The Henryk Niewodniczański Institute of Nuclear Physics
Polish Academy of Sciences

Status of the *PARIS* project

Adam Maj
IFJ PAN Krakow
for the PARIS Collaboration

PARIS Collaboration meeting
Warsaw, January 25-25, 2018

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

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 (E
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

PARIS physics cases for SPIRAL2

a) **Jacobi and Poincare shape transitions (+AGATA) ***

130-142 Ba, 116-120Cd, 88-98Mo, 71Zn

(A. Maj, J. Dudek, K. Mazurek et al.)

b) Studies of shape phase diagrams of hot nuclei – GDR differential methods

186-193Os, 190-197Pt

(I. Mazumdar, A. Maj et al.)

c) Hot GDR studies in neutron rich nuclei *

(D.R. Chakrabarty, M. Kmiecik et al.)

d) Isospin mixing at finite temperature

68Se, 80Zr, 84Mo, 96Cd, 112Ba

(M. Kicińska-Habior et al.)

e) Onset of the multifragmentation and the GDR (+FAZIA)

120<A<140, 180<A<200

(J.P. Wieleczko, D. Santonocito et al.)

f) Reaction dynamics by means of γ-ray measurements

214-222Ra, 118-226Th, 229-234U

(Ch. Schmitt, O. Dorvaux et al.)

g) Heavy ion radiative capture *

24Mg, 28Si

* - flagship

h) **Multiple Coulex of SD bands**

36<A<50

(P. Napiorkowski, F, Azaiez, A. Maj et al.)

i) **Relativistic Coulex (after postacceleration)**

40<A<90

(P. Bednarczyk et al.)

j) Nuclear astrophysics (p,γ)

e.g. *90Zr*

(S. Harissopulos al.)

k) Shell structure at intermediate energies (SISSI/LISE)

20<A<40

(Z. Dombradi et al.)

l) Shell structure at low energies (separator part of S3) *

30<A<150

(F. Azaiez, I. Stefan, B. Fornal et al.)

m) **PDR studied with GASPARD+PARIS**

D. Beaumel et al.

n) **PDR in proton-rich nuclei with NEDA+PARIS**

G. De Angelis et al.

o) **Onset of chaotic regime: PARIS+AGATA**

S. Leoni et al.

p) **Evolution of nuclear structure of 78Ni**

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 (<500 ps)
- have energy resolution as good as possible (2%)
- have some position sensitivity
- be transportable (SPIRAL2/GANIL will be the primary site, but experimental campaigns are planned in other facilities: ALTO, Warsaw,

Groups actively working for PARIS

POLAND (coord.: A. Maj): IFJ PAN Krakow, HIL Warsaw

FRANCE (coord.: I. Matea): IPN Orsay, IPHC Strasbourg, IPN Lyon, GANIL

ITALY (coord.: F. Camera): U. and INFN Milano, LNL Legnaro, LNS Catania

INDIA (coord.: V. Nanal): TIFR Mumbai, BARC Mumbai, VECC Kolkata

UK (coord.: D. Jenkins): U. York, U. Surrey, STFC Daresbury, U. Manchester

TURKEY (coord.: S. Ertürk): U. Istanbul, U. Nigde, U. Kayseri, U. Akteniz

ROMANIA (coord.: M. Stanoiu) IFIN-HH Bucharest

PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

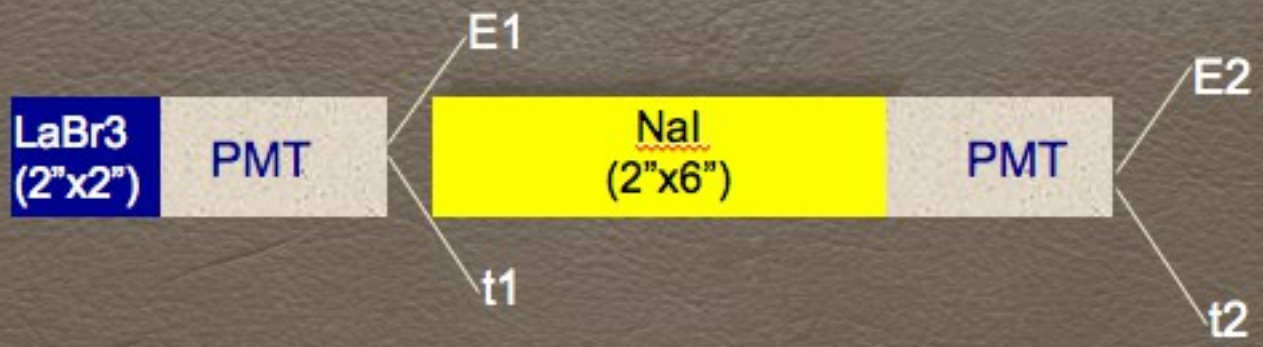
PARIS design concept:

High efficiency (4π) gamma detector, based on new scintilation materials, consisting of 2 shells *(or 1 phoswich shell)* for medium resolution spectroscopy and calorimetry of γ-rays in large energy range

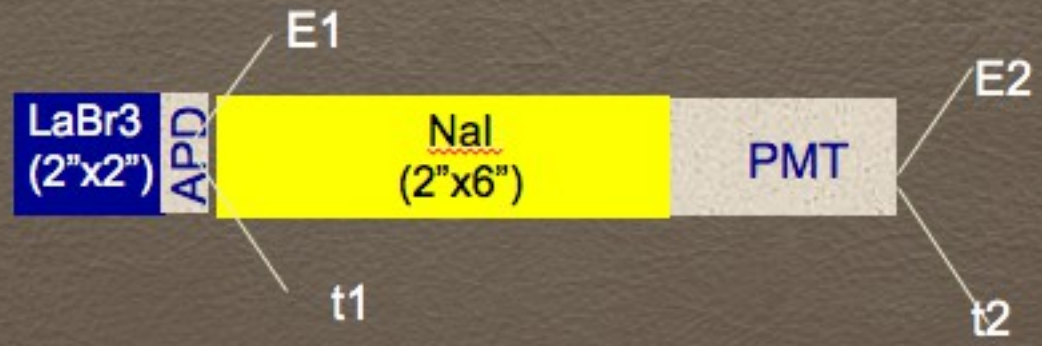
2006 - First ideas of PARIS
2007-2010 - R&D work
2010 - PARIS basic detector (phoswich) ready
2011 - Construction starts
….
….
2017 (December) - 1/6 of 4π PARIS ready
…..

3 POSSIBILITIES FOR A „GAMMA-TELESCOPE” ELEMENT

Possibility 1.

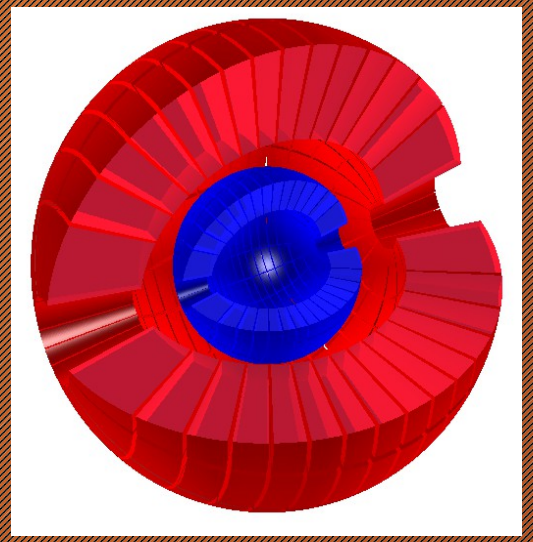


Possibility 2.



Possibility 3 – „phoswich”.

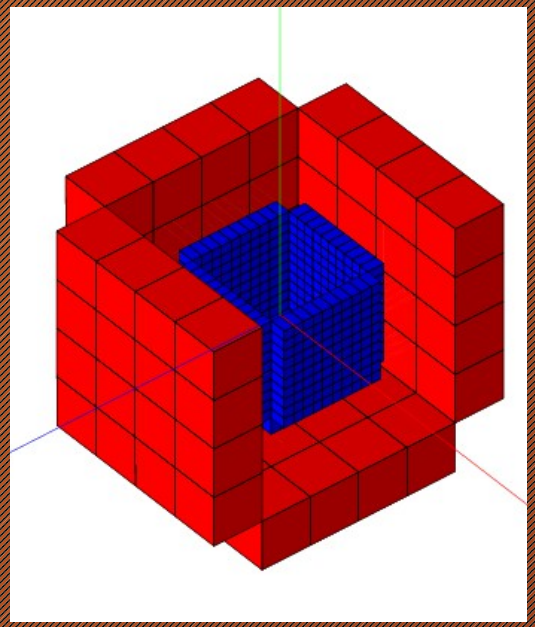
POSSIBLE GEOMETRIES of PARIS



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):

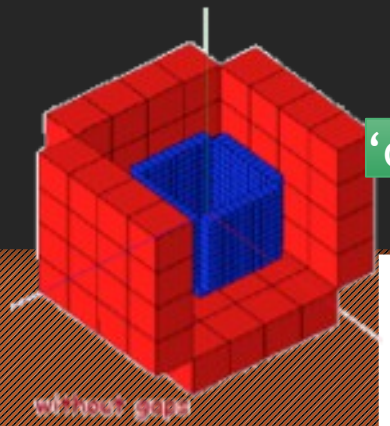
+ : adjustable to different distances, compatibility with many detectors, lower cost for a segment, easier mechanical support,

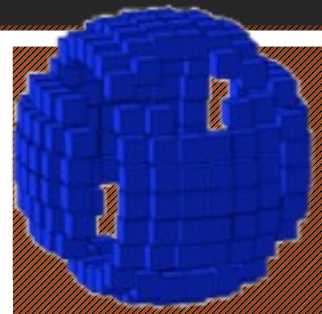
- : More complicated reconstruction, worse line shape, …

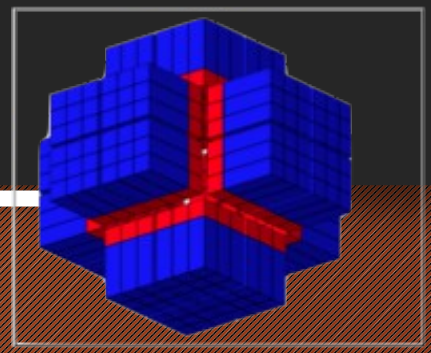
Several geometries studied

‘Ideal’ - spherical

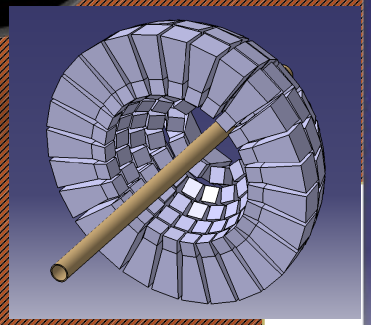
‘cubic’-like

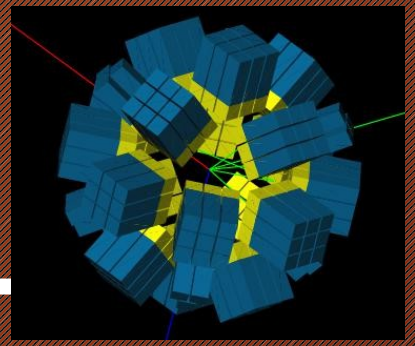






‘radial’-like





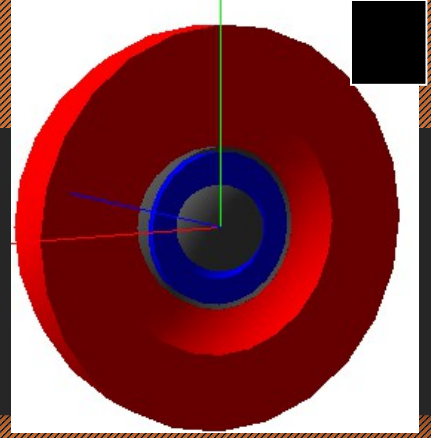
CONCLUSION:

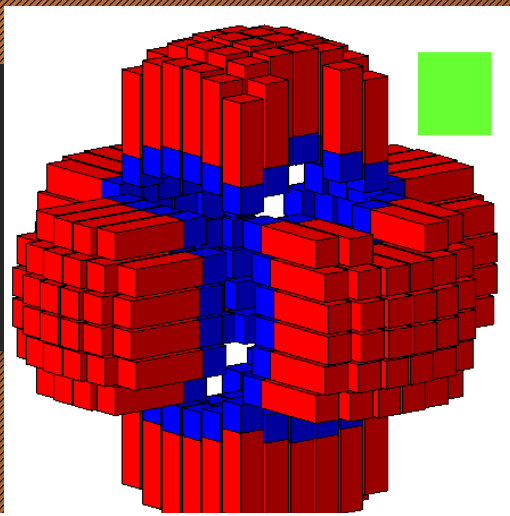
ARIS to be made of clusters:

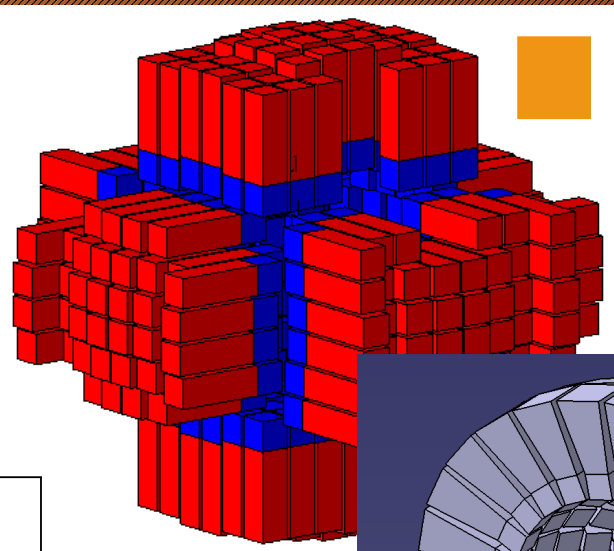
Cluster = *9 phoswiches*

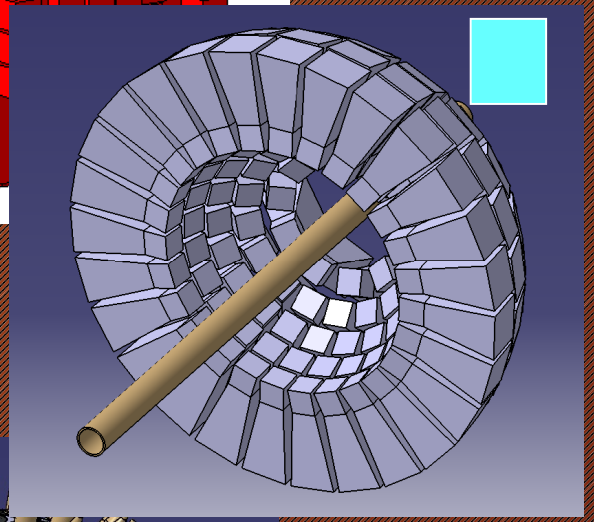
This allows *cubic* or *semi-spherical* geometry with 24 clusters (216 phoswiches)

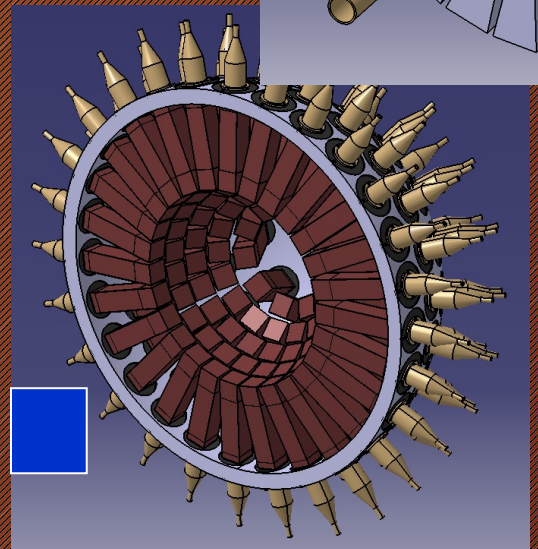
Cubic vs. Radial geometry

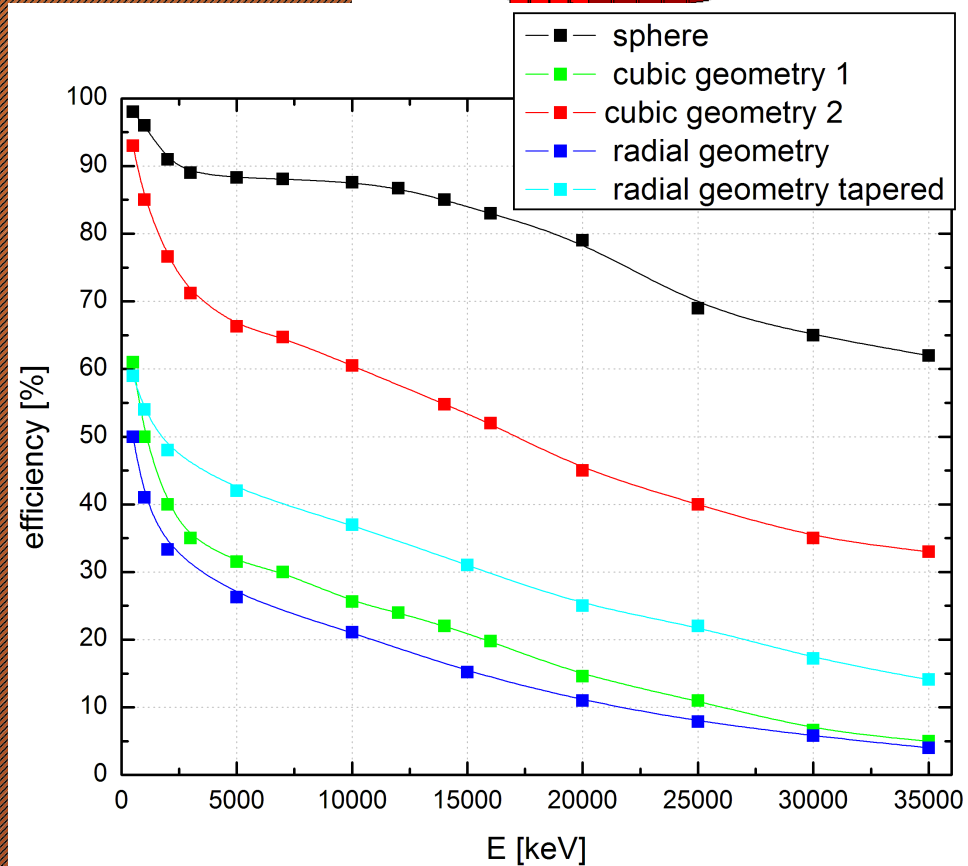




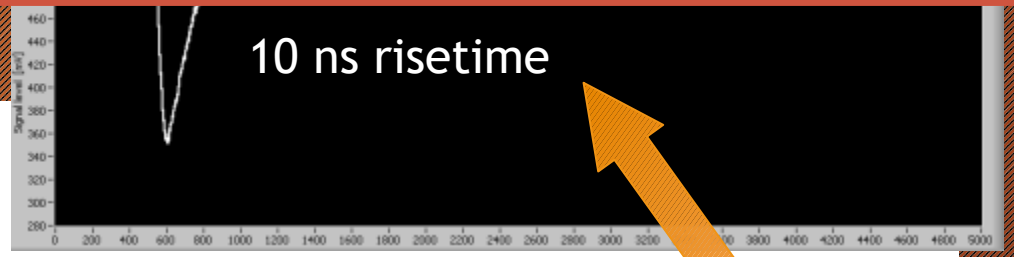


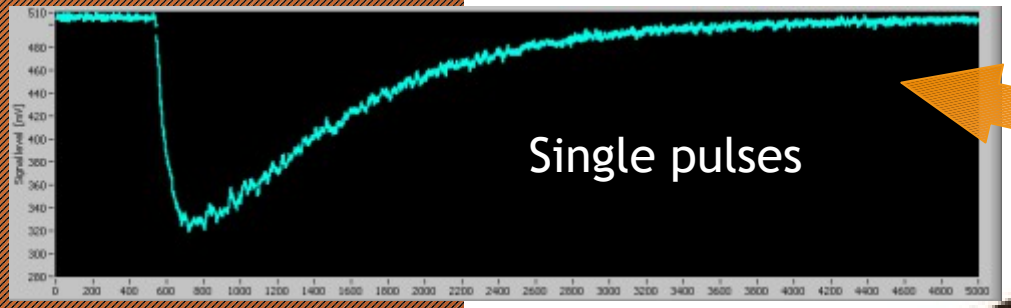


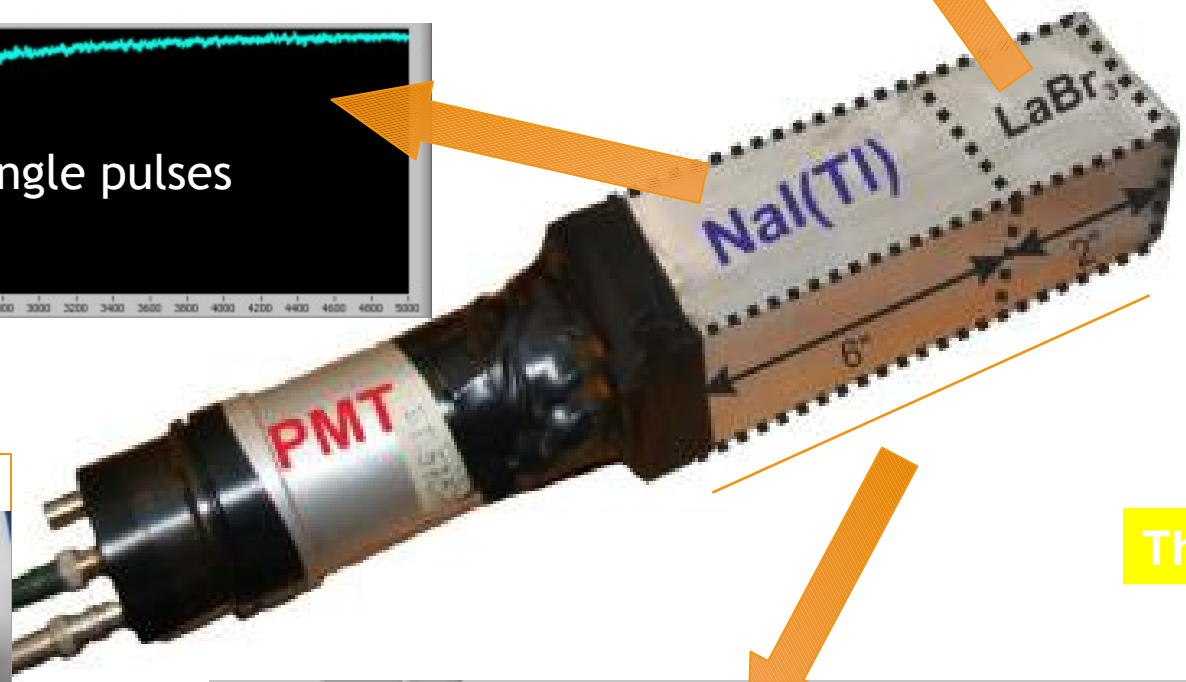


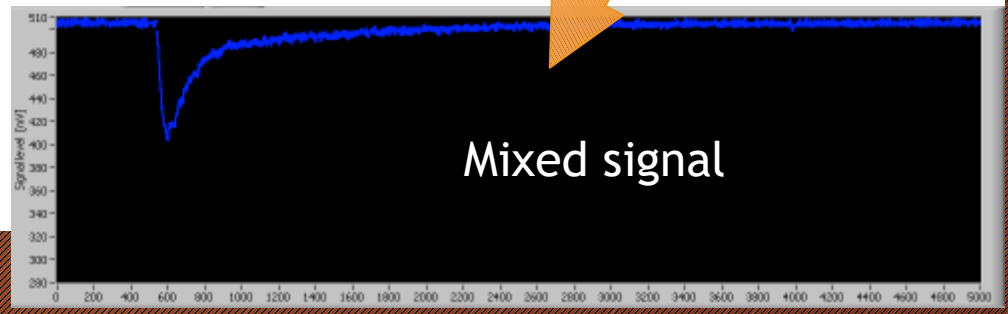


O. Dorvaux, M. Zięblíński, I. Matea, J. Pouthas, V. Nanal, S. Brambilla: Phoswich tests

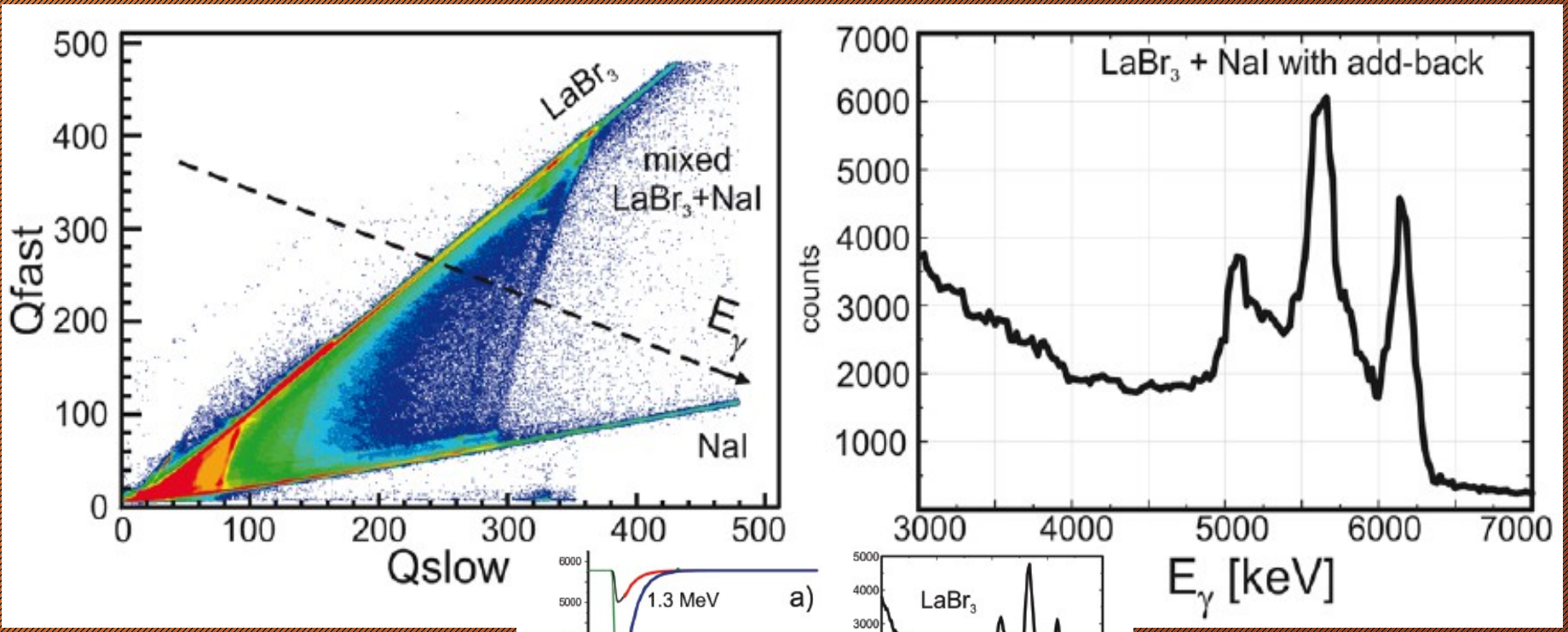


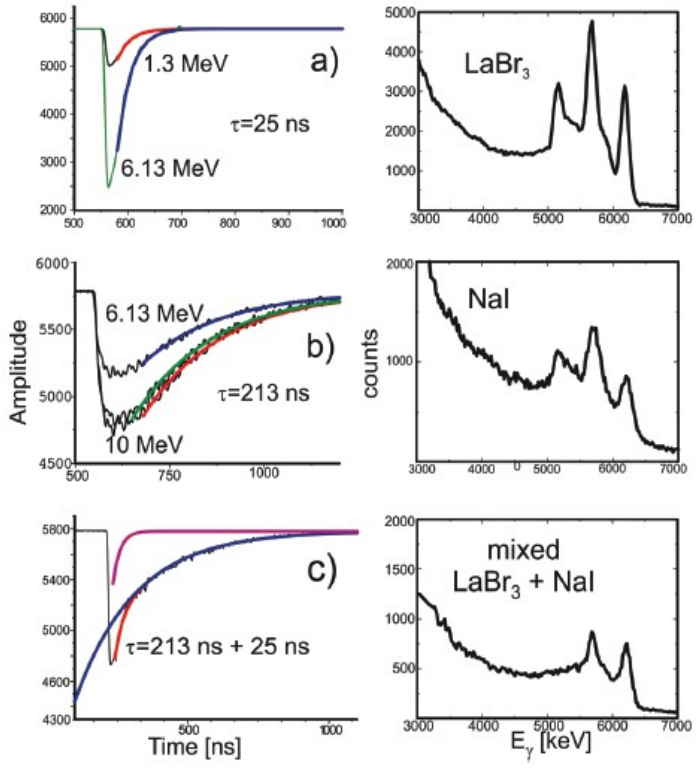






The PARIS PHOSWICH at work





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%

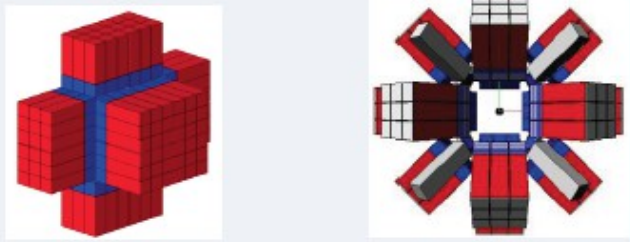
The phoswich concept works !

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

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 **PARIS Demonstrator**	5 clusters: 45 phoswiches		1100 k€	**Only if Phase1 validated** Funds: MoU Ph1Day1 exp@S3
Phase 3 **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 **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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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)

Campaign Spokespersons

GANIL: C. Schmitt / M. Ciemala
IPN Orsay: I. Matea
IFJ PAN Kraków: M. Ciemała

PARIS Collaboration meeting, Krakow, November 2009

PARIS Collaboration meeting, Bormio, February 2012

PARIS Collaboration meeting, Mumbai, January 2013

Next PARIS collaboration meeting: Warsaw, January 25-26, 2018

P. Bednarczyk, S. Brambilla, O. Dorvaux, M. Jastrząb, 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.

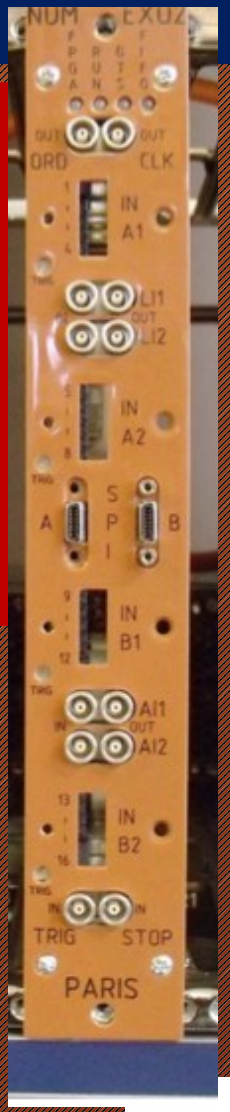
A dedicated PARIS FADS front end electronics (mezzanine) is being designed. The digitizer will be integrated with the NUMEXO2 carrier board. Implementation of algorithms for on line PSA on the FPGA Virtex6LX platform is in progress.

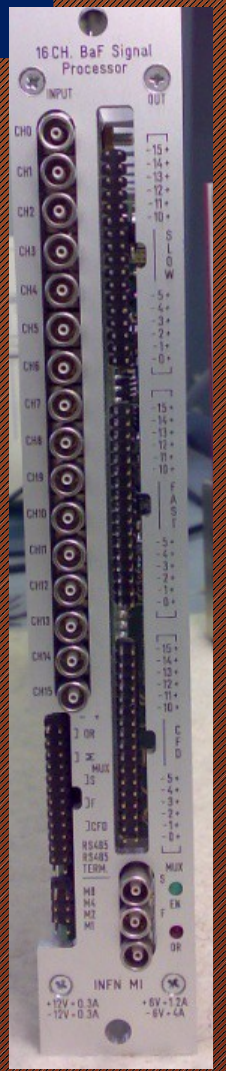
2) **Analogue electronics** based on **Milano "PARIS_Pro"** cards (S. Brambilla et al.) + **AGAVA** interface (A. Czermak et al..):
Already tested in AGATA LNL and GSU camapigns!
Will be used for first experiments with AGATA. (integrated to the VAMOS branch)

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)



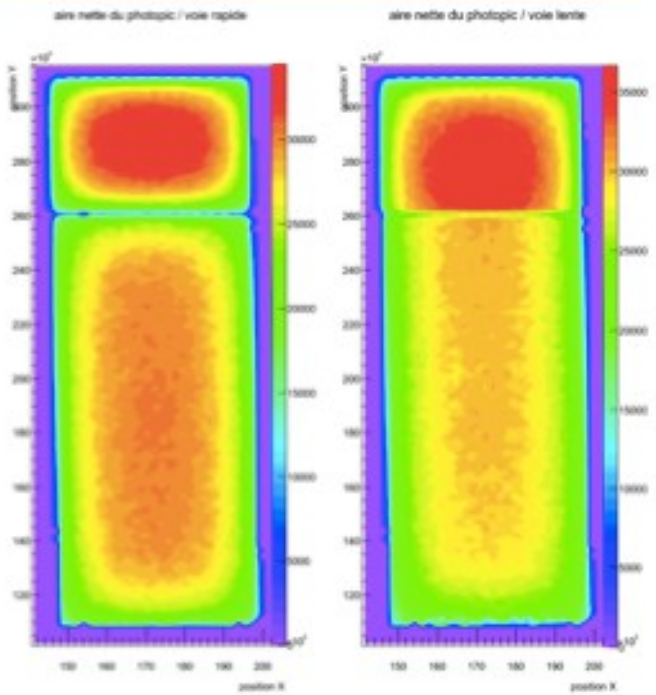


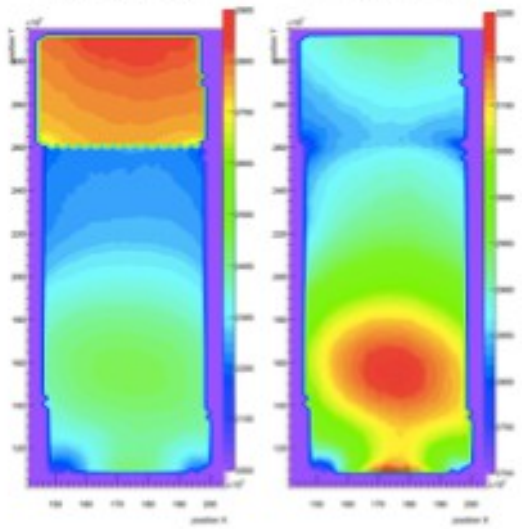
First PARIS cluster

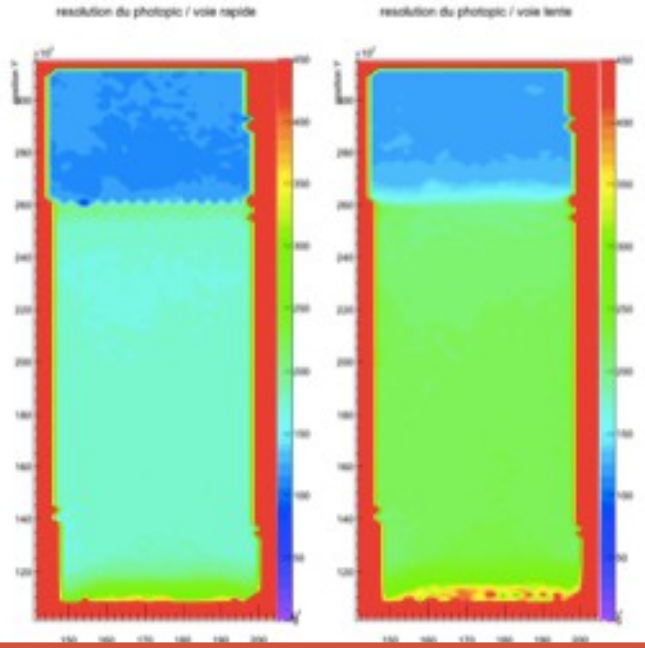
Cluster tests were performed in
IPHC Strasbourg, IPN Orsay, IFJ PAN Krakow, TIFR Mumbai,
ELBE Rosendorf, INFN Milano, ATOMKI Debrecen
using sources and beams

A example of scanning detector using the AGATA scanning table (1500 points)

IPHC Strasbourg
O. Dorvaux, S. Kihel et al..

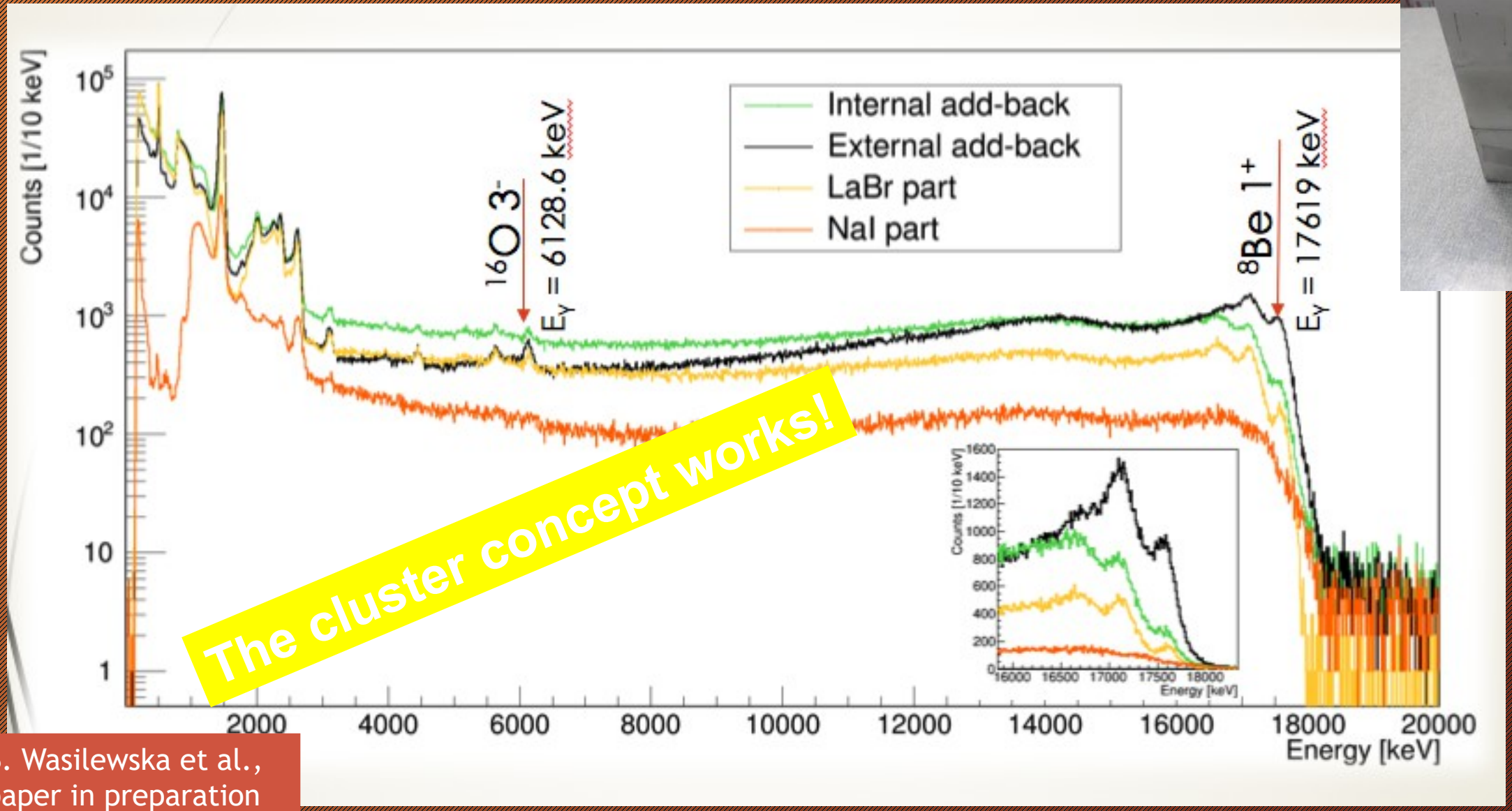






IPHC Strassbourg: Database of all PARIS phoswiches

Exp. in ATOMKI Debrecen – March 2017
(p,gamma) – reaction on LiBO target



B. Wasilewska et al.,
paper in preparation

Experiments performed, accepted and planned

GANIL

PARIS coupled to AGATA@GANIL

3 proposals accepted by the GANIL PAC

- S. Leoni, B. Fornal, M. Ciemala et al., Lifetimes in A=18 region measured with PARIS (2 clusters + 2 large LaBr3), *AGATA, VAMOS, Plunger*
  (DONE! 11-23 July 2017)
- P. Bednarczyk, A. Maj et al., Investigation of a high spin structure in 44Ti via discrete and continuumγ-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 (4 clusters) , PARIS, NEDA, DIAMAND, DSSD

LoI and proposal for PARIS with LISE@GANIL

(Not accepted this time. Will be repeated)

- Y. Blumenfeld, A. Maj et al., „**Study of giant and pygmy resonances in exotic nuclei at LISE",** ACTAR TPC, Chateau de Cristall, CATS, PARIS, large LaBr3

ALTO at IPN Orsay

Performed:

- I. Matea, J. Wilson, M. Ciemala et al. „PARIS cluster response to fast neutrons”
- A. Kozulin, I. Harca et al. “Prompt γ-rays as a probe of nucleardynamics”
- M. Lebois, Q. Liqiang et al. “Prompt gamma and neutron emission for 238U fast neutron induced fission as a function of incident neutron energy”

Accepted:

- M. Wiedeking et al. ,,Colomb excitation of 14C” (???)
- P.J. Napiorkowski et al., „Coulomb excitation of super-deformed band in 40Ca”
- 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” (probably June 2018)

Presently new call fo proposals

CCB at IFJ PAN Krakow

Partly 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"

Accepted:

- 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. Schmitt, D. Mancusi, B. Kamys et al., „Investigation of proton induced spallation with HECTOR, PARIS, KRATTA"

New call for proposals: July 2018

PARIS@SPES/LNL Legnaro (preliminary LoIs)

- **GDR decay of hot rotating nuclei in A=130 mass region** (Maj, Leoni): GALLILEO, RFD
- **Measurement of Isospin Mixing in N=Z medium mass nuclei** (F. Camera): HECTOR+, GALLILEO
- **Measurement of the Dynamical Dipole emission** and the symmetry term of the EOS (F. Camera, G. Casini): HECTOR+, fusion_evaporation det.
- **Entry distributions for fragments produced in deep- inelastic collisions** with stable and radioactive beams (Królas)
- **Heavy-ion binary reactions** as a tool for detailed gamma spectroscopy in exotic regions (Leoni, Maj): PRISMA, GALILEO
- **High-spin gamma ray spectroscopy of heavy, octupole deformed Ac and Fr** nuclei produced in fusion evaporation reactions with the intense A∼90 Rb radioactive beams at SPES (Bednarczyk): GALILEO
- **GDR feeding od the SD bands in A=30-60 region** (P. Bednarczyk, M. Kmiecik, F. Camera)

Presently (December 2017) PARIS collaboration has 4 clusters:

- **3 LaBr3_NaI clusters** (produced by Saint Gobain)
- **1 CeBr3_NaI cluster** (produced by Scionix)

Present MoU

Partner	2012-2017	
	$LaBr_3$_NaI	$CeBr_3$_NaI
FRANCE–IN2P3	10	
FRANCE-GANIL	2	1
POLAND	6	4
INDIA	2	4
UK	2	
ITALY	2	
TURKEY	1	
ROMANIA		4
DUBNA		
Total	**25**	**13**

Clusters: 3 1

Publications, Master thesis, Ph.D. Thesis

- A. Maj et al., The Paris Project, Acta Physica Polonica B 40 (2009) 565,
- 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. Dey, C Ghosh, S. Pal, V Nanal, R.G. Pillay, K.V. Anoop, M.S. Pose, „Neutron response of PARIS phoswich detector", arXiv:1708.06346, to appear in Advanced detectors for Nuclear, High energy and Astroparticle physics (Springer Nature Singapore Pvt Ltd, 2018)
- Q. Liqiang et al. (exp, in Orsay), submited,
- I. Harca et al. (exp. In Orsay), in final stage of preparation
- B. Wasilewska (ELBE treests), in final stage of prepraration
- B. Wasilewska et al., (ATOMKI tests), to be prepared
- M. Ciemala, I. Matea, J. Wilson (test of PARIS at Licorne), in preparation

Ph.D's:

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

Conclusions

- LaBr3/CeBr3+NaI phoswich and a cluster of 9 phoswiches were proved to work according to expectations based on simulations
- First PARIS experiments with were done in 3 TNA facilities: GANIL, IPN Orsay and CCB at IFJ PAN Krakow.
- Experimental campaings in which PARIS was coupled to AGATA has started in GANIL
- PARIS performs very well
- Possible PARIS experiments in other facilities (LNL Legnaro, TIFR Mumbai, GSI/FAIR, Dubna,…) are discussed
- At present PARIS possesses 4 clusters.
- Extension of the MoU till 2020 (up to 8 clusters) is in the final process of preparation

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- *COPIGAL Project*