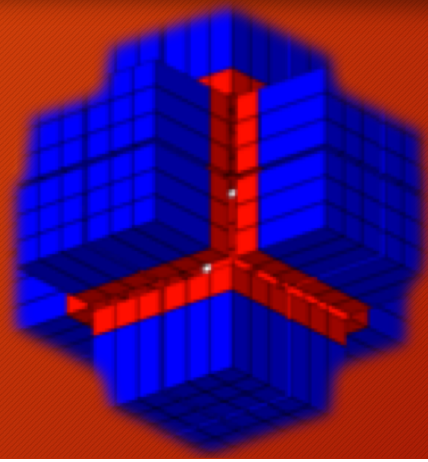
The Henryk Niewodniczański Institute of Nuclear Physics
Polish Academy of Sciences

PARIS

Latest results from PARIS

Adam Maj
IFJ PAN Krakow
for the PARIS Collaboration



NUSTAR Annual Meeting 2018

GSI, 26.02 - 2.02 2018

paris.ifj.edu.pl

Plan of the talk

- Idea of PARIS
- Design
- Performance of first prototype and first cluster of PARIS
- Results from first PARIS experiments in Orsay, Krakow and GANIL
- PARIS organization, construction status and plans
- PARIS @ HISPEC/DESPEC ?
- Summary

Idea of PARIS

PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

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

GANIL
SAC open session
October 19th, 2006

Spiral2

Letter of Intent for SPIRAL 2

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

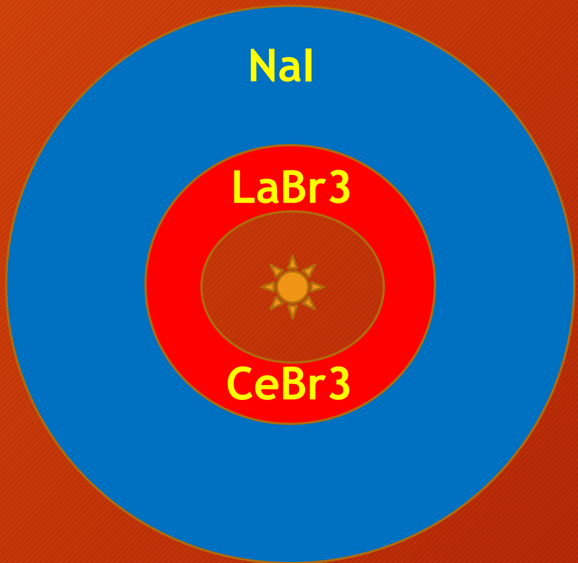
GANIL contact person
Jean-Pierre Wieleczko, GANIL, wieleczko@ganil.fr

Aim:
to design and build
efficient gamma calorimeter
PARIS

PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

PARIS design assumptions:

High efficiency (≈4π) gamma detector, based on new scintilation 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 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

PARIS main physics cases

HOT ROTATING NUCLEI

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

A.Maj, J. Dudek, K. Mazurek, M. Kmiecik, A. Bracco, F. Camera, I. Mazumdar, D.R. Chakrabarty, V. Nanal, M. Kicinska-Habior, M. Harakeh, P. Bednarczyk. S. Leoni

COLLECTIVE MODES

PDR in neutron-rich and proton-rich nuclei (+GASPARD, NEDA)
Gamma -decay of GDR and GQR built on ground states

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

REACTION MECHANISMS

Onset of multifragmentation and GDR (+FAZIA)
Reaction mechanism studied via gamma-rays
Heavy ion radiative capture
Nuclear astrophysics

J.P. Wieleczko, S. santonocito, Ch. Schmitt, O. Dorvaux, S. Courting, D.G. Jenkins, S. Harissopulos

SHELL STRUCTURE

Multiple Coulex of SD bands in light nuclei
Relativistic coulex
Shell structure at intermediate energies (+LISE, S3, ACTAR)
Near barrier resonances

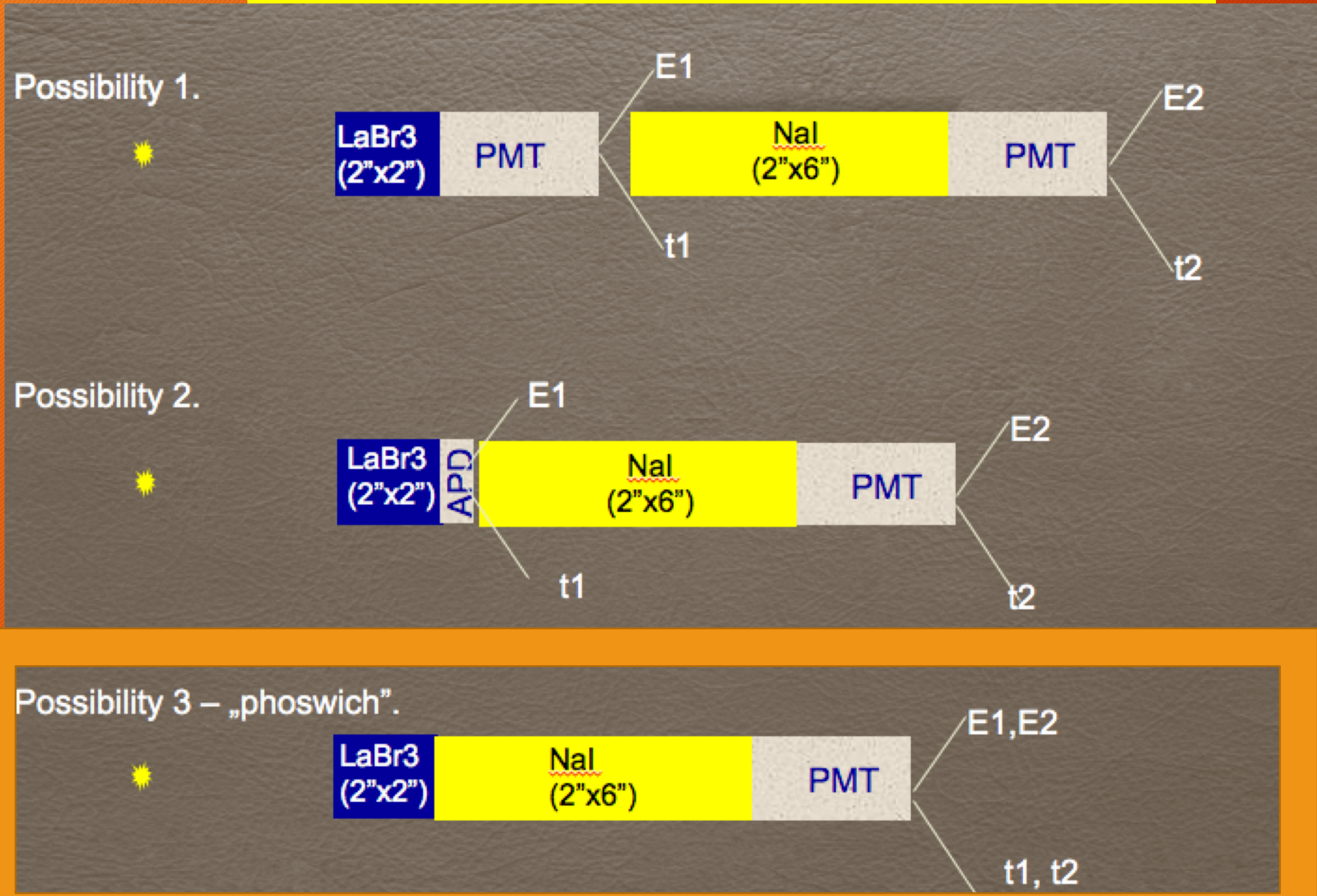
F. Azaiez, J. Stephan, B. Fornal, S. Leoni, P. Napiorkowski, P. Bednarczyk, A. Maj, Z. Dombradi, G. Grinyer, M. Ploszajczak

Main physics cases require that PARIS has to

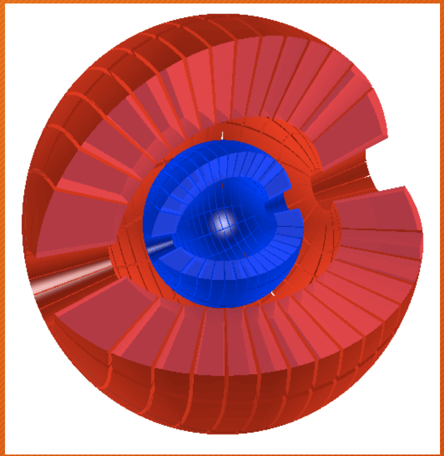
- be modular (to be connected with other detectors: AGATA, EXOGAM, GASPARD, NEDA, FAZIA, ACTAR, HECTOR, EAGLE, GALILEO, LICORNE, nuBALL...)
- have high granulation (multiplicity measurement, Doppler correction,...)
- have very high efficiency for high-energy g-rays (~50 MeV)
- stand high count-rate (50MHz)
- have good timing resolution (<1 ns)
- have energy resolution as good as possible (4%)
- have some position sensitivity
- be transportable (apart of SPIRAL2/GANIL experimental campaigns are planned in other facilities: ALTO, Warsaw, Krakow, LNL/SPES, Mumbai, IFIN-HH/ELI-NP, GSI/FAIR?)

Design

3 POSSIBILITIES FOR A „GAMMA-TELESCOPE” ELEMENT



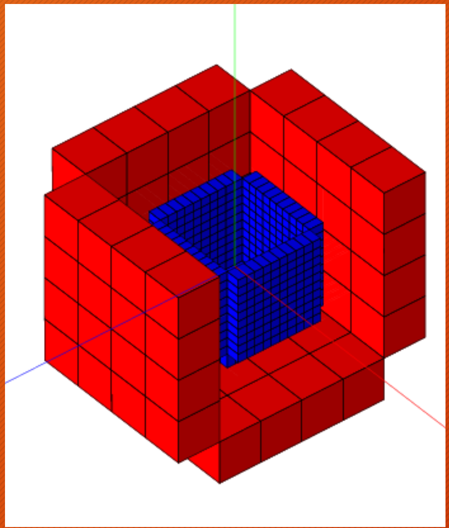
POSSIBLE GEOMETRIES of PARIS



SPHERICAL (e.g. same as AGATA modules):

+ : easy reconstruction, good line shape, compability with other spherical detectors,..

- : Limited to one distance, high cost of a segment,…

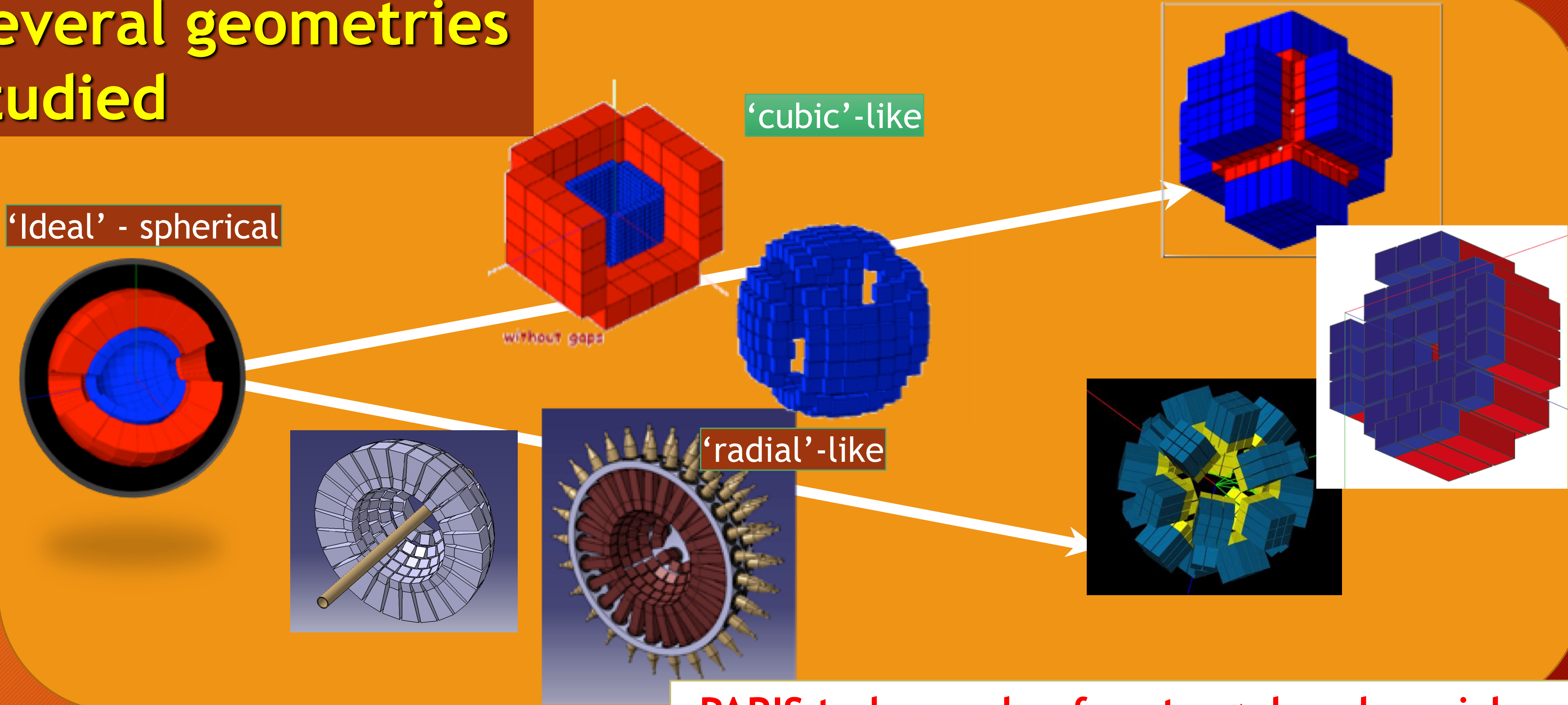


CUBIC (offering variable geometry):

+ : adjustable to different distances, compatibility with many detectors, lower cost for a segment, easier mechanical support,

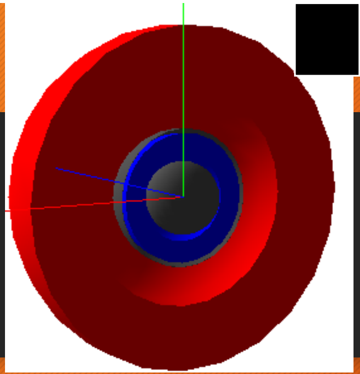
- : More complicated reconstruction, worse line shape, …

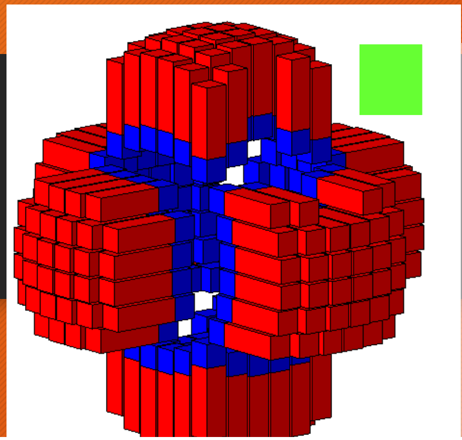
Several geometries studied

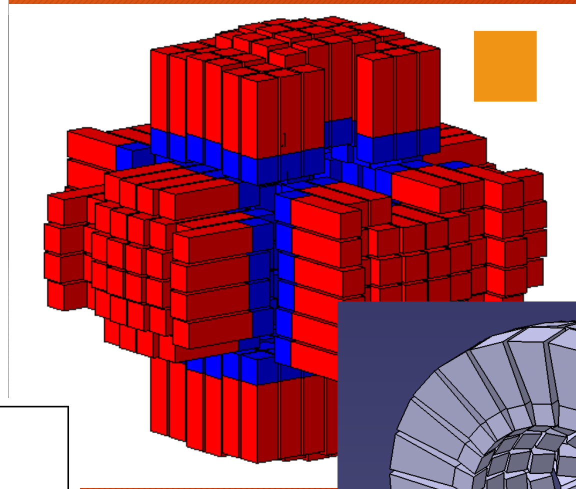


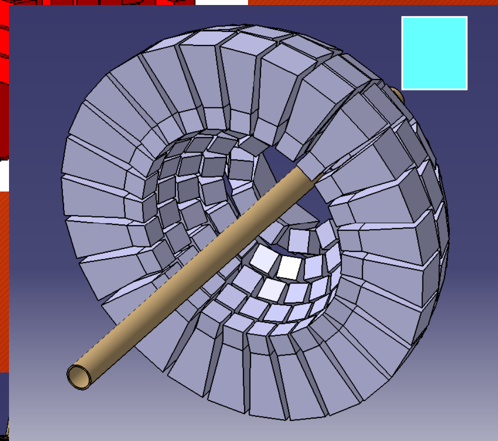
PARIS to be made of rectangular phoswiches
Arranged in clusters *(9 phoswiches each)*
This allows *cubic*, *wall* or *semi-spherical* geometry with 24 clusters (216 phoswiches)

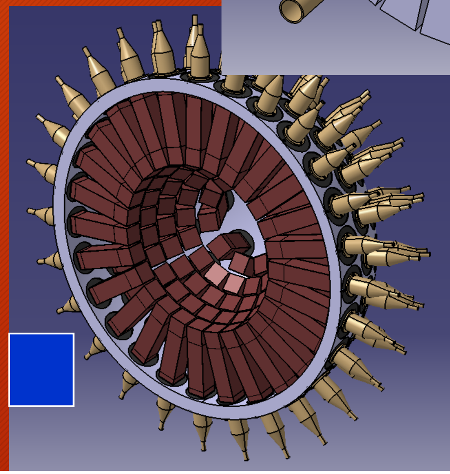
Cubic vs. Radial geometry

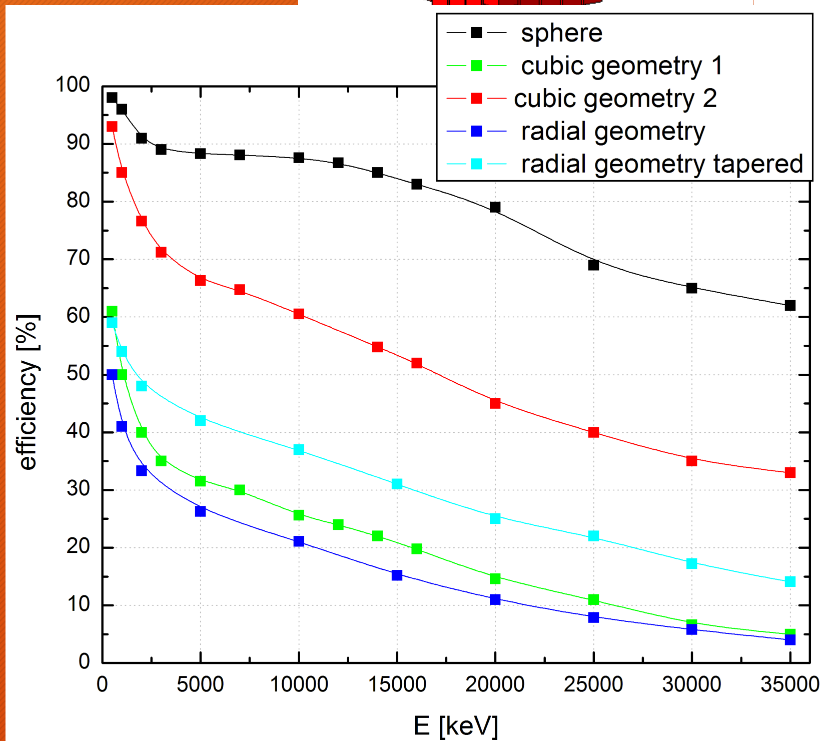






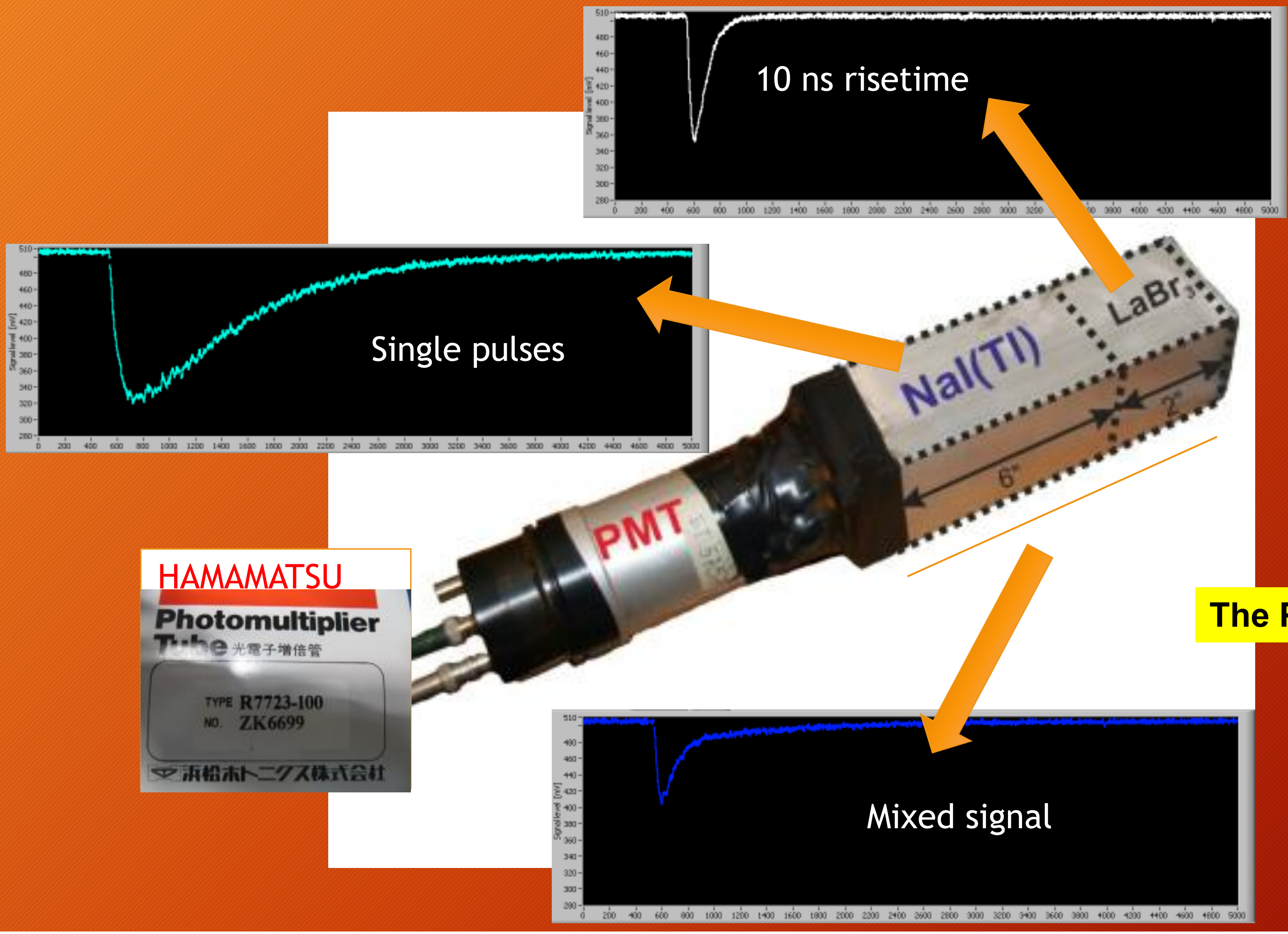




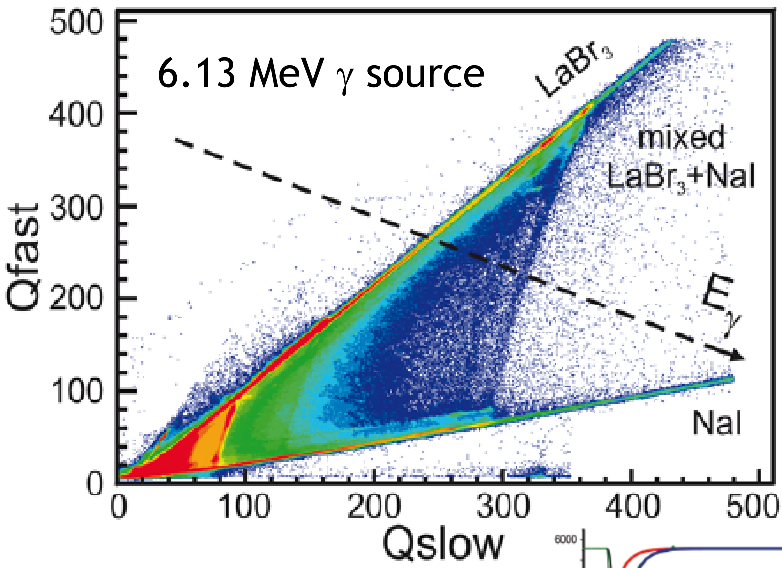


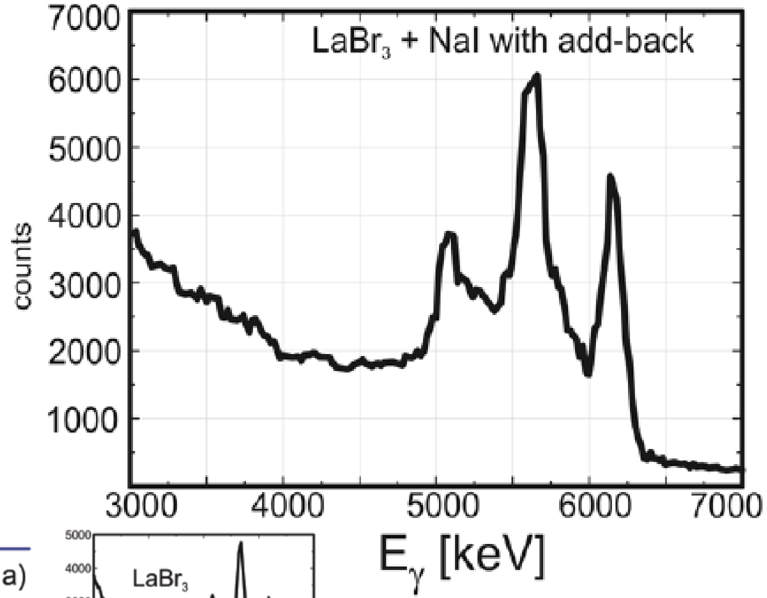
Performance of first prototype and first cluster of PARIS

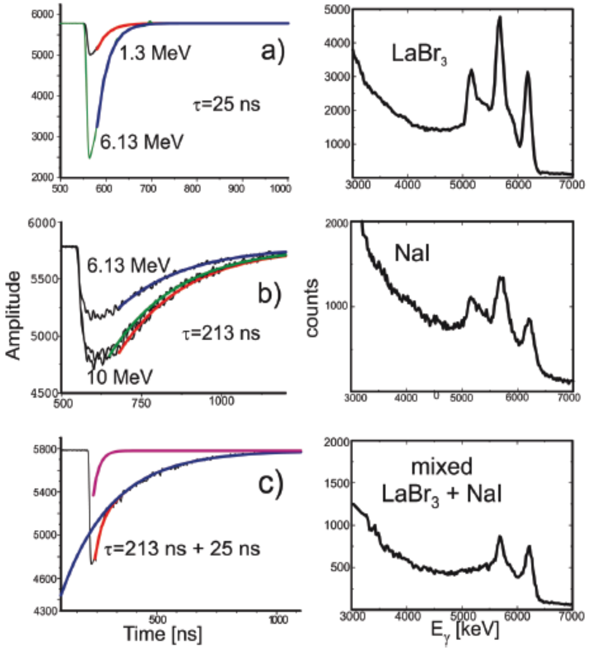
Phoswich tests



The PARIS PHOSWICH at work







A test measurement at IFJ PAN, Kraków (2011) with BafPro module from Milano

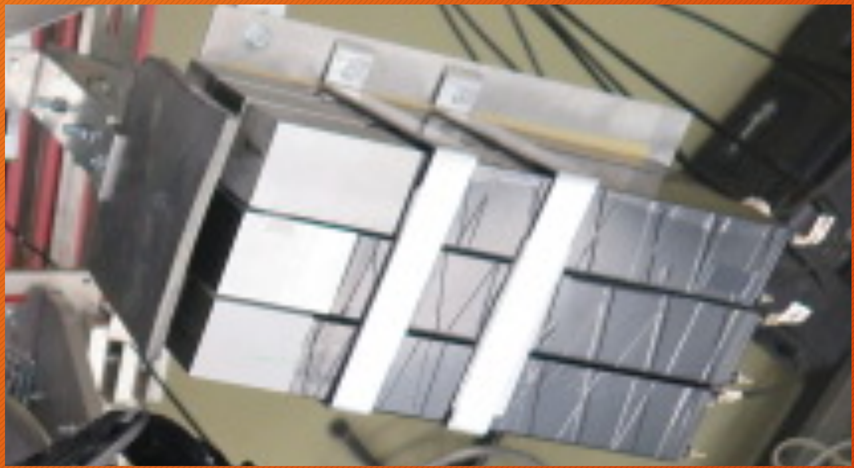
- Sources
- proton beam

LaBr3 resolution (seen through 6” long NaI): ca. 4%

The phoswich concept works !

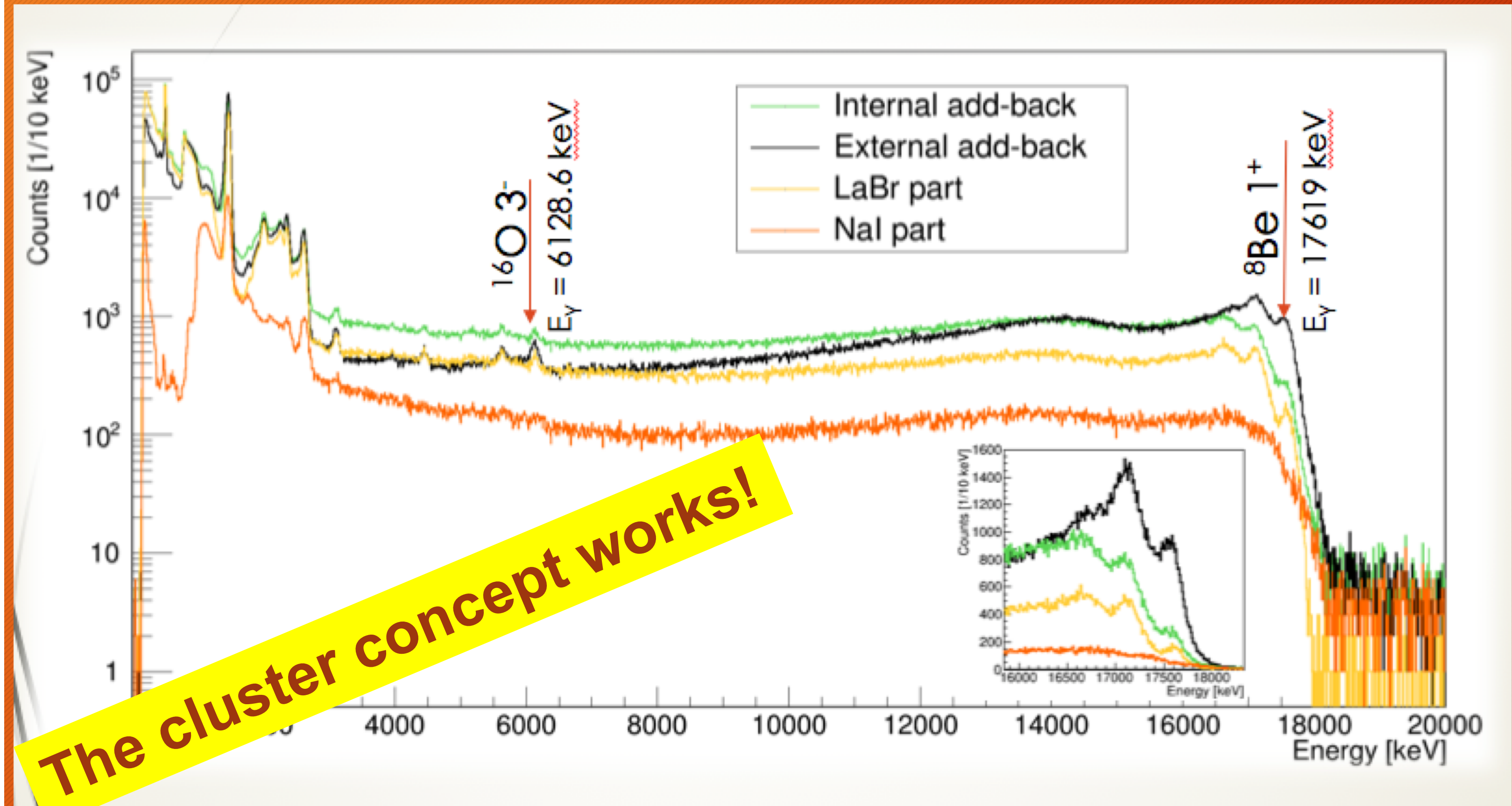
M. Zieblinski et al., Acta Phys.Pol. B44, 651 (2013)

First PARIS cluster



Cluster tests were performed in
IPHC Strasbourg, IPN Orsay, IFJ PAN Krakow, TIFR Mumbai,
ELBE Rosendorf, INFN Milano, ATOMKI Debrecen
using sources and beams

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



The cluster concept works!

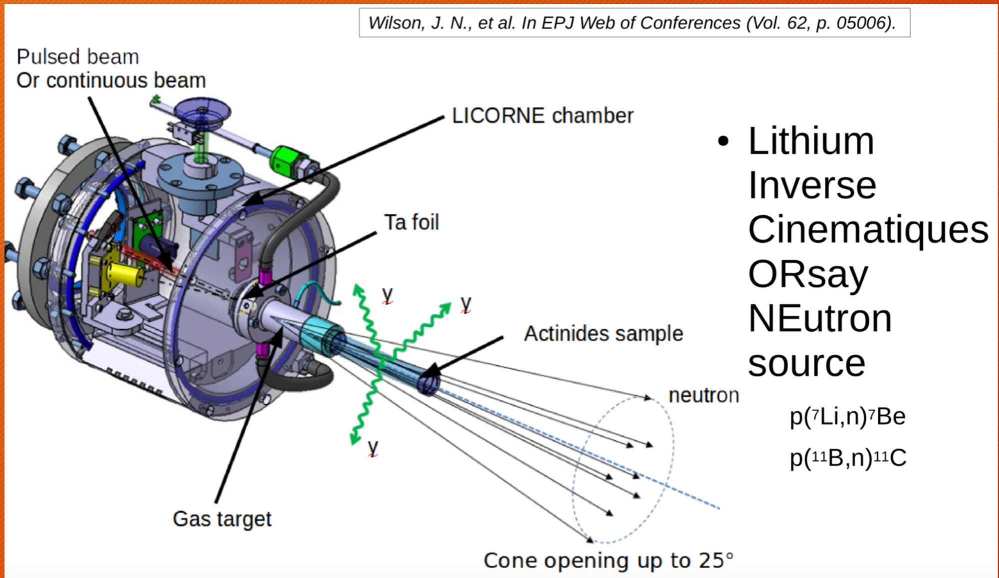
B. Wasilewska et al., paper in preparation

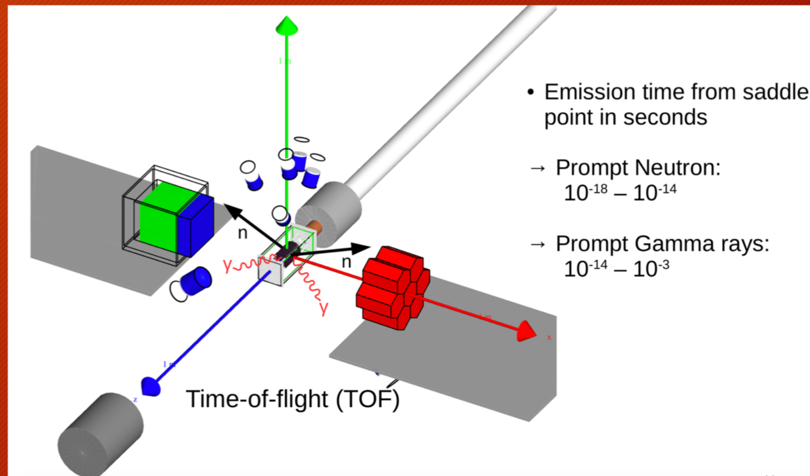
Results from first PARIS experiments in Orsay, Krakow and GANIL

IPN Orsay

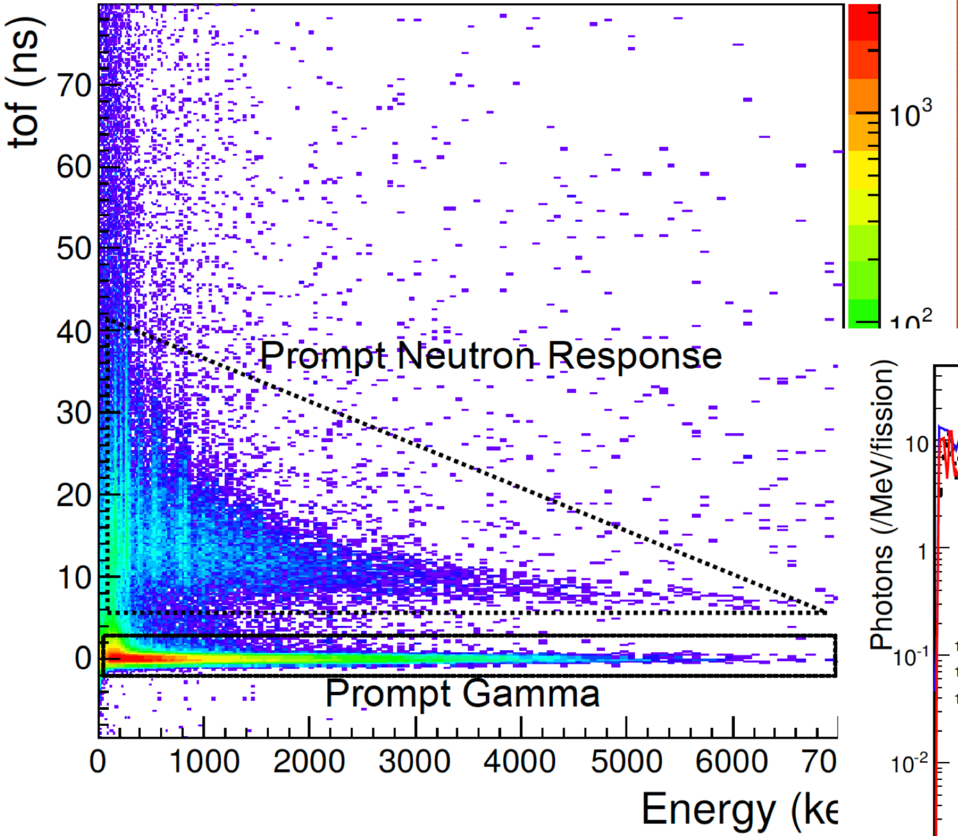
M. Lebois, Q. Liqiang et al. **"Prompt gamma and neutron emission for ^{238}U fast neutron induced fission as a function of incident neutron energy"** (1 PARIS cluster, BaF2 cluster, EDEN, LICORNE)

Main experimental goal
Measurement of Promt Fission Gammas (PFG) for different fissioning system:
252Cf(sf), 238U(n ,f) and 239Pu(n ,f)

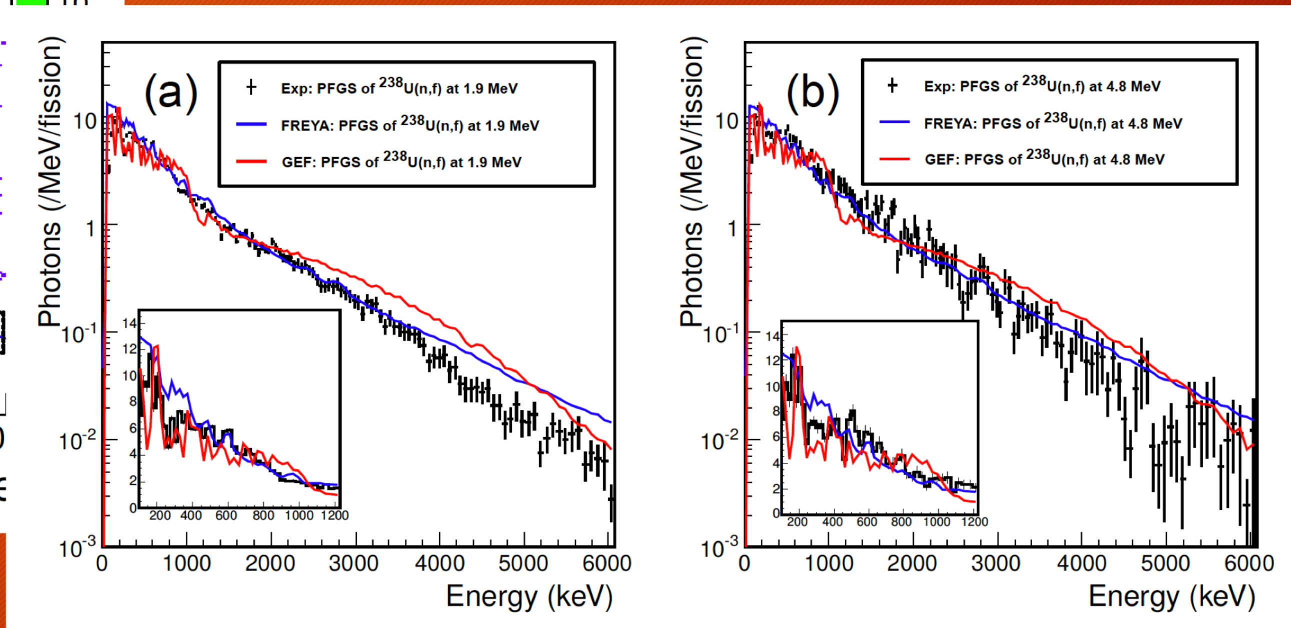




Courtesy of Liqiang Qi



Unfolded PFGs from PARIS at 2 neutron incident energies in comparison to theoretical models

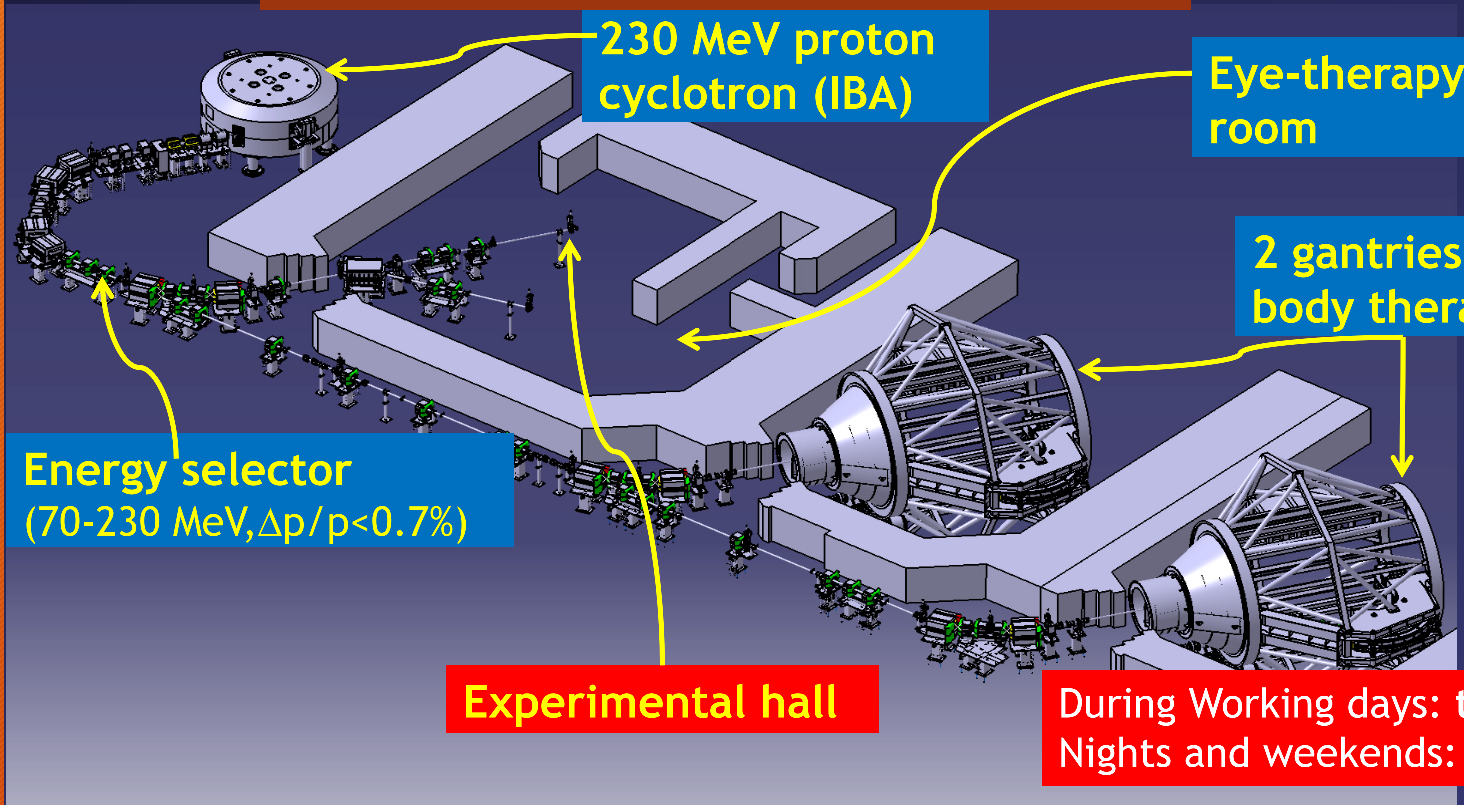


L. Qi, M. Lebois, J.N. Wilson et al., submitted to PRC

IFJ PAN Kraków

M. Kmiecik, F. Crespi, A. Maj et al. **"Gamma decay from high-lying states and giant resonances excited via (p,p'γ)"**
(1 PARIS cluster, HECTOR array, KRATTA)

Cyclotron Cemter Bronowice (CCB)

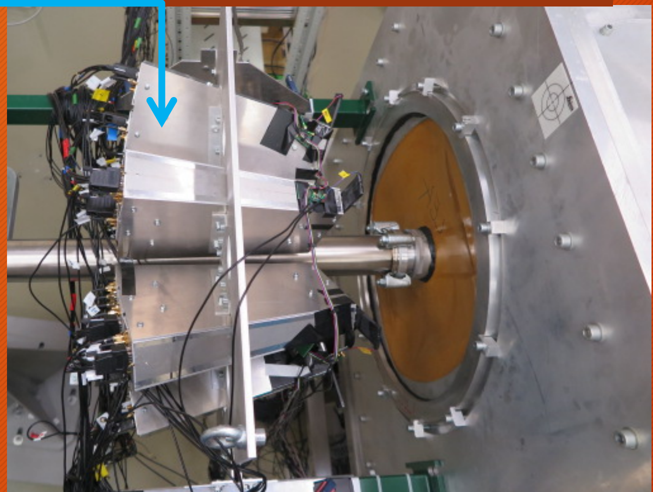


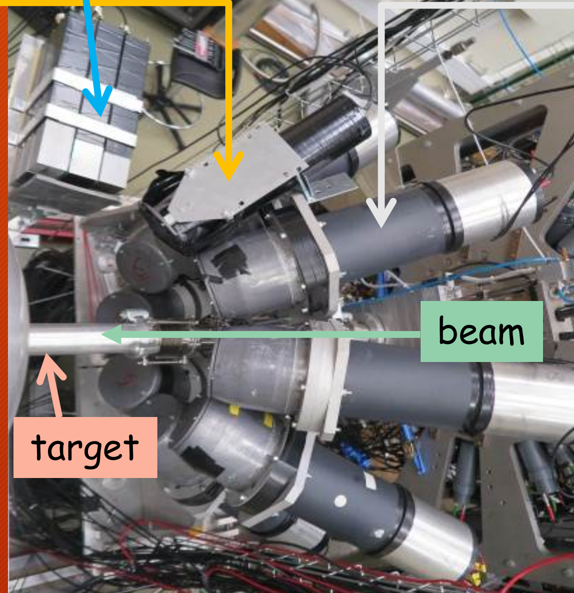
During Working days: **therapy**
Nights and weekends: **experiments**

Main experimental goal
Measure gamma decay of the GQR and PDR in ^{208}Pb excited in p,p'γ reactions

KRATTA (16 CsI telescopes, at 8-15.3°)
fast plastic scintillators in the front of KRATTA

HECTOR (8 BaF_2)
$LaBr_3$ (large volume 3.5"x8")
PARIS (cluster of 9 „phoswiches" $LaBr_3/CeBr_3$ + NaI)

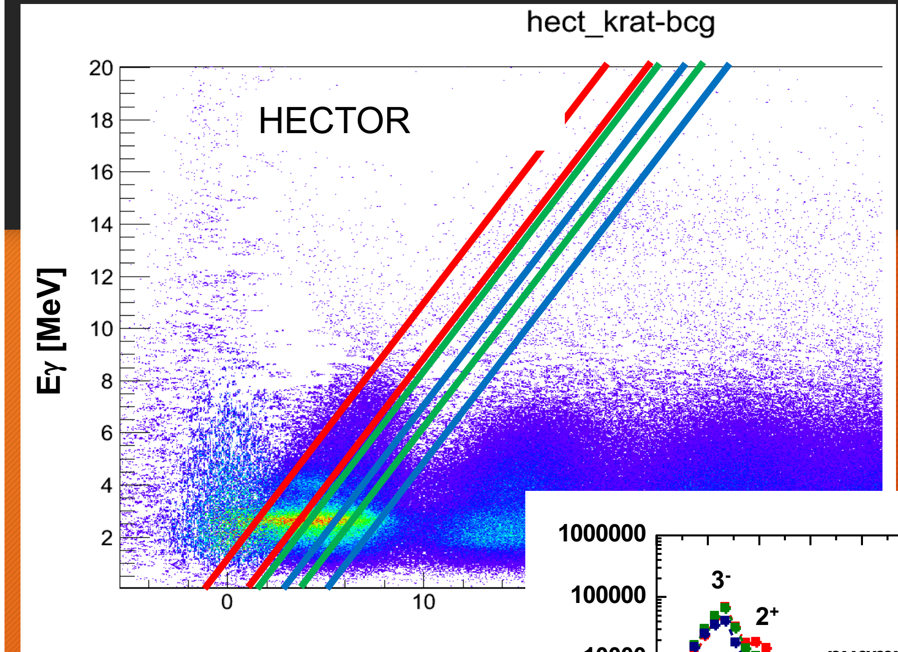


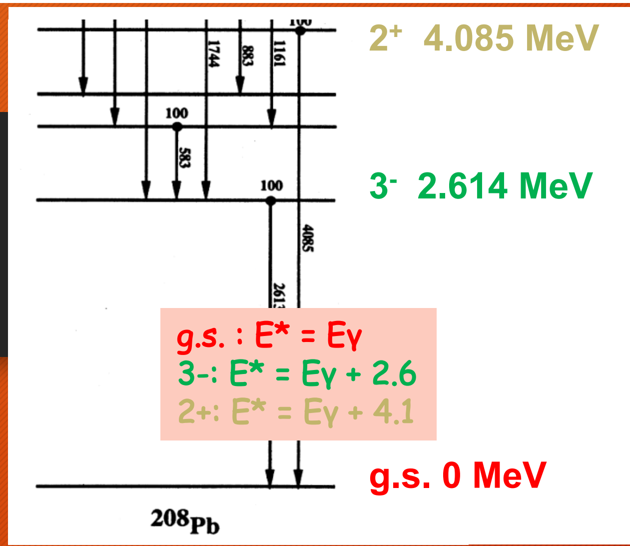


Grafite + concrete beam dump

Experimental setup

Preliminary results

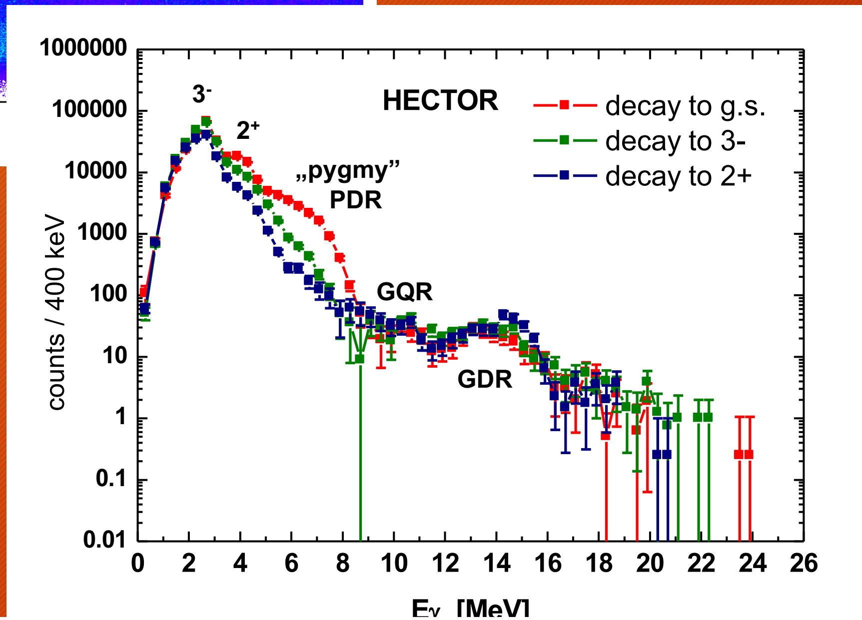


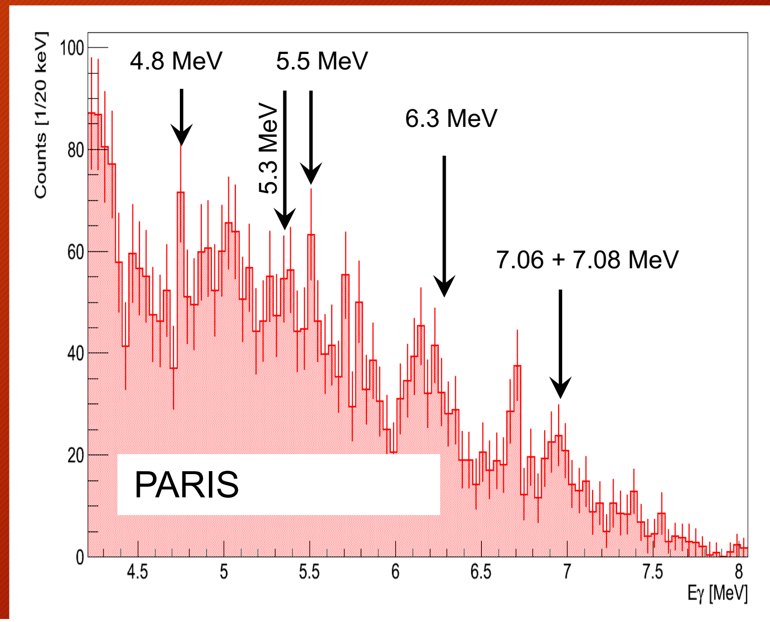


Courtesy of Basia Wasilewska

gamma decay of GDR, GQR and low-lying states (PDR) observed

more quantitative analysis ongoing



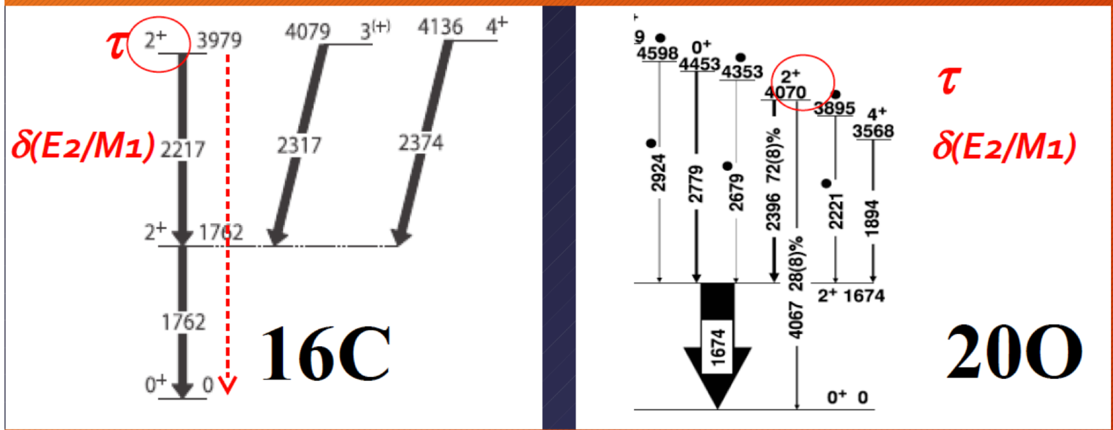


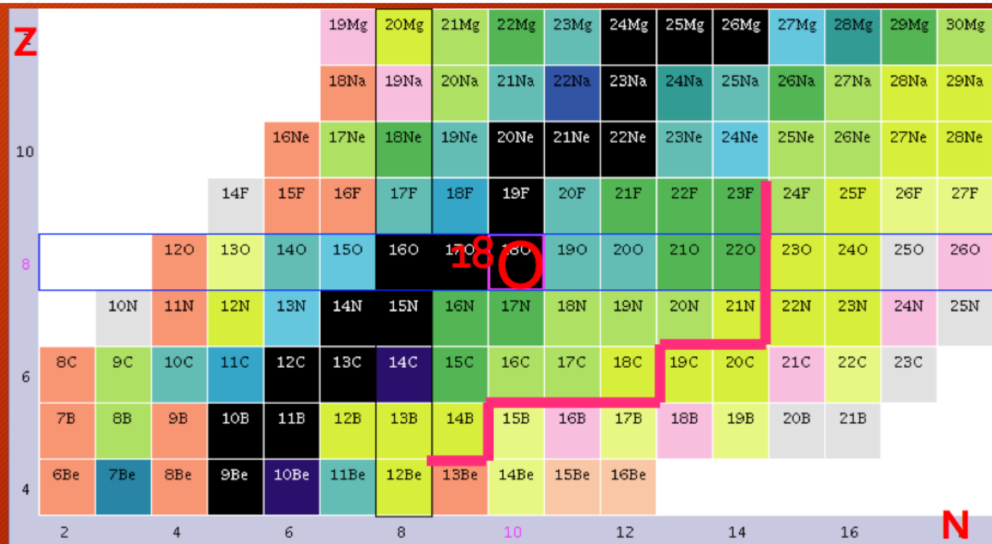
GANIL, Caen

S. Leoni, B. Fornal, M. Ciemala et al.,
Lifetime measurements of excited states in neutron-rich C and O isotopes
PARIS (2 clusters), 2 large $LaBr_3$, AGATA, VAMOS

Main experimental goal
Measure second 2^+ lifetimes for ^{20}O and ^{16}C with use of Doppler shift method

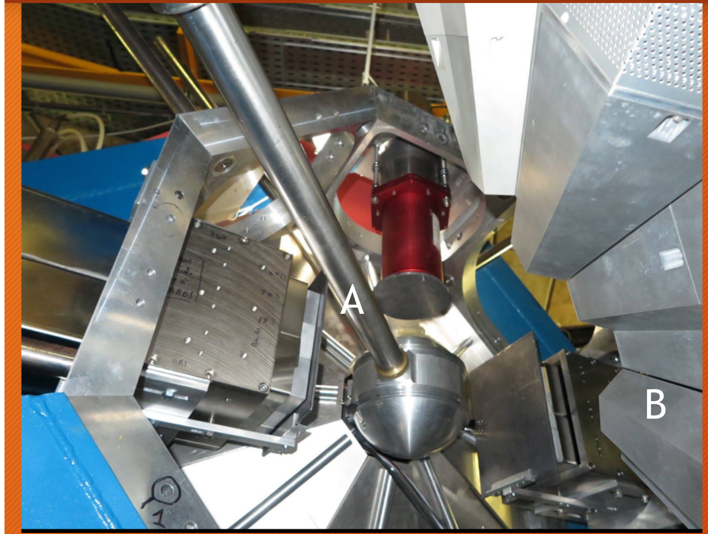
Nucleus	Excited state	Interactions: lifetime τ [ps] (*ab initio* NN)	Interactions: lifetime τ [ps] (*ab initio* NN+ NNN)	Interactions: mixing ratio δ (E2/M1) for $2^+_2 \to 2^+_1$ (*ab initio* NN)	Interactions: mixing ratio δ (E2/M1) for $2^+_2 \to 2^+_1$ (*ab initio* NN+NNN)	Experiment τ [ps]
^{16}C	2^+_1	24	24			11.4(10) - 18.3(50)
	2^+_2	0.23	0.08	0.30	0.08	< 4
^{18}C	2^+_1	19.4	20			22.4(3.5)
	2^+_2	2.2	1.1	0.02	0.04	< 4.6
^{20}O	2^+_1	10,3	11,7			10.70(40)
	2^+_2	0.32	0.20	0.24	0.04	-
^{22}O	2^+_1	0.40	0.46			0.69(28)
	2^+_2	0.064	0.043	0.33	0.05	-





PARIS setup

1 $LaBr_3$-NaI cluster (A) in magnetic shield
1 $CeBr_3$-NaI cluster (B) in magnetic shield
1 big $LaBr_3$ in magnetic shield
1 big $LaBr_3$ without magnet shield
All placed around 90 degree

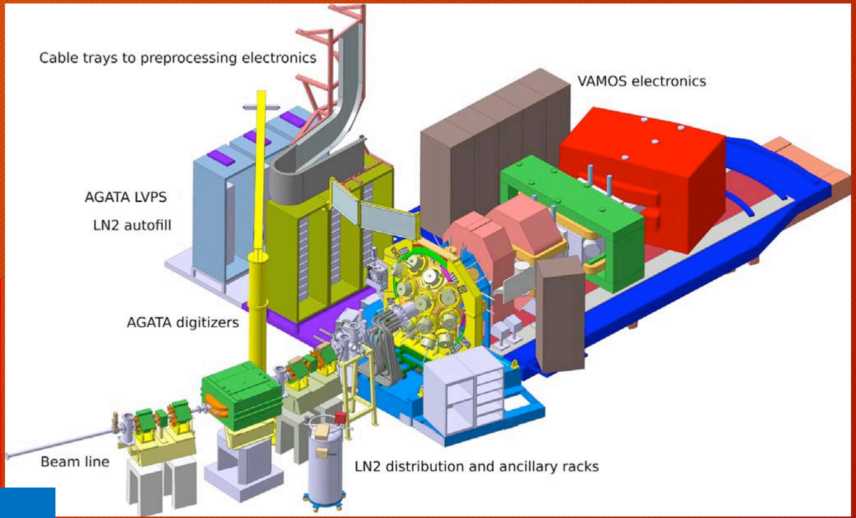


A shield for VAMOS magnetic field needed!
Designed at IPHC Strasbourg and tested in dec. 2016 at VAMOS (build of 2 mm mu-metal + 10 mm of mild steel)
Additional EXOGAM 3x2mm mu-metal plates

PARIS and $LaBr_3$ shielded with 5 mm Pb in front, covering solid angle of 0.4π

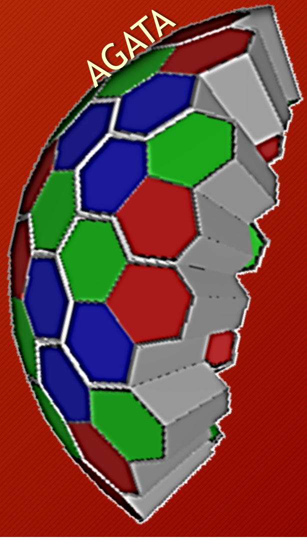
Reaction:
^{18}O 7.0 MeV/A beam on ^{181}Ta (4 μm thick)

VAMOS++ at 45 degree
VAMOS entrance detector:
2 DC (for ions entrance angles)
VAMOS focal plane:
DC (for Brho reconstruction),
6 rows of IC (for ΔE)
Plastic (for trigger and ToF)

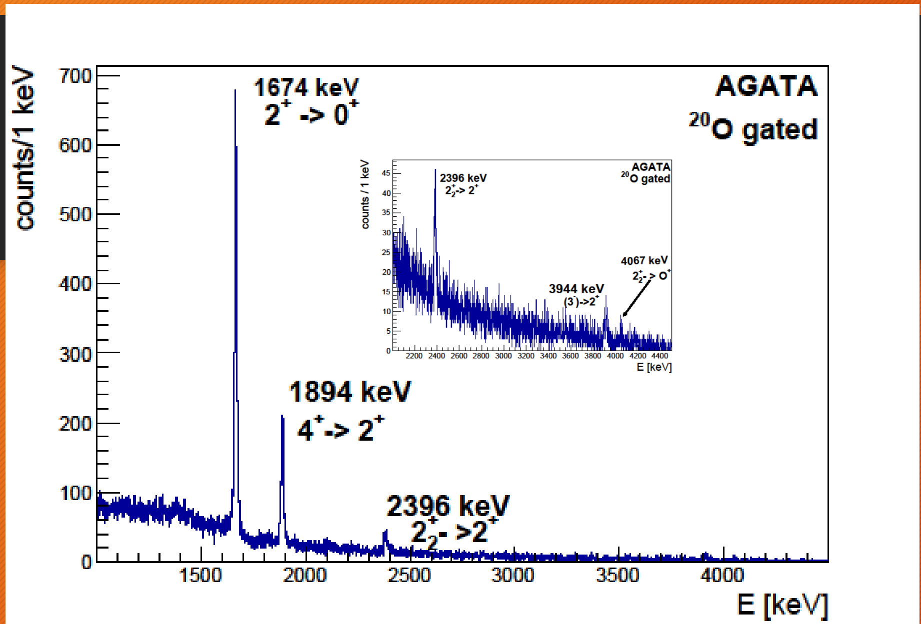


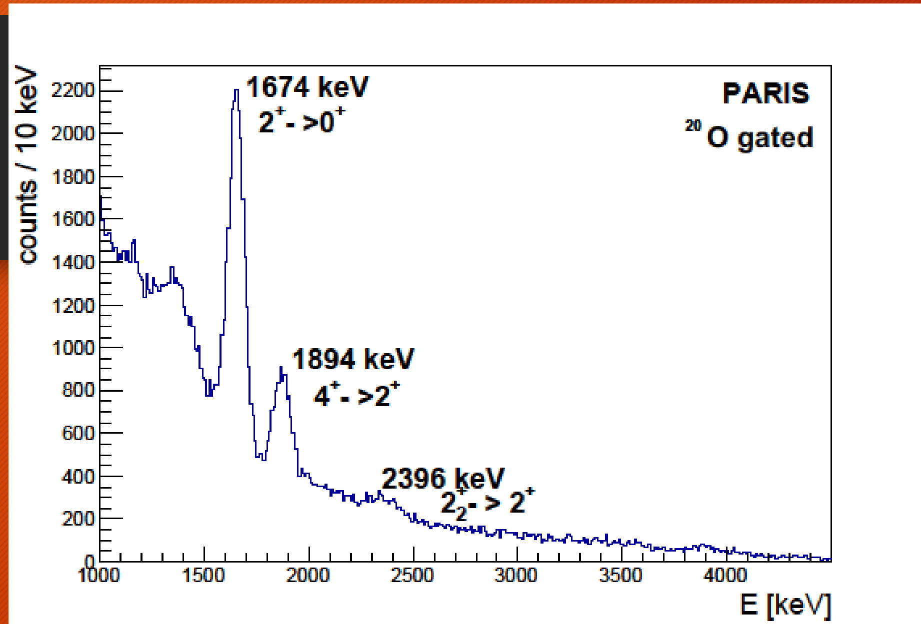
E. Clement et al. NIMA 885, 1-12 (2017)

AGATA
32 detectors



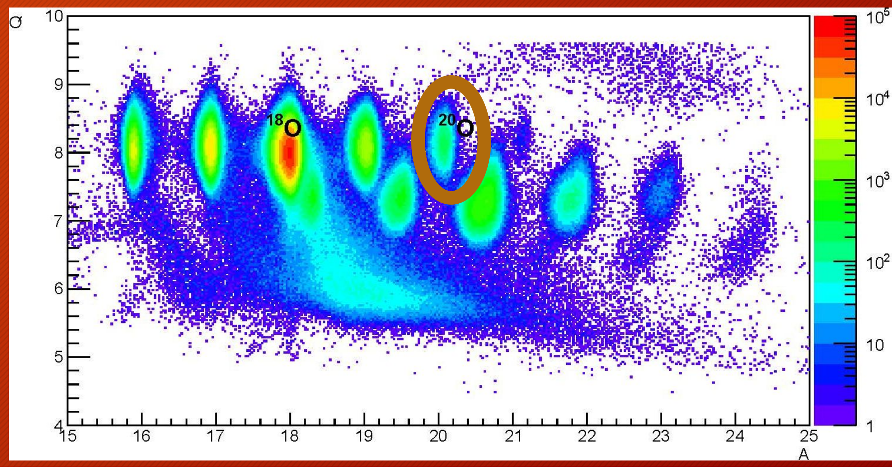
^{20}O spectra *(ion of interest)* *Courtesy of Michal Ciemala*





Gamma-rays measured by PARIS in coincidence with AGATA, will be used for determining gamma decay branching ratios for most populated C, N and O isotopes.

Moreover, PARIS data will be used for measuring the gamma-ray angular distributions, providing the data point for theta angle around 90 degrees.



PARIS organization, construction status and plans

PARIS Organization

PARIS Steering Committee
(by nominations of the MoU partners):
- **IN2P3 France: I. Matea**
- **GANIL France: M. Lewitowicz**
- **COPIN Poland: B. Fornal (dep.chair)**
- **India: V. Nanal (chair)**
- **Italy: A. Bracco**
- **Romania: M. Stanoiu**
- **UK: W. Catford**
- **Turkey: S. Erturk**

PARIS Project Manager
(nominated by PSC)
A. Maj (Poland)

Working Groups and their Coordinators
(proposed by PPM and aproved by PSC):

Geant4 simulation: **O. Stezowski** (Lyon)
Detectors: **O. Dorvaux** (Strasbourg)
Electronics and DAQ: **P. Bednarczyk** (Krakow)
Mechanical integrations: **I. Matea** (Orsay)
Data analysis: **S. Leoni** (Milano)
New materials: **F. Camera** (Milano)
New Physics case: **I. Mazumdar** (Mumbai)

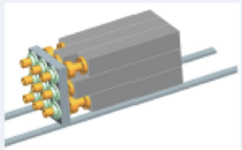
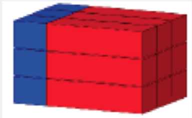
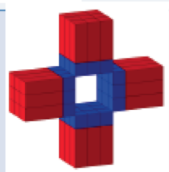
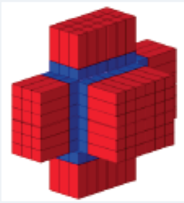
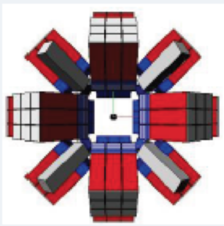
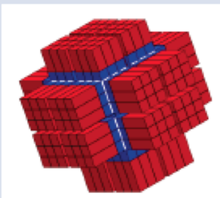
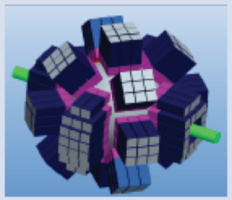
PARIS Management Board:
PARIS Project Manager + WG coordinators

PARIS Collaboration Council:
David Jenkins (University of York, UK) - chair and PARIS spokesman
Sudhee R. Banerjee (VECC Kolkata, India)
Franco Camera (INFN and University of Milano, Italy)
Wilton N. Catford (University of Surrey, UK)
Marco Cinausero (LNL Legnaro, Italy)
Sandrine Courtin (IPHC Strasbourg, France)
Zsolt Dombradi (ATOMKI Debrecen, Hungary)
Camille Ducoin (IPN Lyon, France)
Sefa Ertuerk (Nigde, Turkey)
Juergen Gerl (GSI, Germany)
Anil K. Gourishetty (IIT Roorkee, India)
Maria Kmiecik (IFJ PAN Krakow, Poland)
Suresh Kumar (BARC Mumbai, India)
Marc Labiche (STFC Daresbury, UK)
Vandana Nanal (TIFR Mumbai, India)
Pawel Napiorkowski (HIL Warsaw, Poland)
Marek Ploszajczak (GANIL, France)
Mihai Stanoiu (IFIN-HH Bucharest, Romania)
Jonathan Wilson (IPN Orsay, France)

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
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 consortiun Regular experimer in various labs

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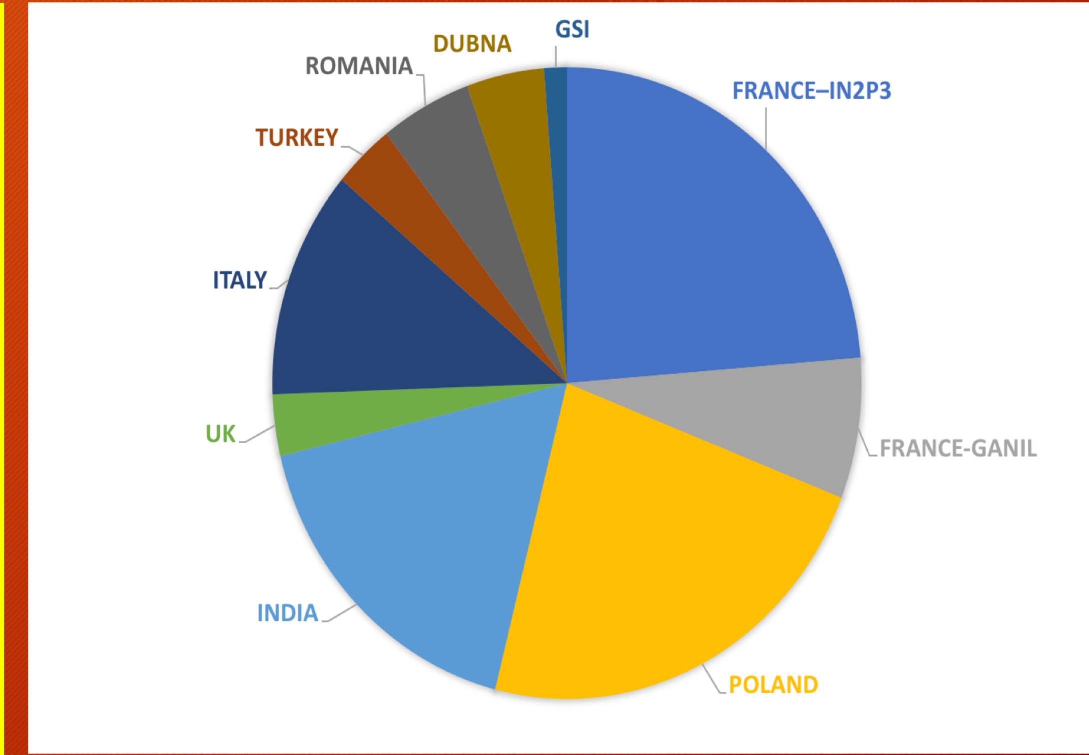
Presently PARIS collaboration has 4 clusters:
3 LaBr3_NaI clusters (produced by Saint Gobain)
1 CeBr3_NaI cluster (produced by Scionix)
So the goal of the original MoU on PARIS Demonstrator was achieved

Recently PSC decided to extend the <u>PARIS Demonstrator MoU</u> until <u>2020</u> with the goal to reach <u>at least 8 clusters (33% of 4π)</u> (process of signing is ongoing)
Total cost: ≈1.8 M€

<u>New partners:</u>
JINR Dubna and GSI



PARIS @ HISPEC/DESPEC ?

Total Absorbtion Spectroscopy

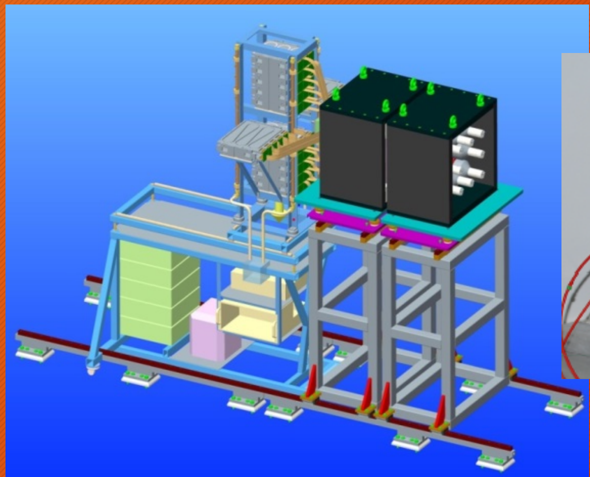
Spectroscopy of very exotic nuclei

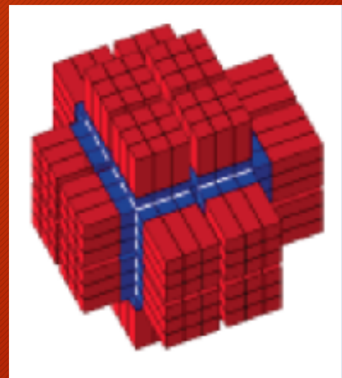
Complete β-decay level schemes, $\gamma\gamma$-coincidences

K-Isomer spectroscopy

PARIS

- Increased efficiency
- Better energy resolution
- Fast timing
- Complementing DTAS





Courtesy of Juergen Gerl

DEGAS Decay Spectroscopy

High-resolution decay spectroscopy of exotic nuclei

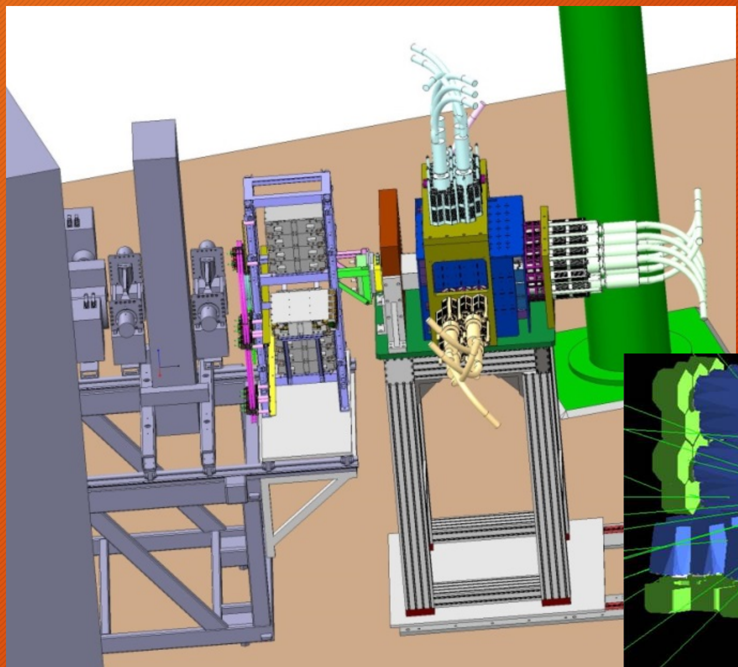
Detailed level schemes, $\gamma\gamma$-coincidences

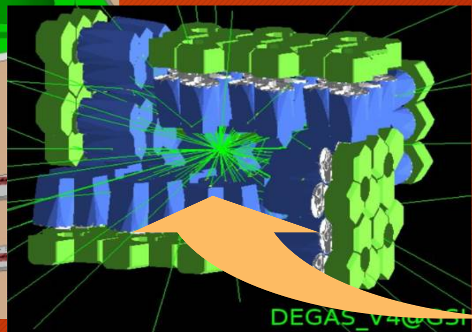
PDR with β-decay

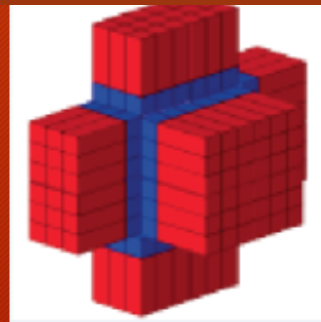
Lifetimes

PARIS

- Increased efficiency
- High efficiency at high energy
- Sufficient energy resolution
- Fast timing
- Complementing Ge





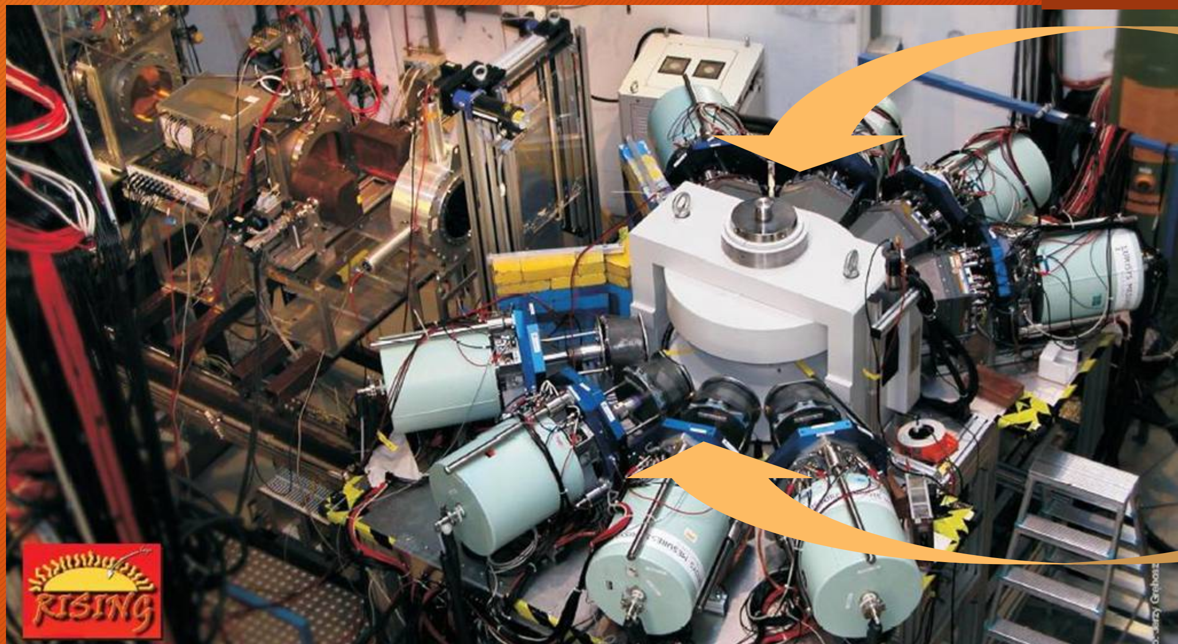


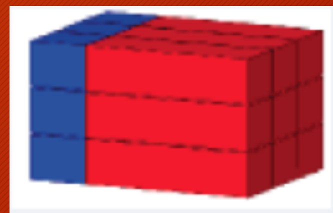
Courtesy of Juergen Gerl

gSPEC Nuclear Moments

PARIS

- Increased efficiency
- Sufficient energy resolution
- Complementing Ge





DESPEC Nuclear Moments

g-factors of exotic nuclei

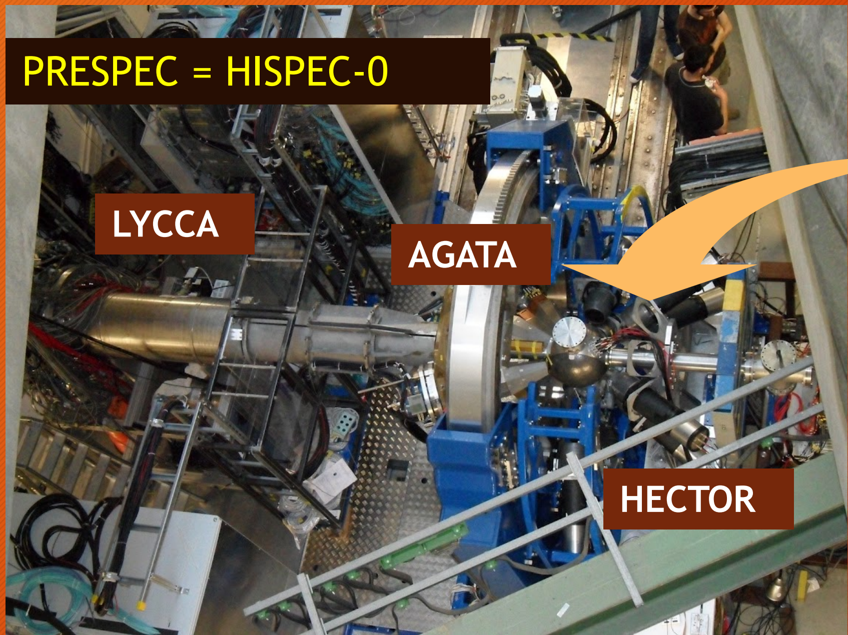
Courtesy of Juergen Gerl

Dipole response of exotic nuclei and/or isomeric states

HISPEC In-Flight Spectroscopy at relativistic energies

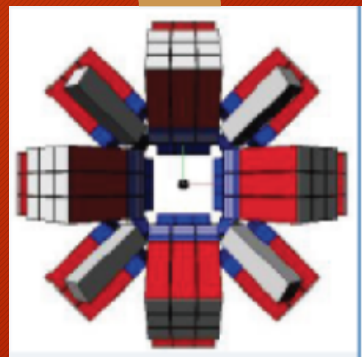
PDR and GDR of exotic nuclei, fine structure,

PDR and GDR build on isomeric beams



PARIS

- Increased efficiency
- Better energy resolution
- Better Doppler correction



Courtesy of Juergen Gerl

Summary

PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

paris.ifj.edu.pl

- The concepts of PARIS phoswich (LaBr3+NaI, CeBr3+NaI) and PARIS cluster of 9 phoswiches, were proved to work according to expectations based on simulations.
- First PARIS experiments (1 or 2 clusters) were done in 3 ENSAR2 TNA facilities: GANIL, IPN Orsay and CCB at IFJ PAN Krakow. More experiments are coming.
- PARIS, either standalone or coupled to other detectors, performs well.
- At present PARIS possesses 4 clusters.
- Extension of the MoU till 2020 (at least 8 clusters) is in the final process of preparation. GSI (HISPEC/DESPEC) is part of the new MoU.
- There are many Physics Opportunities at HISPEC/DESPEC with PARIS - possible use of PARIS in HISPEC/DESPEC experiments is under discussions.

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- Saint Gobain and Scionic
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Zakopane Conference on Nuclear Physics

"Extremes of the Nuclear Landscape"

Zakopane, Poland, 26.08.2018 - 02.09.2018

http://zakopane2018.ifj.edu.pl

Topical Sessions and Conveners:

- Interdisciplinary Applications on Nuclear Physics , N.Alamanos
- Collective Modes in Nuclei , A.Maj
- Forefront Topics in Nuclear Theory, W.Nazarewicz
- New Instrumentation and Techniques in Nuclear Spectroscopy, J.Nyberg
- Nuclear Rotation and High Spins, J.Sharpey-Schafer
- New Facilities for Nuclear Physics Research, S.Gales
- Heavy nuclei – production mechanism and properties, K.Siwek-Wilczynska
- Nuclear Isomerism , P.Walker
- Latest achievements in nuclear structure research

Chair:
Piotr Bednarczyk

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