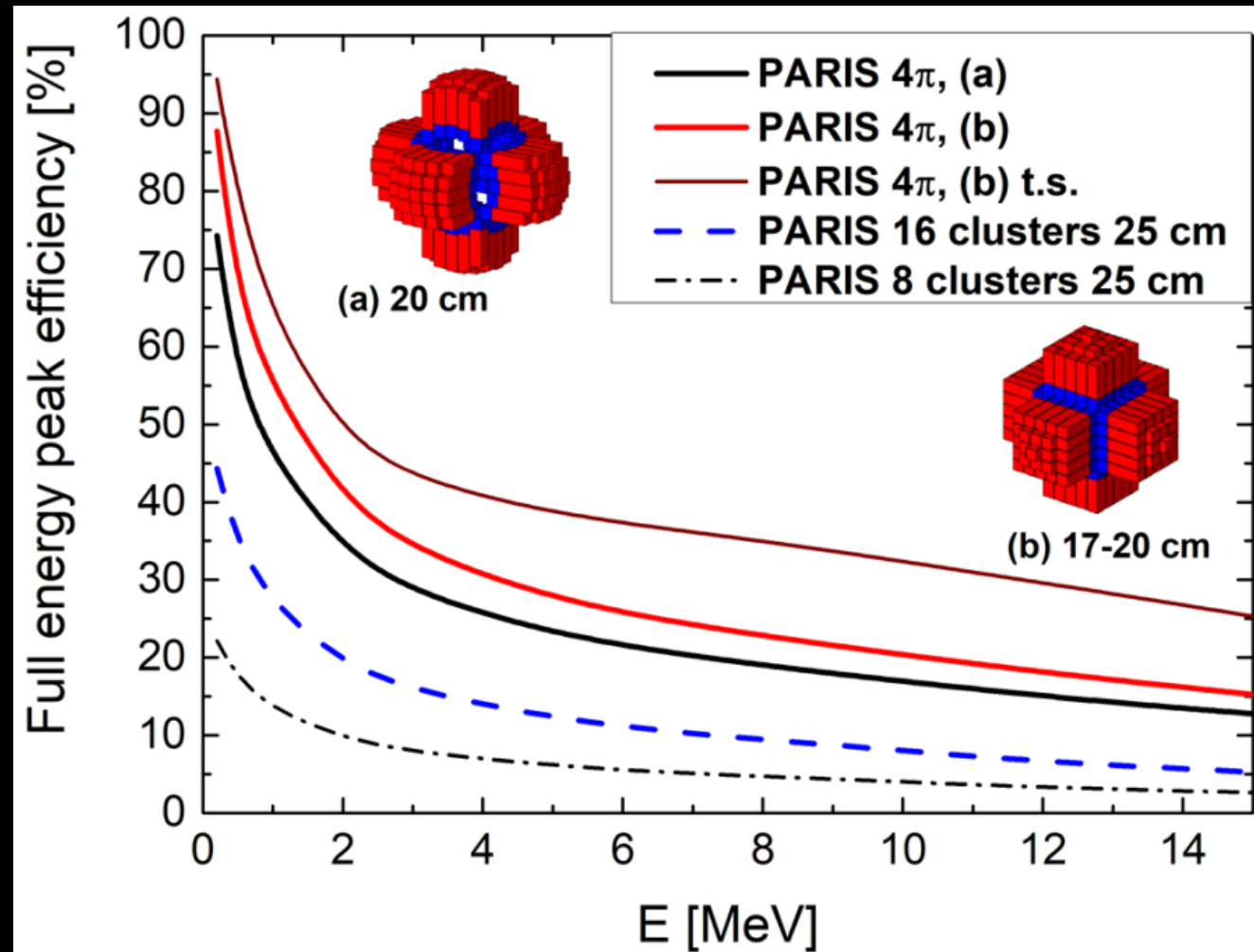
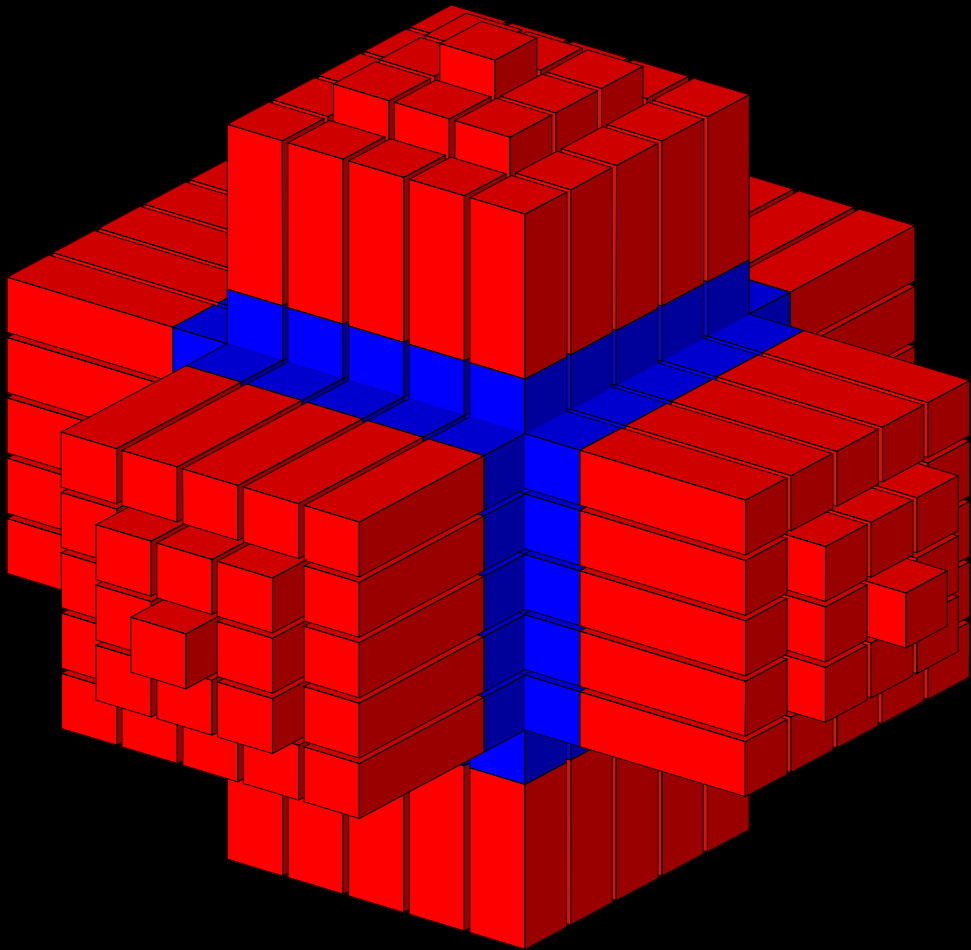
ISBN 978-83-63542-22-1

PARIS PROJECT



PARIS PROJECT

Following the conclusion of the PARIS Whitebook
PARIS Steering Committee approved the plans
to go towards **PARIS 4 π mini-cube** (150 phoswiches)



PARIS Organization

PARIS PROJECT

9 PARTNERS:

IN2P3 (France), COPIN (Poland), GANIL/SPIRAL2 (France), TIFR/BARC/VECC (India), IFIN HH (Romania), INFN (Italy), UK, Turkey, GSI/FAIR Darstadt,

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- **Marek Lewitowicz (GANIL, France) - Chair**
- Vandana Nanal (India)
- Mihai Stanoiu (Romania)

PARIS Project Manager
Adam Maj (Krakow)

Working Groups and their Coordinators

- Piotr Bednarczyk (Krakow) - Online user interface integration
- Sergio Brambilla (Milano) - Electronic and DAQ integration
- Michał Ciemała (Krakow) - Physics event generators, off-line data analysis and data management
- Oliver Dorvaux (Strasbourg) - Detectors
- Iolanda Matea (Orsay) - Mechanical integrations
- Oliver Stezowski (Lyon) - Simulations and characterization

PARIS Collaboration Council (20 institutions)

F. Camera (INFN and U. Milano) - chair and PARIS spokesman

C. Bhattacharya (VECC Kolkata), W. Catford (U. Surrey), M. Cinausero (LNL Legnaro), S. Courtin (IPHC Strasbourg), Zs. Dombardi (ATOMKI Debrecen), C. Ducoin (IPN Lyon), S. Ertuerk (U. Nigde), N. Gelli (U. Florence), J. Gerl (GSI), A.K. Gourishetty (IIT Roorkee), D. Jenkins (U. York), M. Kmiecik (IFJ PAN Krakow), B. Kumar Nayak (BARC Mumbai), M. Labiche (STFC Daresbury), V. Nanal (TIFR Mumbai), P. Napiorkowski (HIL Warsaw), M. Ploszajczak (GANIL), M. Stanoiu (IFIN-HH Bucharest), J. Wilson (IPN Orsay)

FRANCO AT ZAKOPANE

Giving a lecture about

Giant ...

..and Pygmy resonances



Discussing big physics questions



FRANCO AT ZAKOPANE

Exploring extremes of nuclear landscape



Dear Silvia, Franco and Gianluca:

**Happy 60th birthday! All the best for the next years! 100 lat!
Let's hope to continue our longstanding, fruitful and exciting collaboration!**



**Dear Franco:
I wish you to develop another yet
scintillator array**