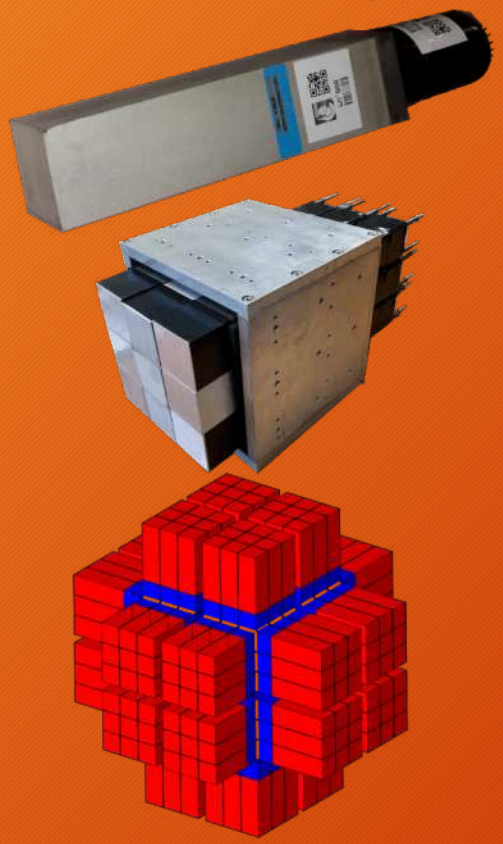
PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS



PARIS calorimeter – idea, status and first experiments

Adam Maj

IFJ PAN Kraków

for the PARIS Collaboration

SEMINARIUM
FIZYKI JĄDRA ATOMOWEGO UW
21.05.2020 r. (Thursday) at 10:15, on-line

paris.ifj.edu.pl

adam.maj@ifj.edu.pl

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

Spiral2

GANIL
SAC open session
October 19th, 2006

Letter of Intent for SPIRAL 2

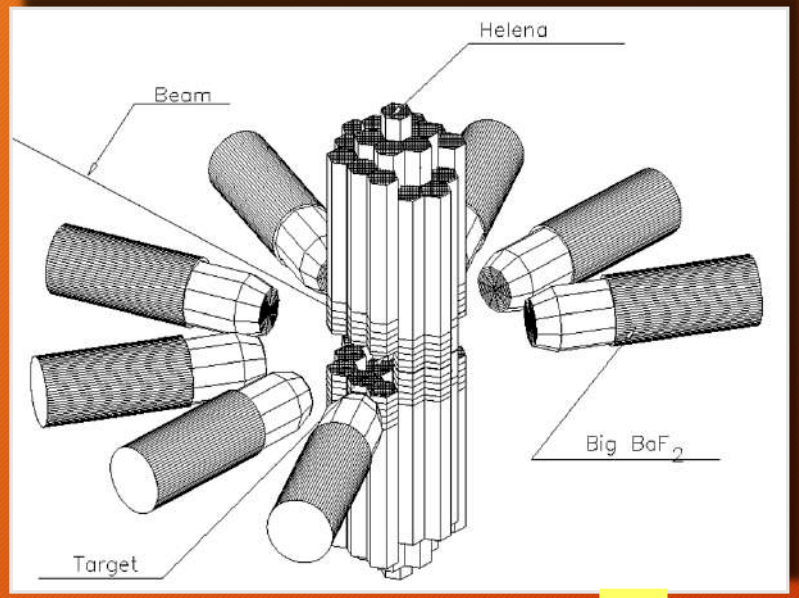
Title: High-energy γ-rays as a probe of hot nuclei and reaction mechanisms

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

Origin of the name *PARIS*



HECTOR+HELENA array,
based on BaF2 crystals
Succesful series of experiments in the **Milano-Krakow** – (Copenhagen-Legnaro-EUROBALL-RISING) collaboration

PARIS

PARIS PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

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, 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 (+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

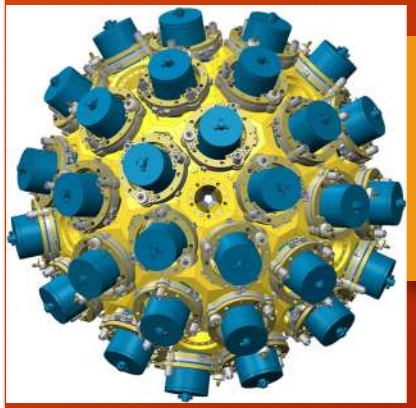
Eur. Phys. J. A (2020) 56:137
https://doi.org/10.1140/epja/s10050-020-00132-w

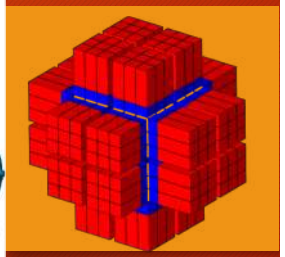
THE EUROPEAN PHYSICAL JOURNAL A

Review

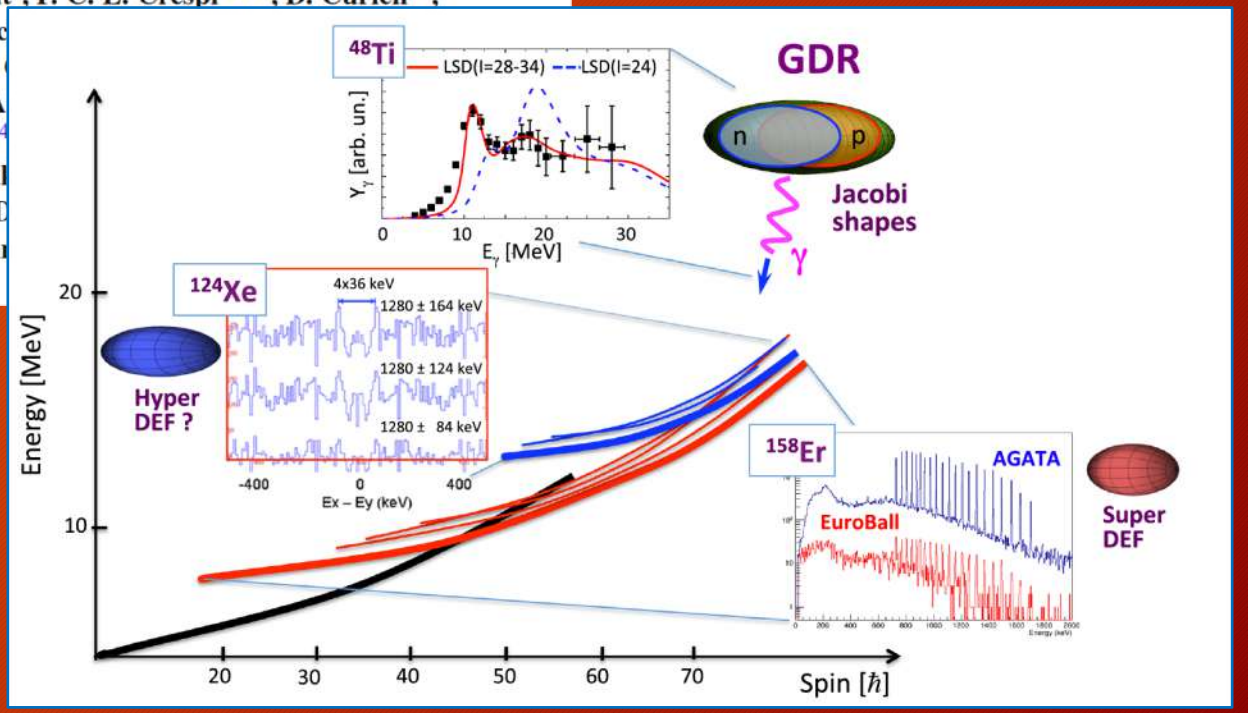
Physics opportunities with the Advanced Gamma Tracking Array: AGATA

W. Korten[9,a], A. Atac[30,35], D. Beaumel[23], P. Bednarczyk[14], M. A. Bentley[34], G. Benzoni[21], A. Boston[17], A. Bracco[20,21], J. Cederkäll[18], B. Cederwall[30], M. Ciemała[14], E. Clément[1], F. C. L. Crespi[20,21], D. Curien[31], G. de Angelis[15], F. Didierjean[31], D. T. Doherty[10], Zs. Dombradi[6], G. Duc
B. Fernandez-Dominguez[27], B. Fornal[14], A. Gadea[33], L. P. Gaffney[17], J.
M. Górska[4], P. T. Greenlees[12], H. Hess[13], D. G. Jenkins[34], P. R. John[5], A
M. Labiche[3], S. Leoni[20,21], J. Ljungvall[22], A. Lopez-Martens[22], A. Maj[14]
A. Nannini[8], D. Napoli[15], P. J. Nolan[17], J. Nyberg[32], A. Obertelli[5], J. Pal
B. Quintana[26], R. Raabe[16], G. Rainovski[28], F. Recchia[24,25], P. Reiter[13], D
D. Tonev[29], A. Tumino[2,7], J. J. Valiente-Dobón[15], O. Wieland[21], K. Wimm
the AGATA Collaboration





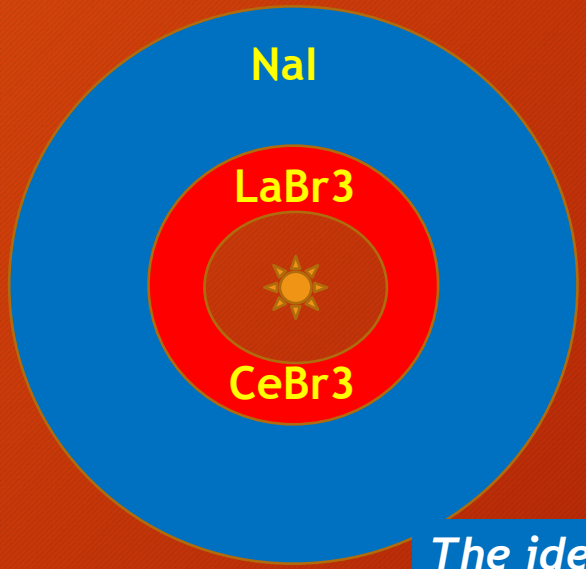
the AGATA collaboration has also access to a wide range of complementary detectors, most of which are also travelling detectors: charged-particle detectors for tagging (DIAMANT [26], EUCLIDES [27], MUSETT [28], TRACE [29]) and for spectroscopy (MUST2 [30], GRIT [31]), neutron detectors (NEDA [32], NWALL [33,34]), $LaBr_3(Ce)$ scintillators for fast-timing measurements (FATIMA [35]) or high-energy γ-ray spectrometers (PARIS [36]) and others.



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



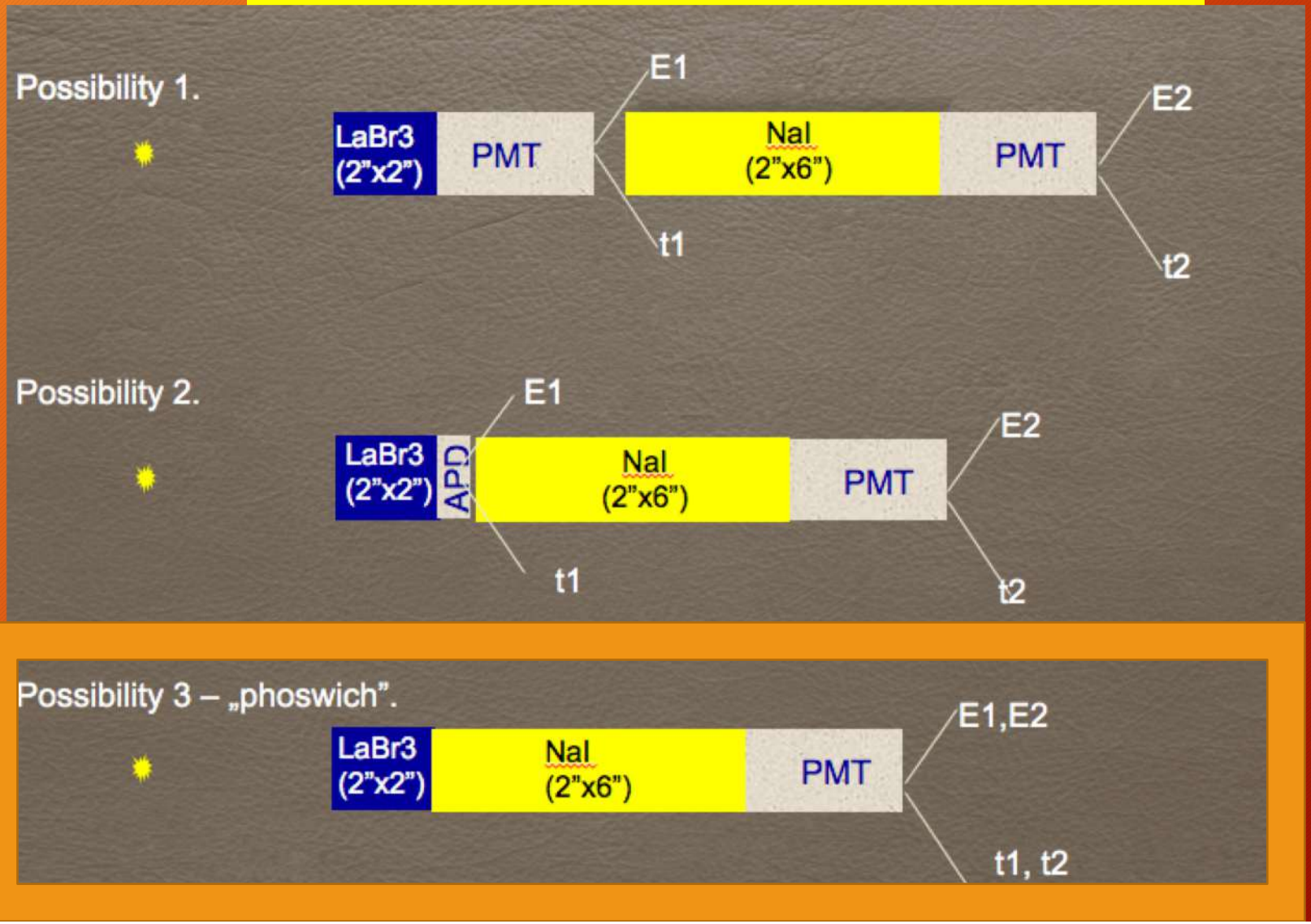
Inner sphere, highly granular, made of new crystals (LaBr3 or CeBr3), to be used as a gamma multiplicity filter, sum-energy detector (calorimeter), detector for the gamma-transition up 10 MeV with medium energy resolution, fast timing.

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

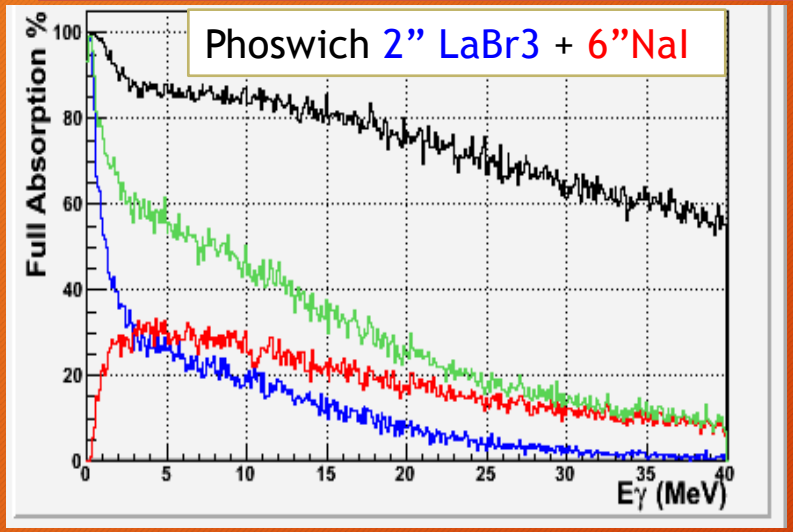
2-shell concept, in addition to being more economic, shall help to distinguish a high-energy photon from a cascade of low energy gamma transitions in fusion evaporation reactions

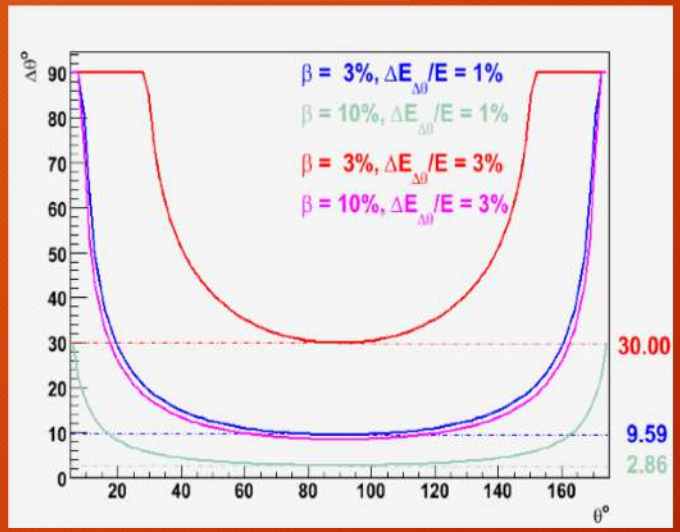
The idea od PARIS was proposed by the Krakow group and developped jointly by physicists from Poland, France, India, UK and Italy

3 POSSIBILITIES FOR A „GAMMA-TELESCOPE" ELEMENT



O. Stezowski, M. Ciemała, M. Labiche et al..





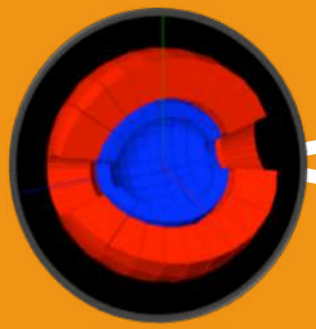
Extensive simulation studies have been performed to understand how γ-rays with energies from few keV up to 50 MeV are absorbed and recovered. Figure above is used for instance to determine the opening angle required to not spoil out the intrinsic LaBr3 resolution.
All the considerations drive the ***design of the basic element*** of PARIS as composed of

a phoswich 2"x2"x2" LaBr3 (or CeBr3) followed by 2"x2"x6" NaI.

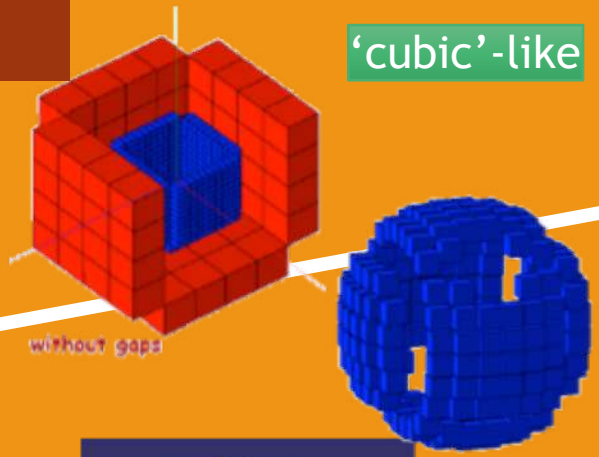
placed at a reasonable distance (ca. 20 cm) from the target position it gives a ***4π array composed of ca. 200 of elements*** for optimal characteristics in ***non-relativistic domain*** (β < 10%).

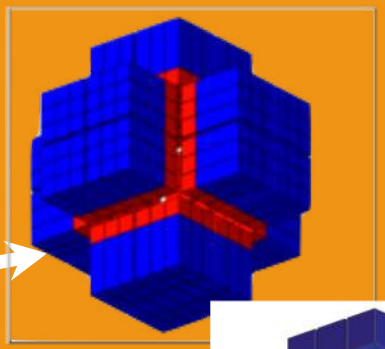
Several geometries studied

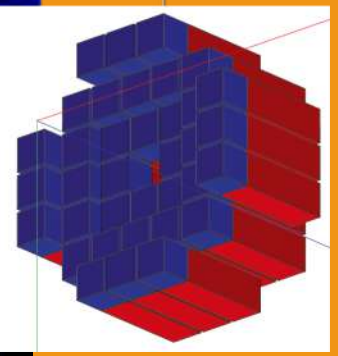
‘Ideal’ - spherical



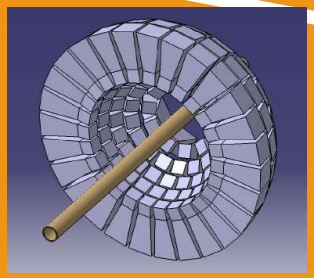
‘cubic’-like

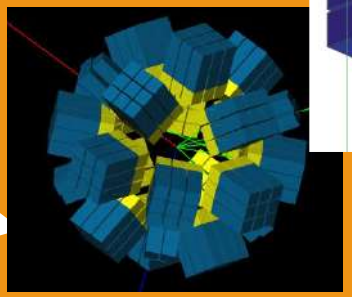


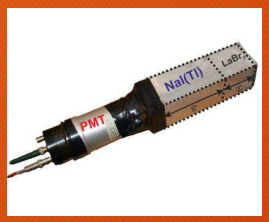


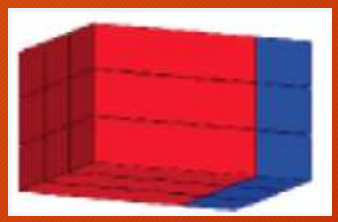


‘radial’-like



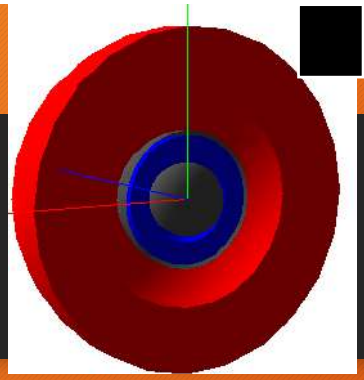


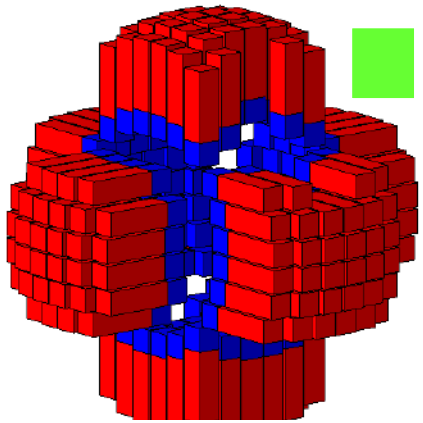


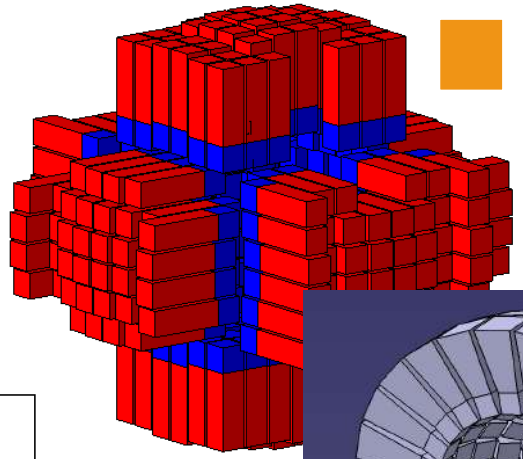


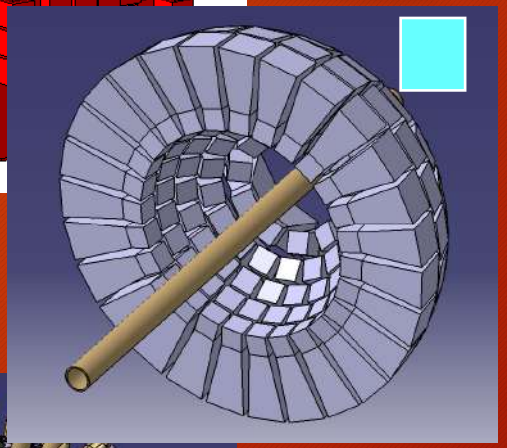
PARIS to be made of rectangular phoswiches
Arranged in clusters *(9 phoswiches each)*
This allows *cubic*, *wall* or *semi-spherical* geometry with 24 clusters (216 phoswiches)

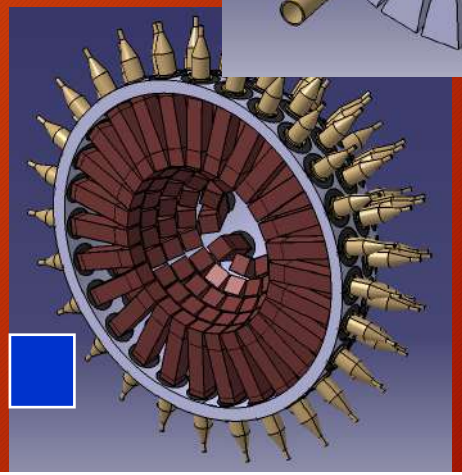
Cubic vs. Radial geometry

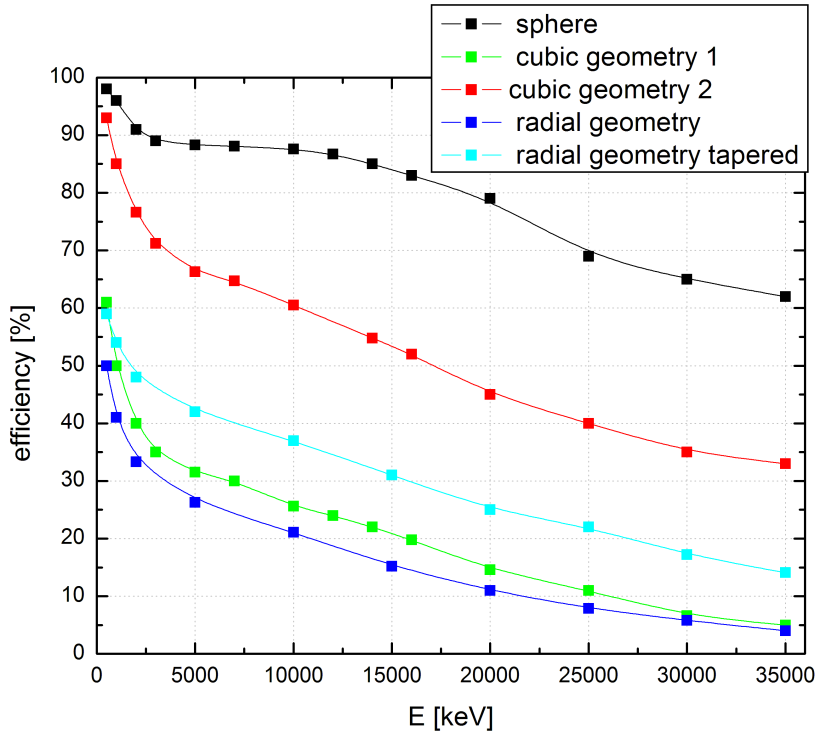




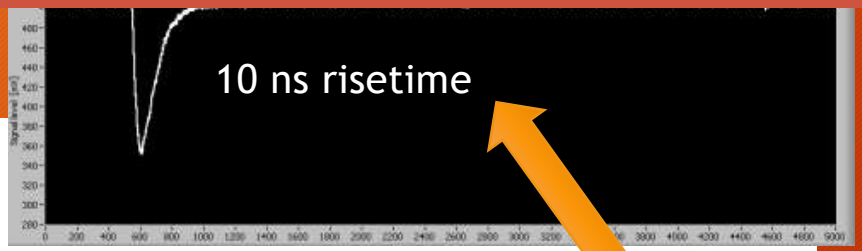


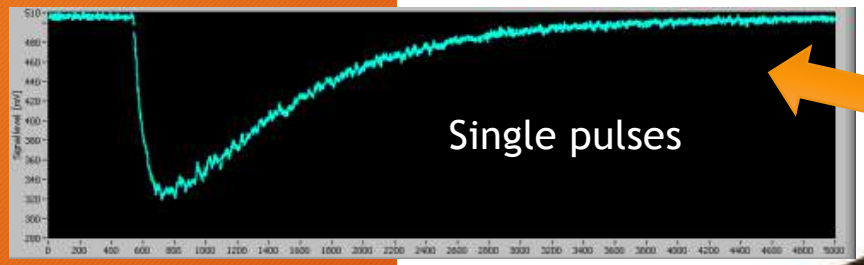


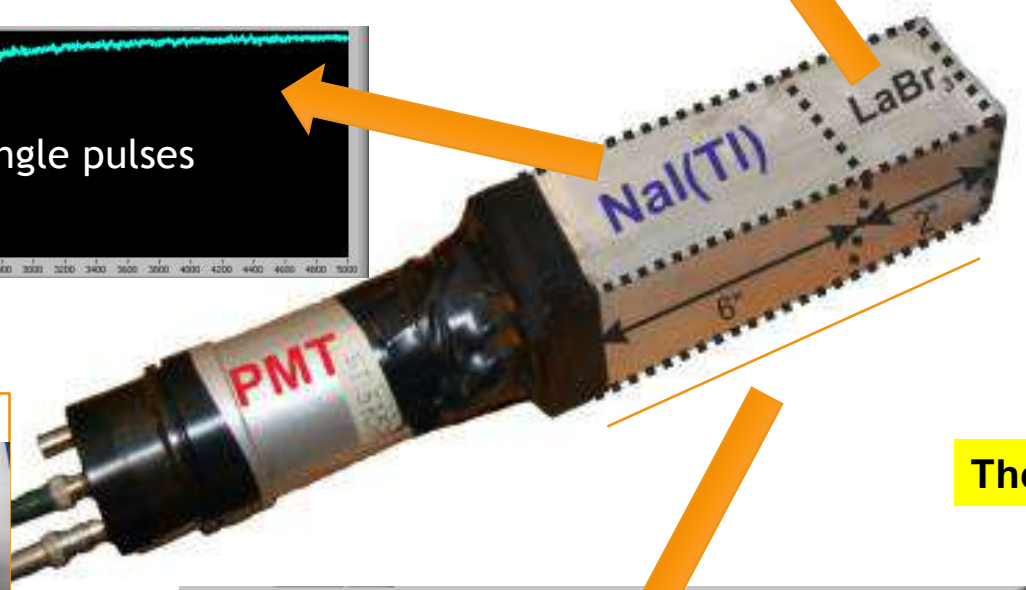


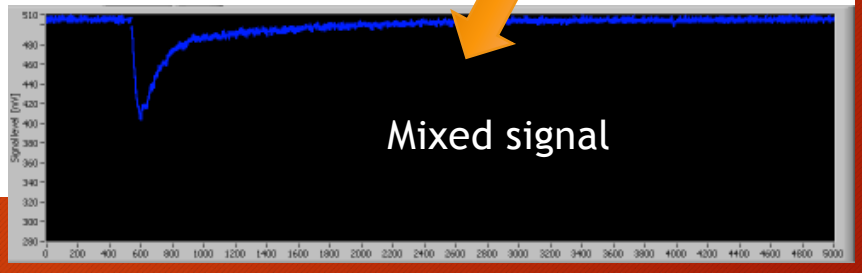


Phoswich tests



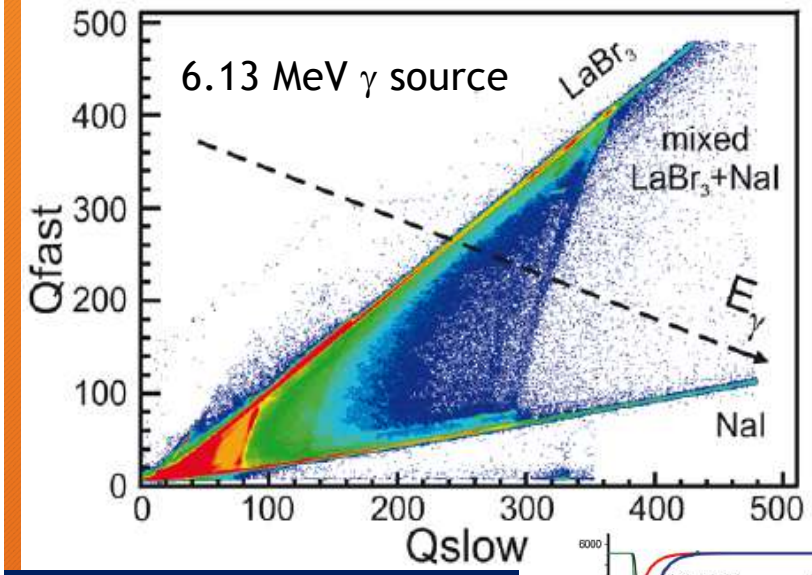


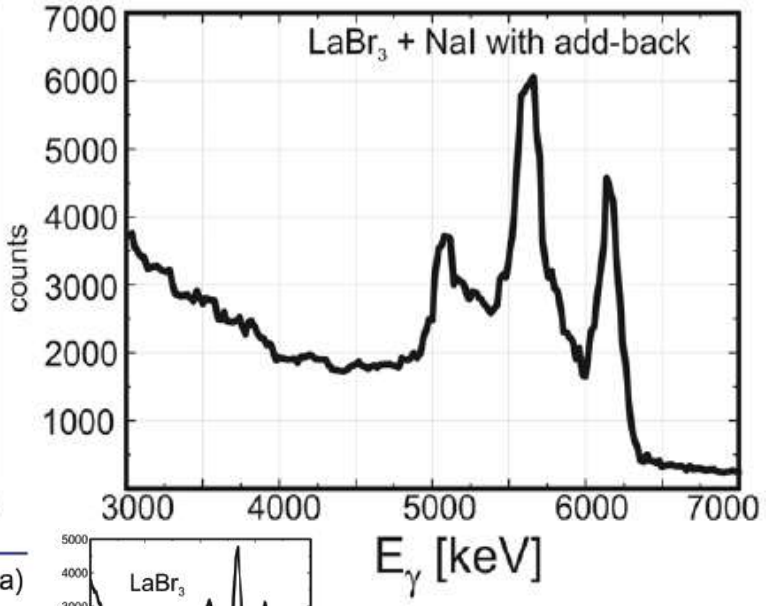




LaBr3 or CeBr3

The PARIS PHOSWICH at work

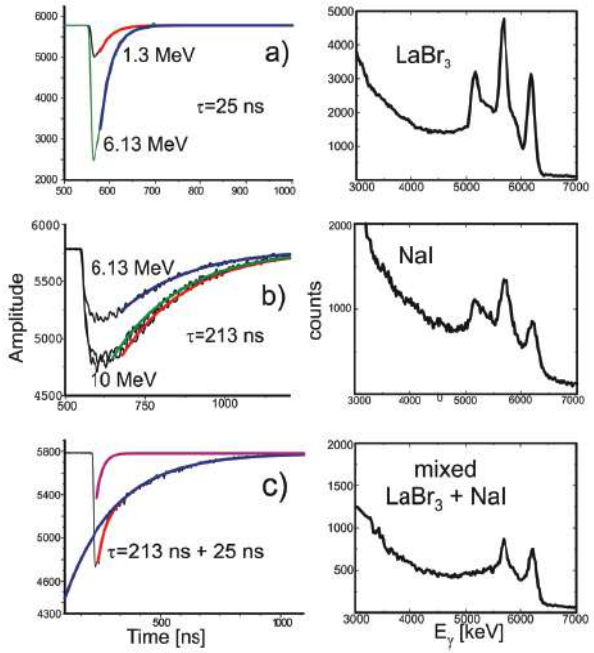




A test measurement at IFJ PAN, Kraków (2011) with BafPro module from Milano

- Sources
- proton beam

Other tests: Strasbourg, Orsay, Milano, Warsaw, Mumbai



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

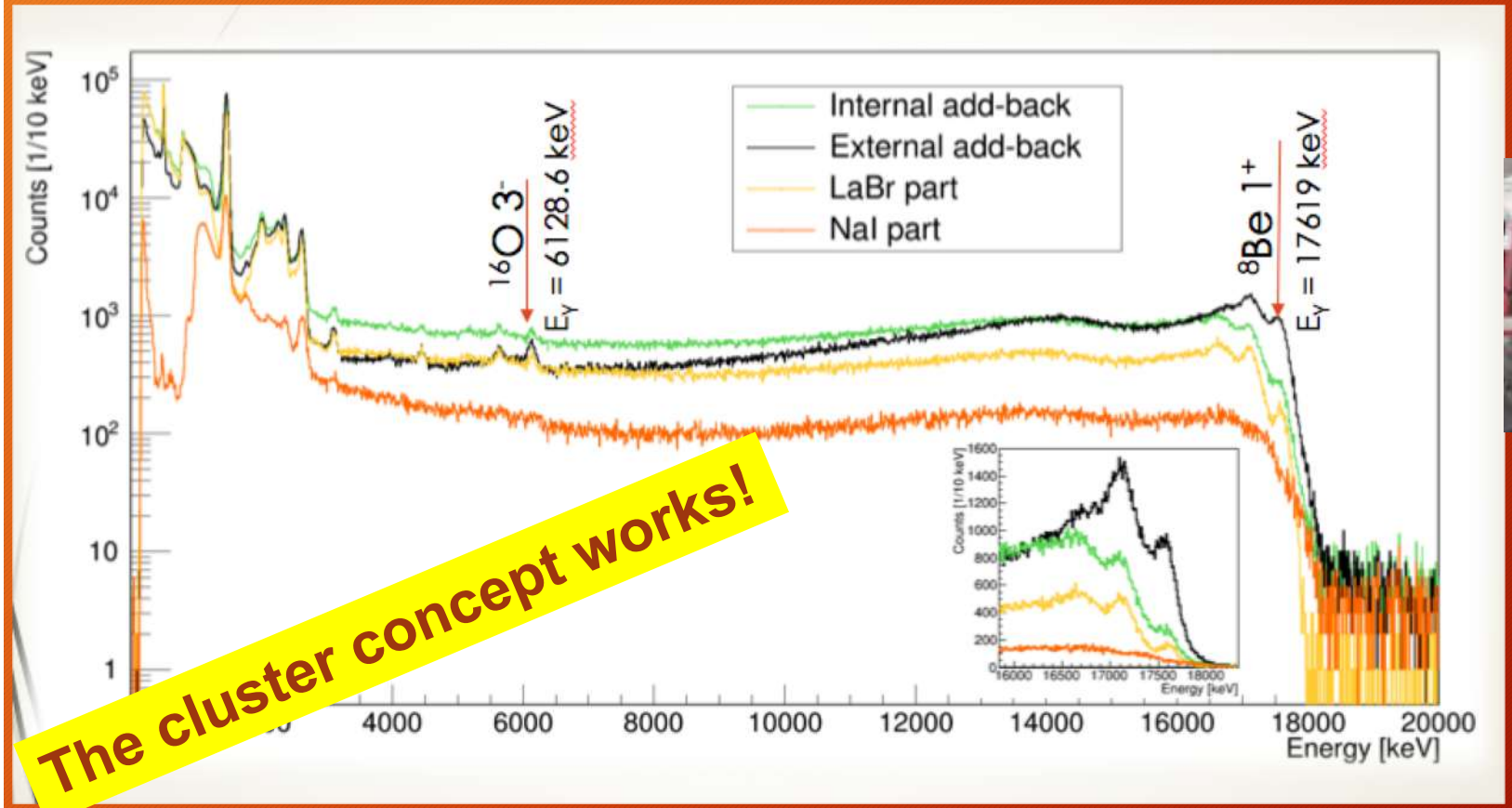
The phoswich concept works !

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



B. Wasilewska et al.,
paper in preparation

Status

PARIS Organization

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

PARIS Steering Committee

- IN2P3 France: F. Farget, O. Dorvaux
- GANIL France: M. Lewitowicz (chair)
- COPIN Poland: B. Fornal (dep. chair)
- India: V. Nanal
- Italy: A. Bracco
- Romania: M. Stanoiu
- UK: W. Catford
- Turkey: S. Erturk
- Dubna: Y. Pienionzkievich
- GSI: J. Gerl

Working Groups and their Coordinators

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:

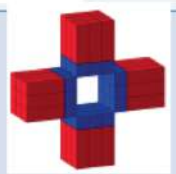
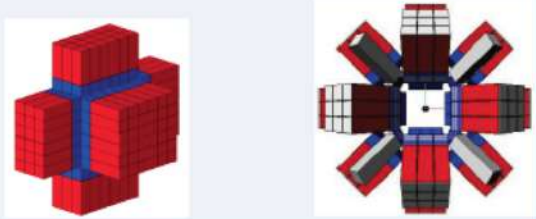
David Jenkins (University of York, UK) - chair and PARIS spokesman
Sudhee R. Banerjee (VECC Kolkata, India)
Franco Camera (INFN and University of Milano, Italy)
Wilton N. Catford (University of Surrey, UK)
Marco Cinausero (LNL Legnaro, Italy)
Sandrine Courtin (IPHC Strasbourg, France)
Zsolt Dombradi (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)

New chair (2018-2020)
Franco Camera (Milano)

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 consortiu 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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By November 2018 PARIS collaboration had 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 PARIS Demonstrator MoU until 2021

with the goal to reach at least 8 clusters (33% of 4π)

Total cost: ≈1.9 M€

New partners:

JINR Dubna and GSI

The extension of the MoU was already signed by all partners

Next steps

Presently PARIS collaboration possesses 6 clusters

New orders for 2020/21:
GANIL: 5 phoswiches
IN2P3: 6 phoswiches
Poland: 2 phoswiches
Italy: 6 phoswiches
India: 2 phoswiches

So we will have at least
8 clusters by the end of 2021

P. Bednarczyk, S. Brambilla, O. Dorvaux, A. Czermak, P. Napiorkowski

Options of electronics for PARIS

1) NUMEXO2 - a general-purpose digital card for GANIL based experiments (collaboration with EXOGAM2 and NEDA projects)

Implementation of the GTS interface into the NUMEXO2 VIRTEX 5 FPGA is currently being finalized.

A dedicated PARIS FADS front end electronics (mezzanine) is being designed. The digitizer will be integrated with the NUMEXO2 carrier board. Implementation of algorithms for on line PSA on the FPGA Virtex6LX platform is in progress.

2) **Analogue electronics** based on **Milano "PARIS_Pro"** cards (S. Brambilla et al.) + **AGAVA** interface (A. Czermak et al..):
Already tested in AGATA LNL and GSU camapigns!
Will be used for first experiments with AGATA. (integrated to the VAMOS branch)

3) Comercial digitizers (V1730, 16 channel, 500 MS/s, 12/14 bit CAEN digitizer)

Tested in Krakow, July 2015 - works very well (good time reolutin, time resolition - 0.7ns, low deadtime)

4) Occasionally other local digitizers (e.g. FASTER in IPN Orsay)

First experiments

First experimental results

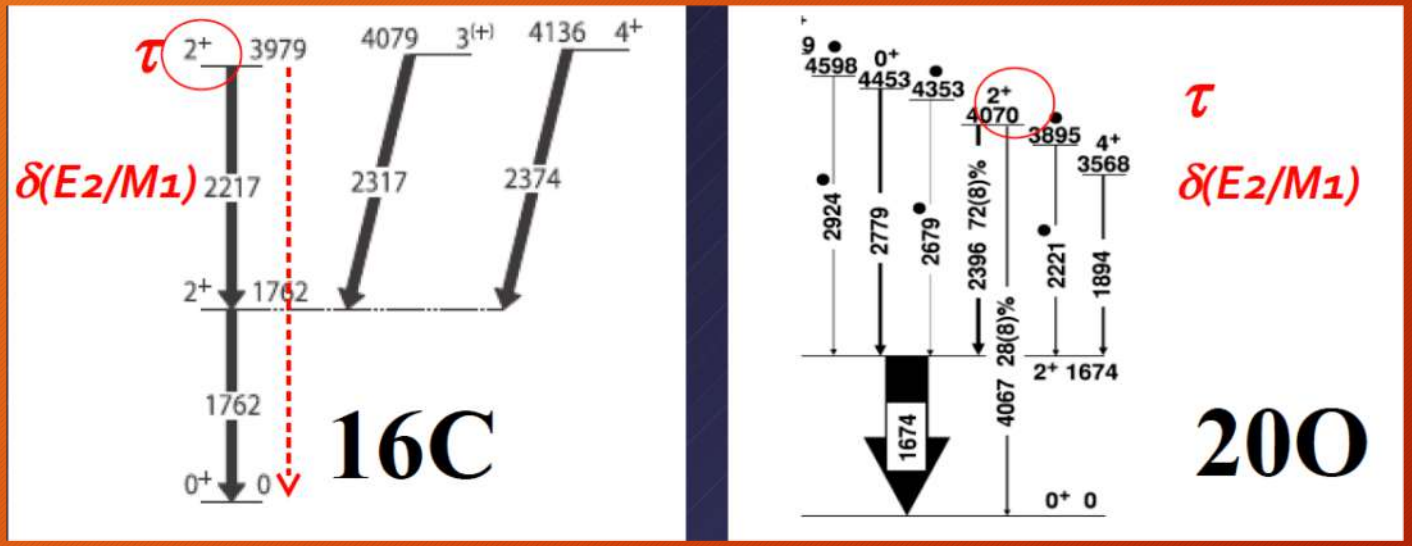
GANIL (France)

Performed:

- **S. Leoni, B. Fornal, M. Ciemala et al., "Lifetimes in A=18 region measured with PARIS", (PARIS: 2 clusters + 2 large LaBr3), AGATA, VAMOS, Plunger (July 2017)**

Main experimental goal

Measure second 2^+ lifetimes for ^{20}O and ^{16}C with use of Doppler shift method to verify the theory predictions (NN or NNN)



PARIS setup

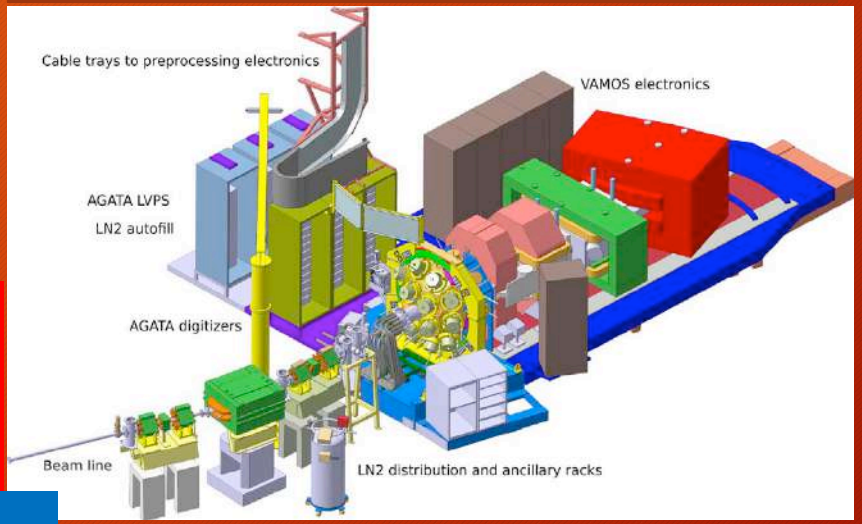
1 $LaBr_3$-NaI cluster (A) in magnetic shield
1 $CeBr_3$-NaI cluster (B) in magnetic shield
1 big $LaBr_3$ in magnetic shield
1 big $LaBr_3$ without magnet shield
All placed around 90 degree

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

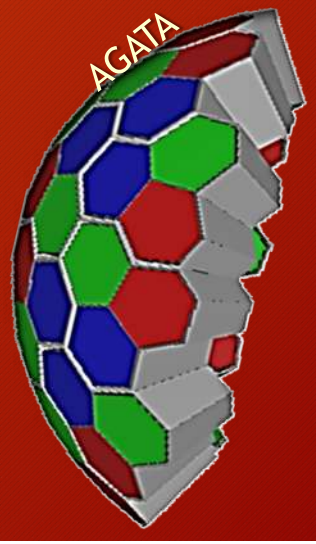
Reaction:
^{18}O 7.0 MeV/A beam on ^{181}Ta (4 μm thick)

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)



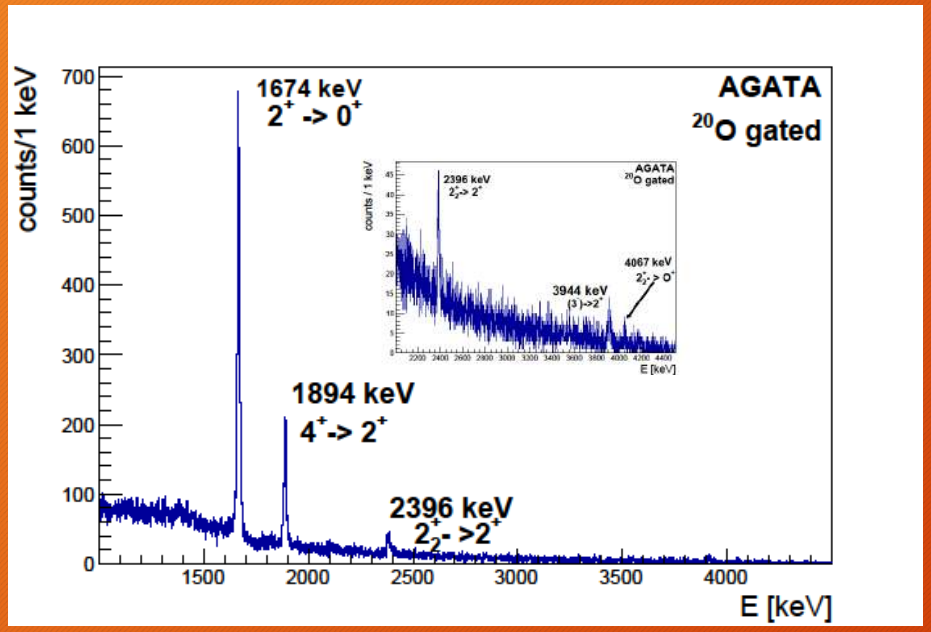
E. Clement et al. NIMA 885, 1-12 (2017)

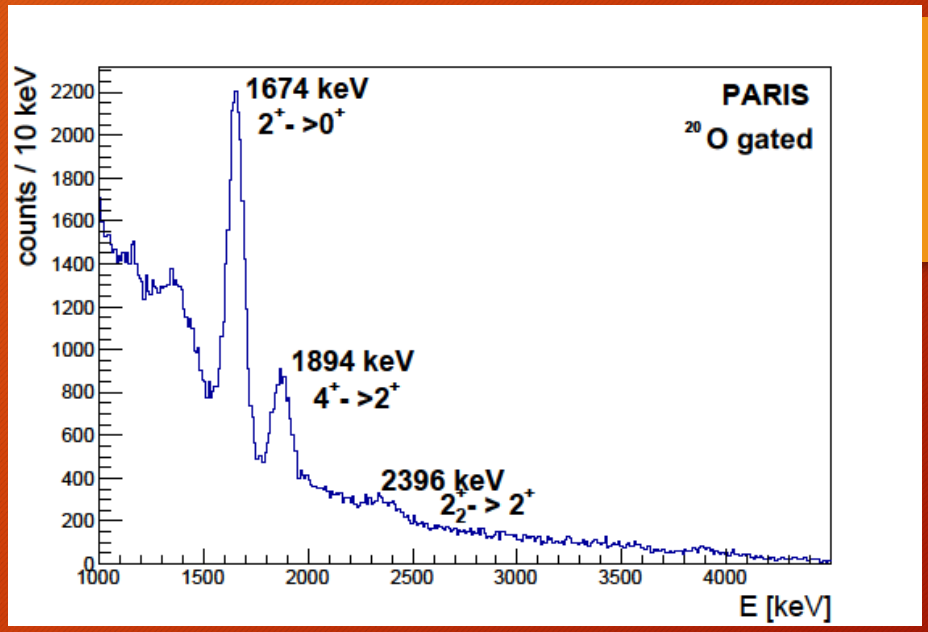
AGATA
32 detectors



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

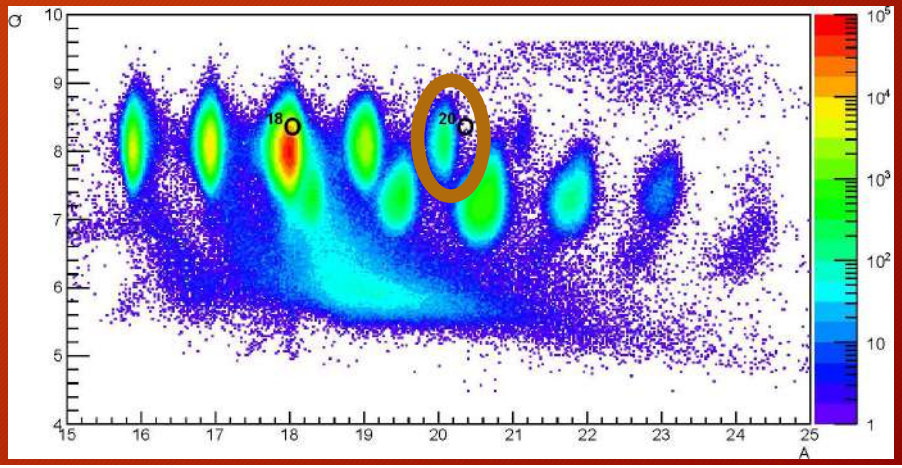
Courtesy of Michal Ciemala



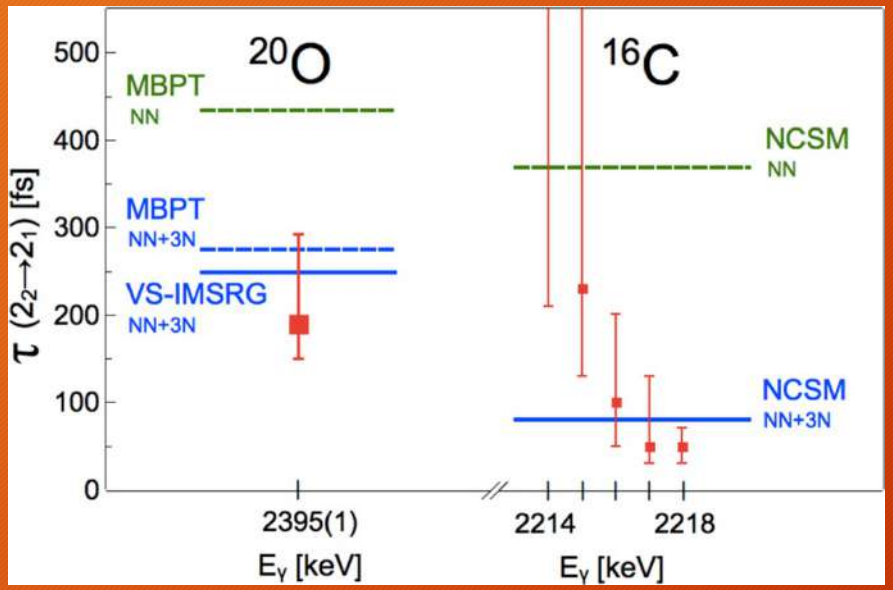


Gamma-rays measured by PARIS in coincidence with AGATA, will be used for determining gamma decay branching ratios for most populated C, N and O isotopes.

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



Results published:
M. Ciemała et al. Phys. Rev. C101, 021303(R) (2020)



The achieved results on transition probabilities agree well with predictions from MBPT and ab initio VS-IMSRG for ^{20}O and NCSM calculations for ^{16}C, showing that 3N interactions are needed to accurately describe electromagnetic observables in neutron-rich nuclei.

First experimental results

GANIL (France)

Performed:

• S. Leoni, B. Fornal, M. Ciemala et al., "Lifetimes in A=18 region measured with PARIS",
(PARIS: 2 clusters + 2 large LaBr3), AGATA, VAMOS, Plunger (July 2017)

Accepted, but not performed:

• P. Bednarczyk, A. Maj et al., "Investigation of a high spin structure in 44Ti via discrete and continuum γ-spectroscopy with AGATA, PARIS (4 clusters) and DIAMANT"

• B. Fornal, S. Leoni, M. Ciemala et al., „Gamma decay from near-threshold states in 14C: a probe of clusterization phenomena in open quantum systems" (AGATA , PARIS, NEDA, DIAMAND, DSSD)

Planned:

- R. Lica, O. Sorlin et al., "Study of deformed and spherical 2+ states via Coulomb excitation and first time measurement of PDR in 34Si" (LISE-PARIS-EXOGAM2)
- Ch. Schmidt, M. Lewitowicz et al., "PARIS for study of fission at VAMOS"

Under dicussion:

- *Coupling PARIS to ACTAR*
- *Coupling PARIS to FAZIA/INDRA*
- *PARIS in SHE studies*

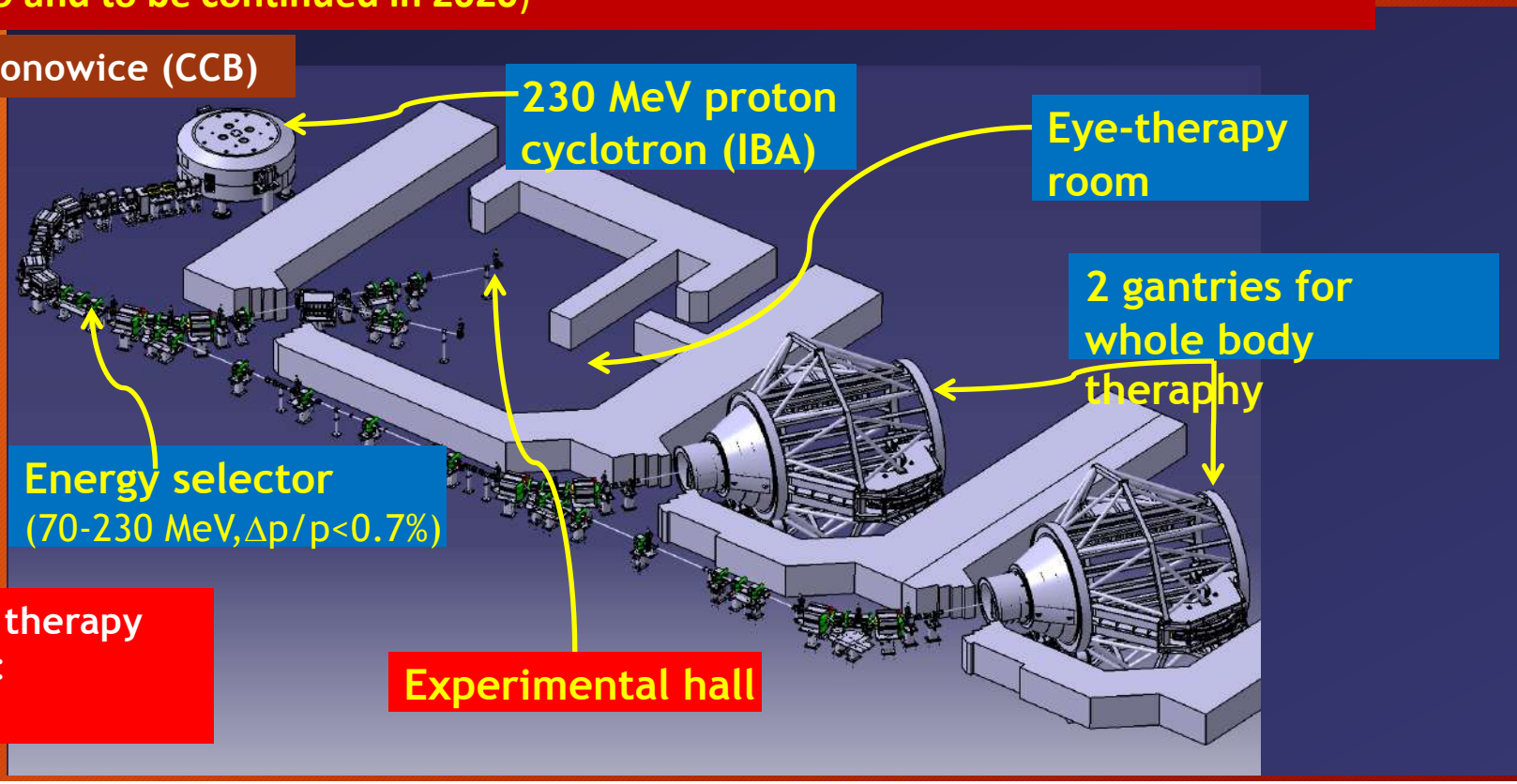
First experimental results

IFJ PAN Krakow (Poland)

Performed:

- **M. Kmiecik, F. Crespi, B. Wasilewska, A. Maj et al. „Studies of resonance states in nuclei using high-energy proton beam in p,p' reactions at forward angles with HECTOR, PARIS, KRATTA (2017, 2018, 2019 and to be continued in 2020)**

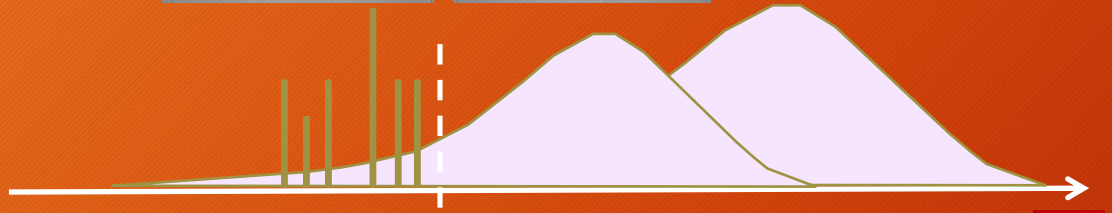
Cyclotron Center Bronowice (CCB)



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

Gamma decay from high-lying states and giant resonances excited via (p,p'γ)

high-lying states and giant resonances



„pygmy" states - PDR (Pygmy Dipole Resonance) - Soft Dipole Mode - low-lying dipole strength (low collectivity)

B_n

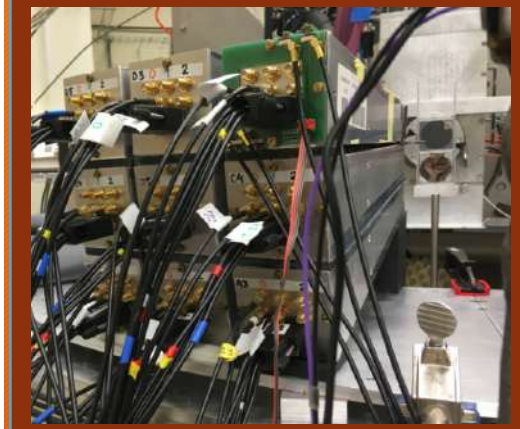
ISGQR (Isoscalar Giant Quadrupole Resonance)

IVGDR (Isovector Giant Dipole Resonance)

Setup

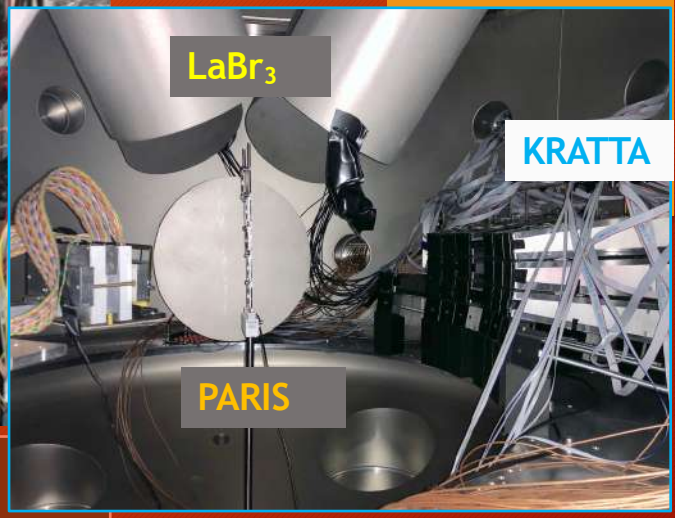
- KRATTA inside the chamber – in the vacuum
- gamma detectors outside
  mounted using holders / cylindrical pockets

4 plastic scintillators
for each KRATTA module
mounted at the front



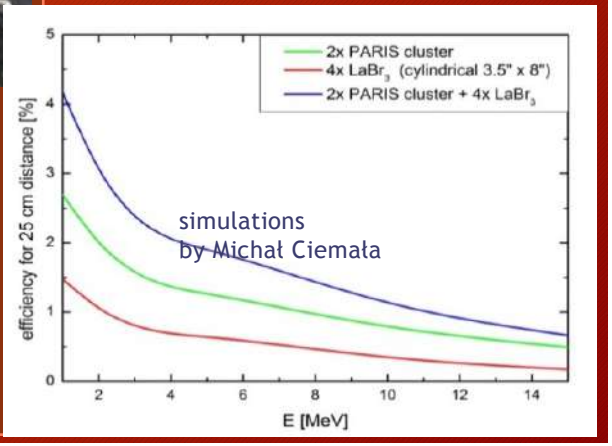
40 cm from the target

possible angles ~ 4° - 45° (with PARIS in the setup)
resolution ~ 2° (with plastic scintillators)



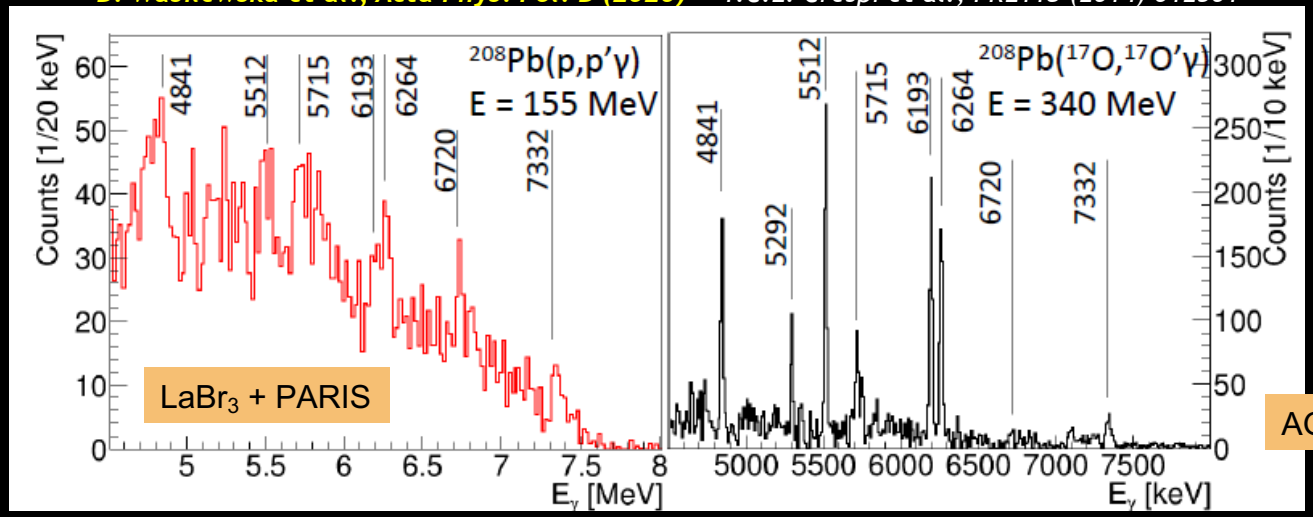
4 large volume **$LaBr_3$** detectors
and

2 **PARIS** clusters:
9 $LaBr_3$+NaI
9 $CeBr_3$+NaI
phoswiches



First results on the PDR in ^{208}Pb

B. Wasilewska et al., Acta Phys. Pol. B (2020) *F.C.L. Crespi et al., PRL113 (2014) 012501*



- similar transitions
- different intensities

First experimental results

IFJ PAN Krakow (Poland)

Performed:

- **M. Kmiecik, F. Crespi, B. Wasilewska et al. „Studies of resonance states in nuclei using high-energy proton beam in p,p' reactions at forward angles with HECTOR, PARIS, KRATTA (2017, 2018, 2019 and to be continued in 2020)**

Accepted and ongoing:

- S. Leoni, B. Fornal, N. Cieplicka et al., „Study of M4 resonance decay in 13C"

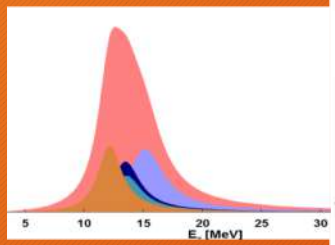
- A. Bracco, B. Fornal „Investigations of (p,2p) reactions in order to identify deep single-particle proton-hole states": HECTOR, PARIS, KRATTA
- Ch. Schmidt, D. Mancusi, B. Kamys et al., „Investigation of proton induced spallation with HECTOR, PARIS, KRATTA"

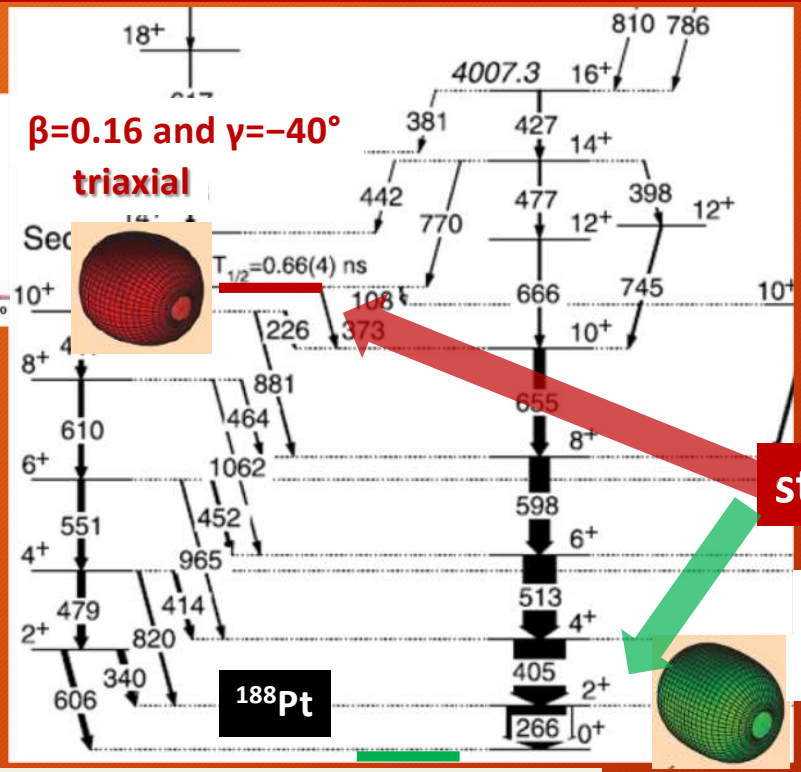
First experimental results

ALTO IPN Orsay (France)

Performed: 82-90 MeV ^{18}O + $^{174}Yb \rightarrow {}^{192}Pt$ ($E^* = 50$-60 MeV, $L_{max} = 20$ -$25\ \hbar$)

- **M. Kmiecik, F. Crespi, J. Wilson et al., „Feeding of low-energy structures in 188Pt of different deformations by the GDR decay: the nuBall array coupled to PARIS" (June 2018)**

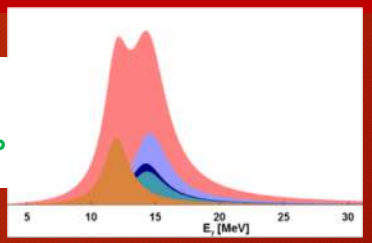




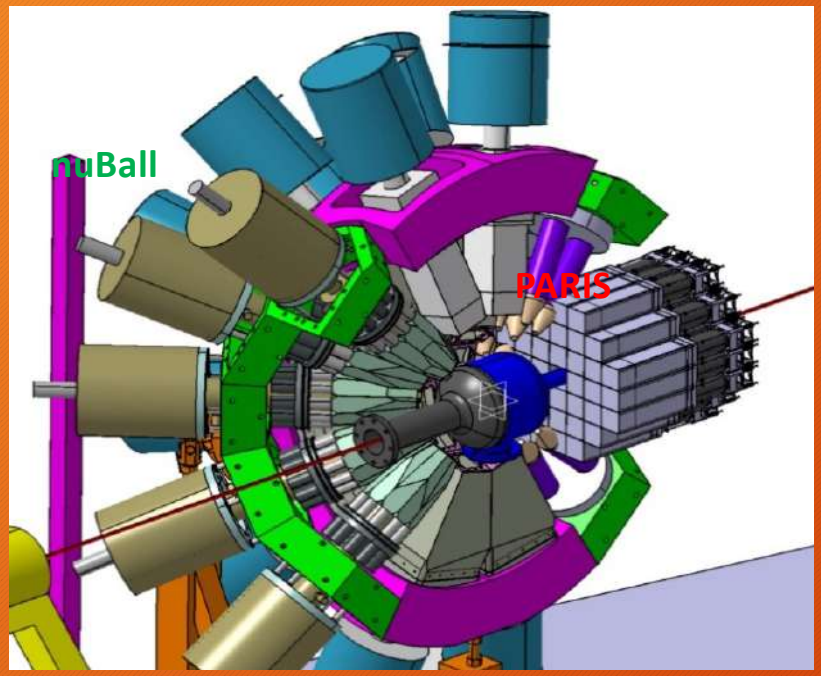
Goal:
Study links between GDR emission and isomeric states

states of different deformations

near prolate
β =0.18and γ=−6°



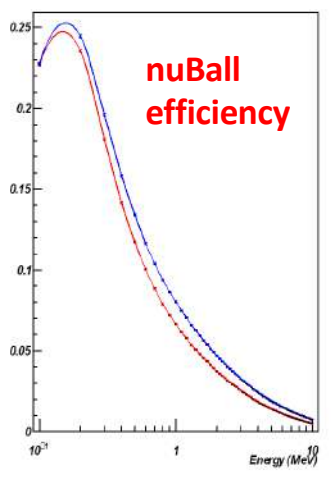
S. Mukhopadhyay et al., Phys. Lett. B 739, 462 (2014)

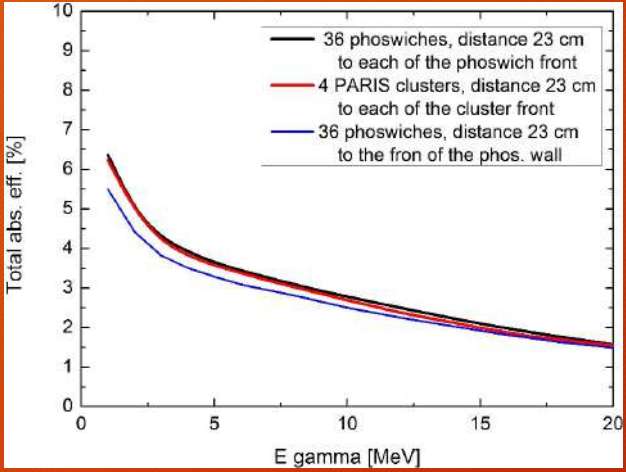


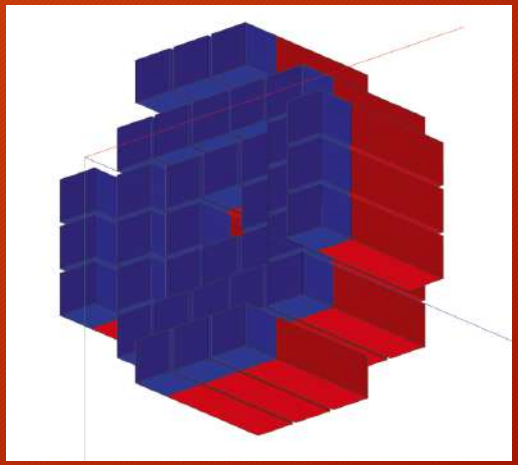
Experimental setup

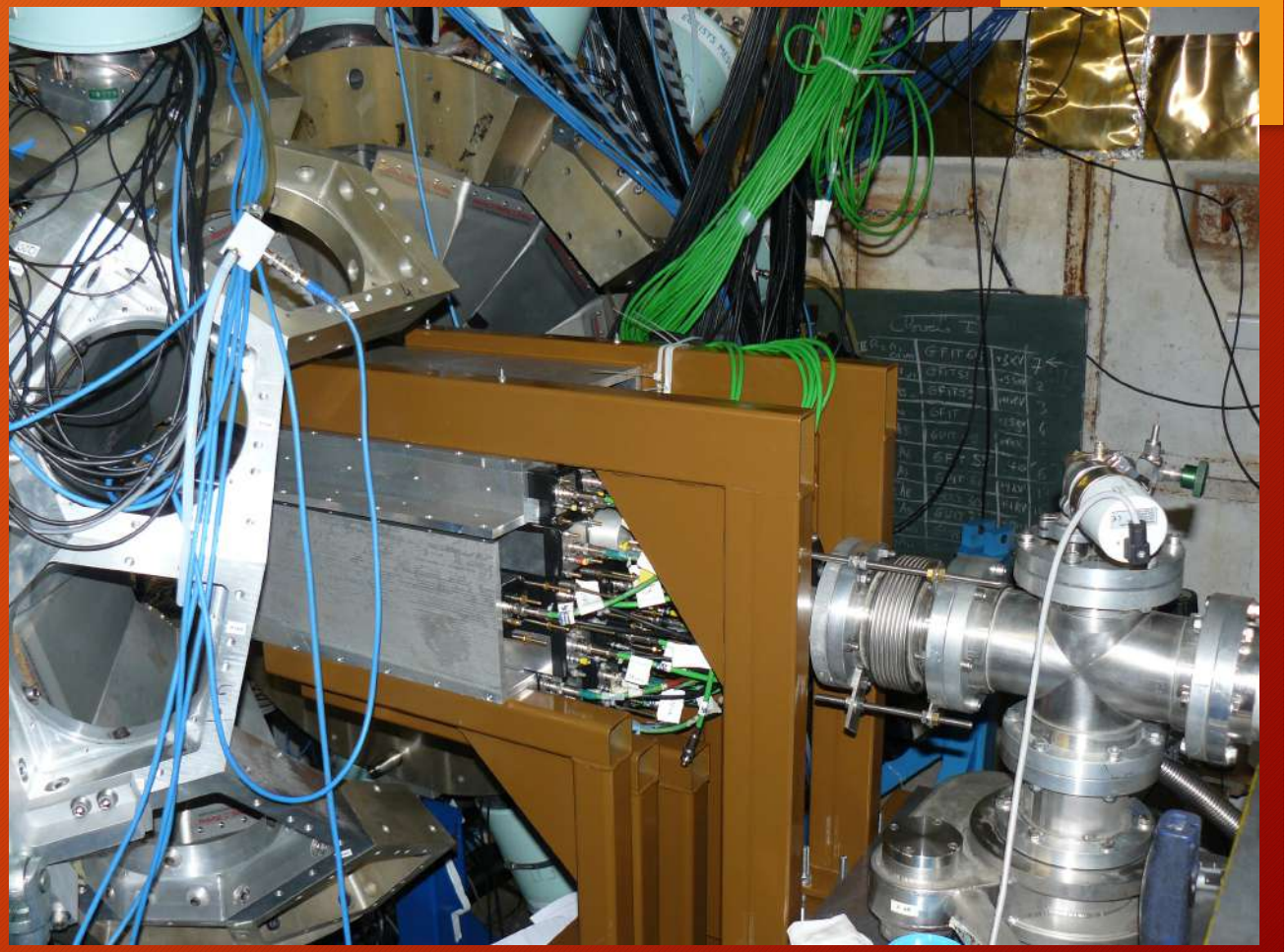
- ***nuBall*** (24 clover HPGe detectors, 10 coaxial Ge detectors)
- ***4 PARIS clusters*** (34 phoswich $LaBr_3/CaBr_3$+NaI detectors - „wall" configuration at backward angles at 23 cm

- *high energy resolution*
- *very good efficiency*



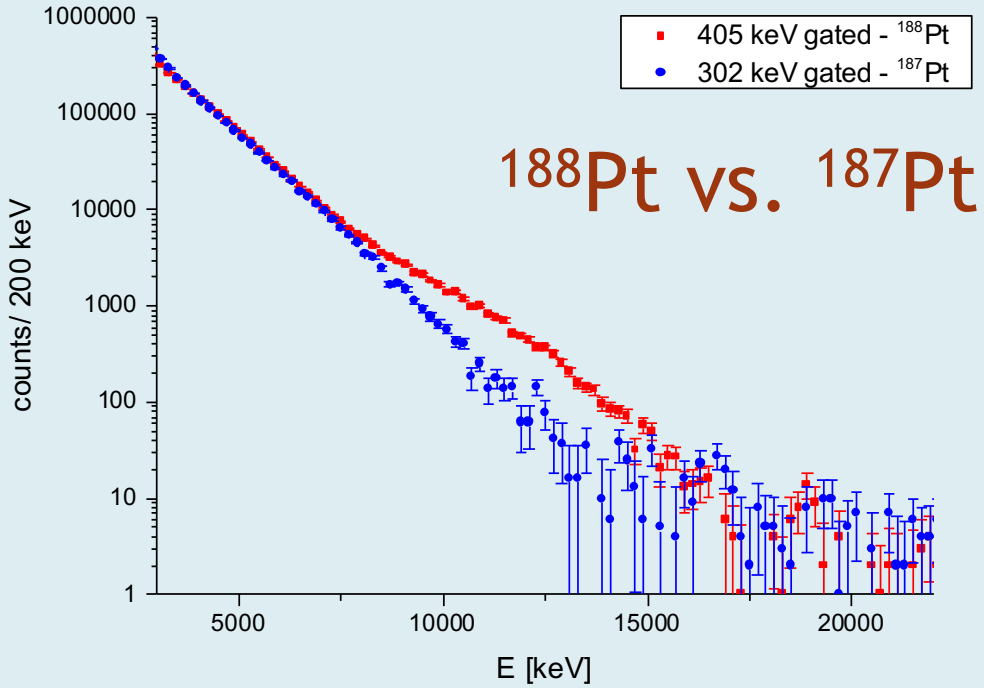


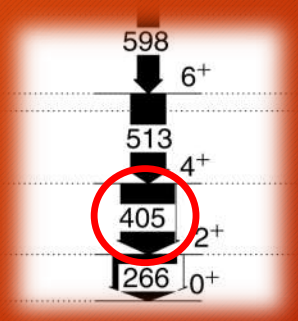


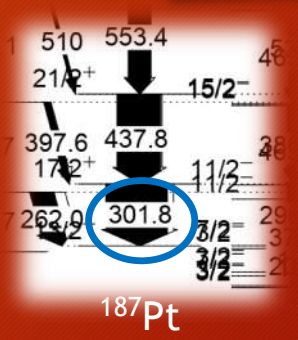


Preliminary results

M. Ciemała, M. Kmiecik, A. Maj, J. Wilson, F. Crespi et al., analysis in progress







Gating on transitions

a) in ^{188}Pt - GDR is visible

b) In 187Pt - no GDR (no avaialable phase space)

First experimental results

ALTO IPN Orsay (France)

Performed:

- I. Matea, J. Wilson, M. Ciemala et al. „PARIS cluster response to fast neutrons”
- E. Kozulin, I. Harca, E. Vardaci et al. “Prompt γ-rays as a probe of nuclear dynamics” (2017) *(paper just published)*
- M. Lebois, Q. Liqiang et al. “Prompt gamma and neutron emission for 238U fast neutron induced fission as a function of incident neutron energy” (2017)
- **M. Kmiecik, F. Crespi, J. Wilson et al., „Feeding of low-energy structures in 188Pt of different deformations by the GDR decay: the nuBall array coupled to PARIS” (June 2018)**

- I. Matea et al., „PDR studies in very neutron rich nuclei around N=50 shell closure through beta-decay” (2019)

Accepted:

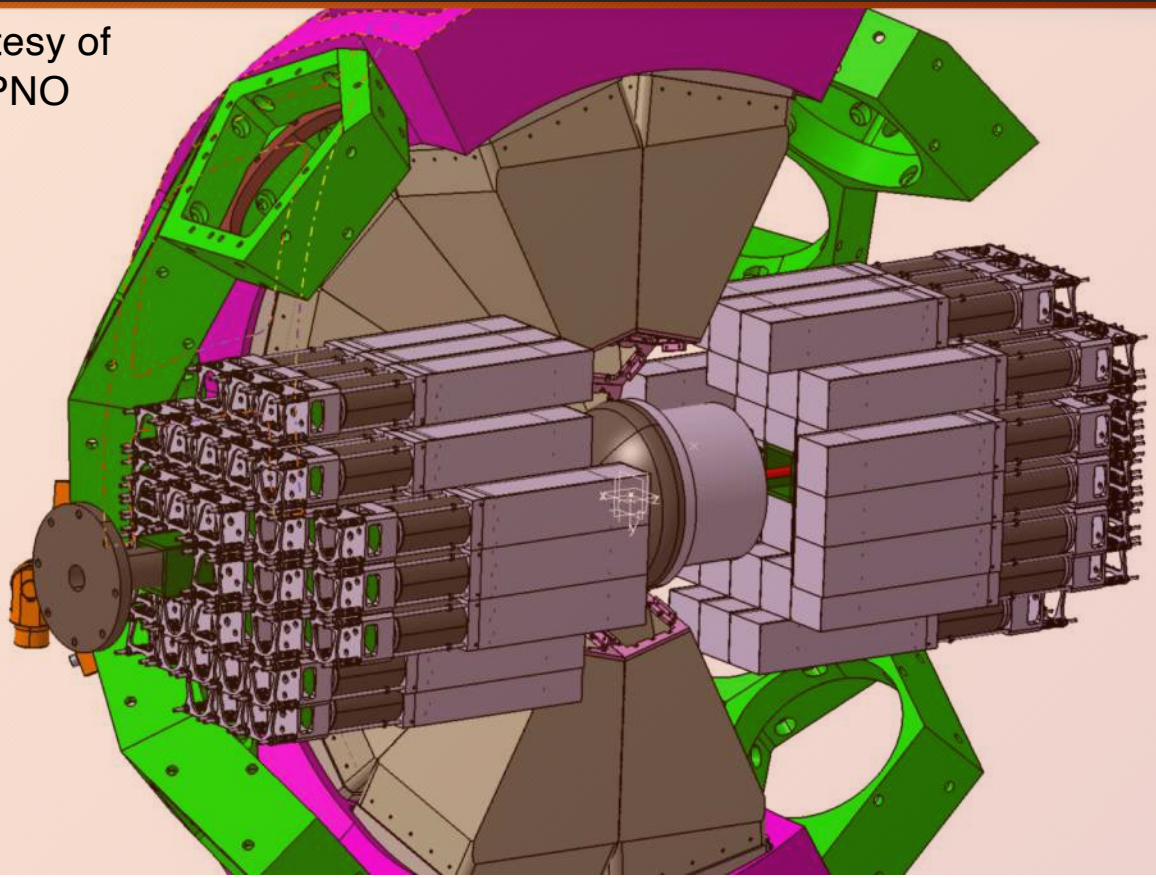
- P.J. Napiorkowski et al., „Coulomb excitation of super-deformed band in 40Ca” (2019)
- M. Babo, A. Gottardo et al., “81Zn ground-state spin determination from pandemonium free beta-delayed spectroscopy of 81Ga” (2019)
- A. Oberstedt, “Measurement of prompt gamma ray spectra from the reaction 233U(n,f)” (2019)

Perspectives

Perspectives: IPN Orsay (2021)

nuBall2 campaign: possibility to couple 72 PARIS detectors

Drawings: courtesy of
C. Legalliard, IPNO



Perspectives: LNL Legnaro

Laboratori Nazionali di Legnaro

AGATA@LNL (2022?)

Preliminary list of LoIs 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 17O ions at 20 MeV/A (F. Crespi et al.)
- Onset of collectivization/clusterization in Oxygen neutron-nuclei (S. Leoni, B. Fornal et al.)

ITALY

- 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 et al.)
- Study on single-particle structure of pygmy dipole resonance (M. Krzysiek et al.)
- Investigation of a high spin structure in the vicinity of 44Ti via discrete and continuum γ-spectroscopy with AGATA+EUCLIDES+RFD and PARIS detectors (P. Bednarczyk et al.)

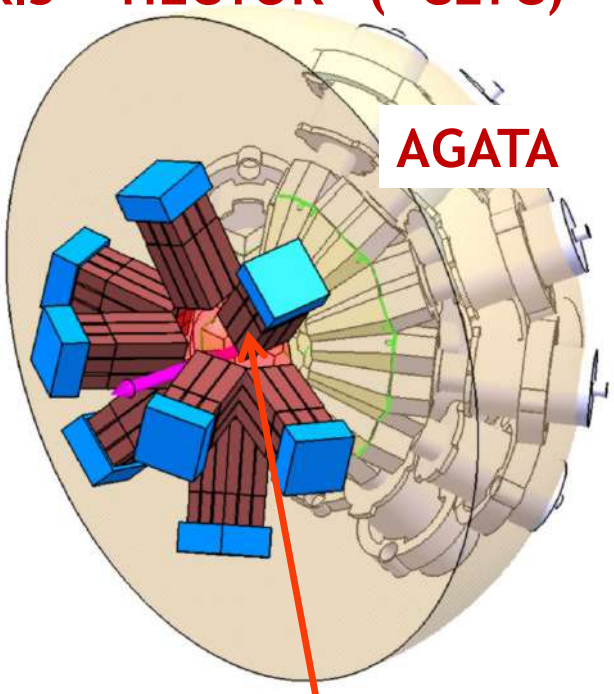
POLAND

- Coulomb excitation of the super-deformed structures in A~40 mass region (AGATA+SPIDER+PARIS) (K. Hadynska-Klek et al.)
- Study of the isovector giant dipole resonance in hot superheavy nuclei (M. Vanderbrouck et al.)

FRANCE

Further experimental cases at SPES, also using PARIS-ACTAR

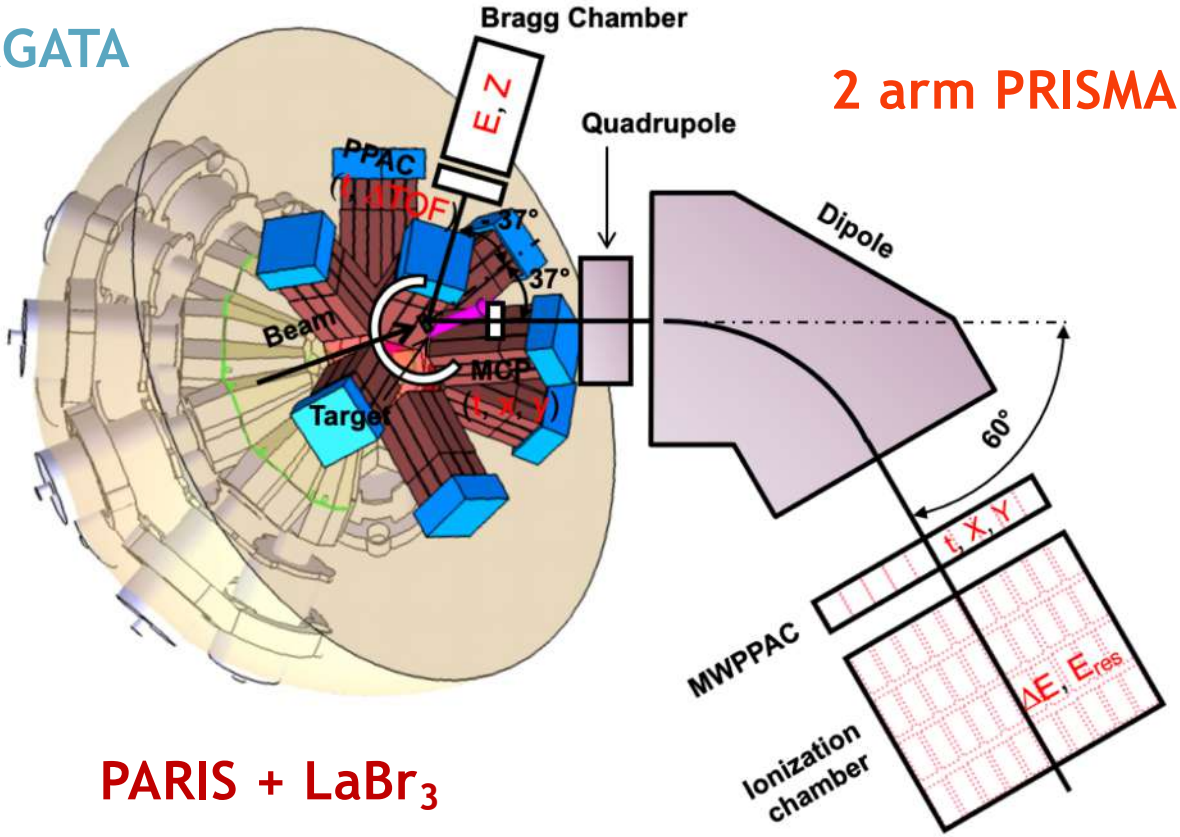
PARIS + HECTOR+ (+CLYC)



EUCLIDES or TRACE

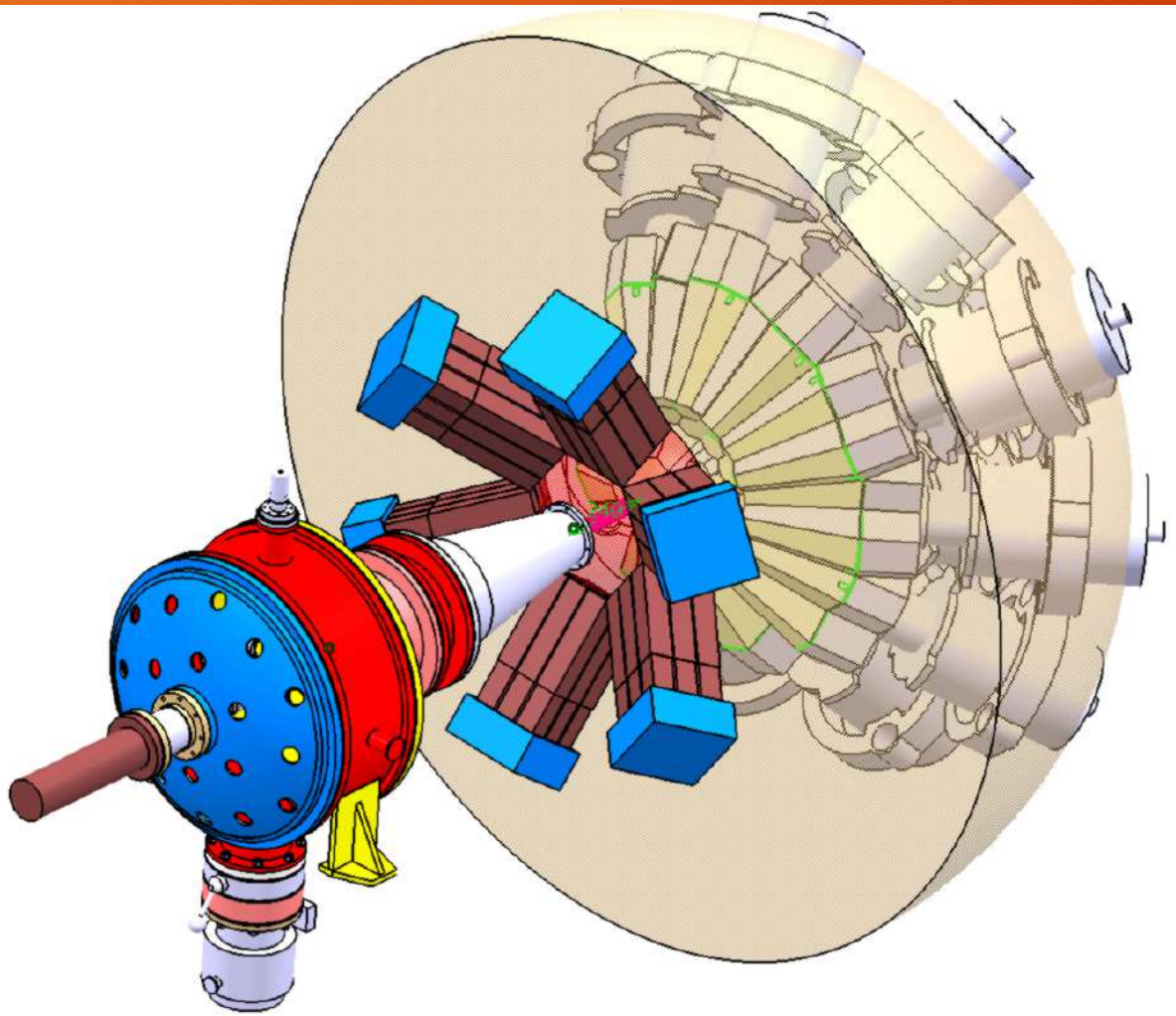
AGATA

2 arm PRISMA



PARIS + $LaBr_3$

AGATA+PARIS + HECTOR+ RFD



PARIS Physics Case Whitebook for 2021-2024

(in preparation, to be ready by the end of 2020)

Editorial Board:

F. Camera (chair), A. Maj (co-chair),
S. Leoni, Ch. Schmidt, I. Mazumdar
M. Lewitowicz (GANIL)
I. Matea, J. Wilson (IPN Orsay)
M. Kmiecik (IFJ PAN Krakow)
M. Cinausero, F. Crespi (LNL Legnaro)
V. Nanal (TIFR Mumbai)

Perspectives for PARIS for > 2024

Campaigns in

- Warsaw Heavy Ion Laboratory
- HiSpec/DeSpec@GSI/FAIR
- Dubna
- Mumbai

Main Publications, Master thesis, Ph.D. Thesis

- A. Maj et al., The Paris Project, Acta Physica Polonica B 40 (2009) 565,
- M. Zięblíński et al., Acta Phys. Pol. B 44, 651 (2013)
- C. Ghosh, V. Nanal, :Characterization of PARIS LaBr3(Ce)-NaI(Tl) phoswich detectors up to Egamma~22 MeV," Journal of Instrumentation 11 (2016)
- B. Wasilewska, M. Kmiecik, A. Maj et al., „The First Results from Studies of Gamma Decay of Proton-induced Excitations at the CCB Facility:, Acta Phys. Pol. B48, 635 (2017)
- B. Wasilewska et al. Acta Phys. Pol. 2019
- B. Dey, C Ghosh, S. Pal, V Nanal, R.G. Pillay, K.V. Anoop, M.S. Pose, „Neutron response of PARIS phoswich detector", Advanced detectors for Nuclear, High energy and Astroparticle physics (Springer Nature Singapore Pvt Ltd, 2018)
- Q. Liqiang et al. Eur. Phys. J. A 56 (2020) 98
- B. Wasilewska et al., (ATOMKI tests), in preparation
- M. Ciemala, I. Matea, J. Wilson (test of PARIS at Licorne), in preparation
- E.M. Kozulin et al. „Features of the Fission Fragments Formed in the Heavy Ion induced 32S+197Au reaction near the interaction barier", EPJA 56 (2020)
- M. Ciemała et al., Phys. Rev. C101, 021303(R) (2020)

Ph.D's:

- C. Ghosh (2017), TIFR
- A.Mentana (2018), Milano
- B. Wasilewska, PhD Krakow, 2018
- Q. Liqiang (2018) IPN Orsay

SUMMARY

- 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
- Results from the first PARIS experiments done in GANIL, IPN Orsay and CCB at IFJ PAN Krakow, are coming and are promising
- PARIS, either standalone or coupled to other detectors, performs well
- At present PARIS possesses 6 clusters: extension of the MoU till 2021 (at least 8 clusters) is signed by all the partners
- GSI (HISPEC/DESPEC) and JINR Dubna are parties in the new MoU
- PARIS campaigns are planned in IPN Orsay (nuBall2), GANIL (LISE, ACTAR), LNL Legnaro (AGATA, ACTAR), IFJ PAN Krakow, HIL Warsaw, TIFR Mumbai, FAIR and Dubna
- PARIS White Book 2021-2024 in preparationumbai

Acknowledgements

- M. Ciemała, M. Kmiecik, B. Wasilewska, B. Fornal, P. Bednarczyk, M. Zięblíński, J. Grębosz, P. Pawłowski, J. Łukasik, B. Sowicki, *(A. Szperłak)* et al. (IFJ PAN Kraków)
- P. Napiorkowski, M. Kicińska-Habior, K. Hadyńska-Klęk et al. (HIL Warsaw)
- A. Bracco, S. Leoni, F. Camera, S. Brambilla. F. Crespi et al. (University of Milano)
- O. Dorvaux, C. Schmitt, S. Kihel et al. (IHPC Strasbourg)
- M. Lebois, L. Qi, J. Wilson, I. Matea et al. (IPN Orsay)
- M. Lewitowicz, E. Clement, A. Lemasson, J.P. Wieleczko (GANIL)
- V. Nanal, C. Gosh, B. Dey, I. Mazumdar et al. (India)
- D. Jenkins et al. (York),
- M. Stanoiu (Bucharest)
- A. Krasznahorkay (Debrecen), R. Schwengner (Rosendorf), J. Gerl (GSI), Y. Pieniozkievich (JINR)
- PARIS, AGATA, VAMOS and LICORNE collaborations
- Technical staff of IPN Orsay, IFJ PAN Krakow, GANIL Caen, ATOMKI Debrecen
- Saint Gobain and Scionix
- *H2020 project ENSAR2 (TNA support), COPIGAL and POLITA collaboration projects, Polish NCN grants*