



Adam Maj
IFJ PAN Krakow

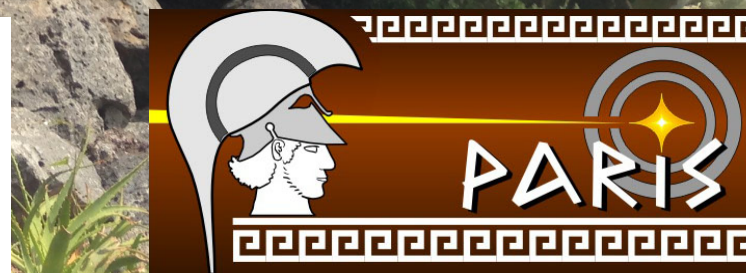
for the PARIS collaboration

The novel gamma calorimeter PARIS – status of the development



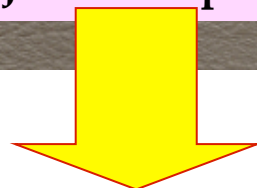
Joint LIA COLL-AGAIN, COPIGAL, and POLITA
Workshop
(French-Italian-Polish Collaborations)

26-29 April 2016 INFN-Laboratori Nazionali del Sud,
Catania, Italy



4-5-6th October, 2005 „Future prospects for high resolution gamma spectroscopy at GANIL” - Convenors : **Bob Wadsworth** (UK) and **Wolfram Korten** (F)

WG „Collective modes in continuum” - convenors: **Silvia Leoni** (I) & **Adam Maj** (PL)
M. Kmiecik (PL): 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)

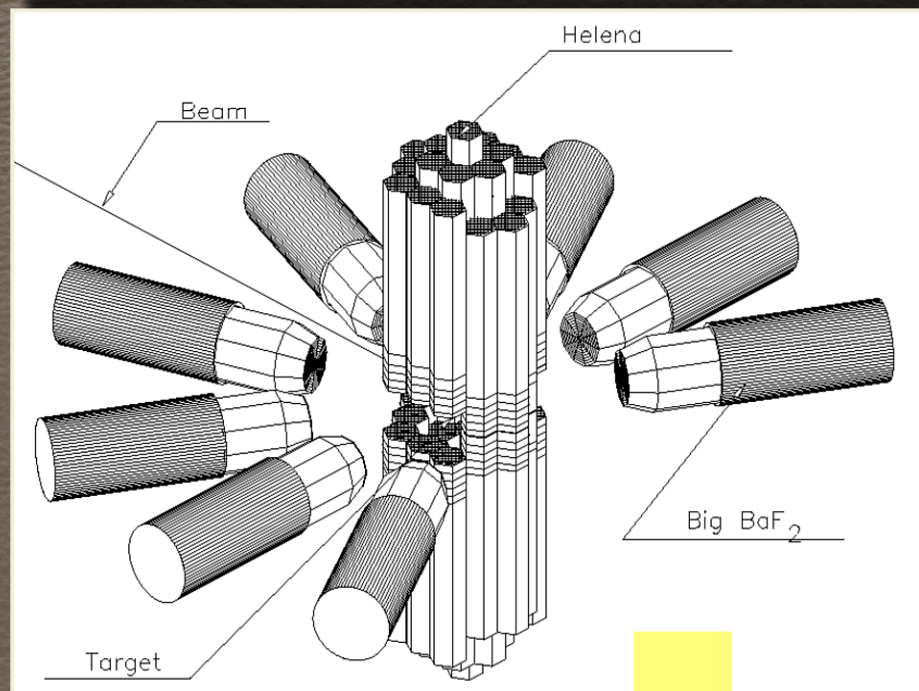
David Jenkins, University of York (UK), dj4@york.ac.uk

GANIL contact person

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

Aim:
to design and build
efficient gamma calorimeter
PARIS

Origin of the name **PARIS**



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





PARIS

PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

PARIS desing concepts:

**Design and build high efficiency detector
consisting of 2 shells (*or 1 phoswich shell*)
for medium resolution spectroscopy
and calorimetry of γ -rays in large energy range**

Inner sphere, highly granular, made of new crystals ($\text{LaBr}_3(\text{Ce})$), to be used as a multiplicity filter of high resolution, sum-energy detector (calorimeter), detector for the gamma-transition up 10 MeV with medium energy resolution. It may serve also for fast timing application.

Outer sphere, with high volume detectors, made of conventional crystals (BaF_2 or NaI), to be used for high-energy photons measurement or as an active shield for the inner shell..

2-shell or phoswich 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 physics cases for **SPIRAL2**

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

$^{130-142}\text{Ba}$, $^{116-120}\text{Cd}$, $^{88-98}\text{Mo}$, ^{71}Zn

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

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

$^{186-193}\text{Os}$, $^{190-197}\text{Pt}$

(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**

^{68}Se , ^{80}Zr , ^{84}Mo , ^{96}Cd , ^{112}Ba

(M. Kicińska-Habior, F. Camera 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**

$^{214-222}\text{Ra}$, $^{118-226}\text{Th}$, $^{229-234}\text{U}$

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

g) **Heavy ion radiative capture ***

^{24}Mg , ^{28}Si

(S. Courtin, D.G. Jenkins et al.)

h) **Multiple Coulex of SD bands**

$36 < A < 50$

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

i) **Relativistic Coulex**

(after postacceleration)

$40 < A < 90$

(P. Bednarczyk et al.)

j) **Nuclear astrophysics (p, γ)**

e.g. ^{90}Zr

(S. Harissopulos et 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: PARI+AGATA**

S. Leoni et al.

p) **Evolution of nuclear structure of ^{78}Ni and ^{132}Sn with ACTAR+PARIS**

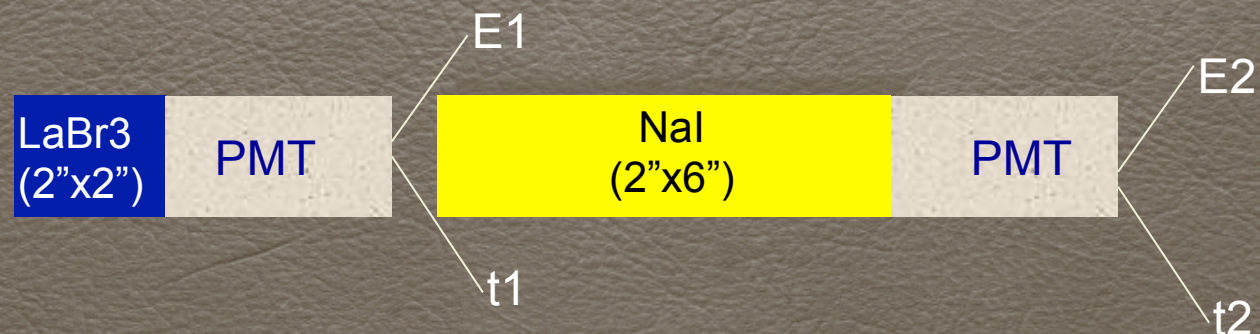
G.F. Grinyer et al..

Main physics cases require that PARIS has to

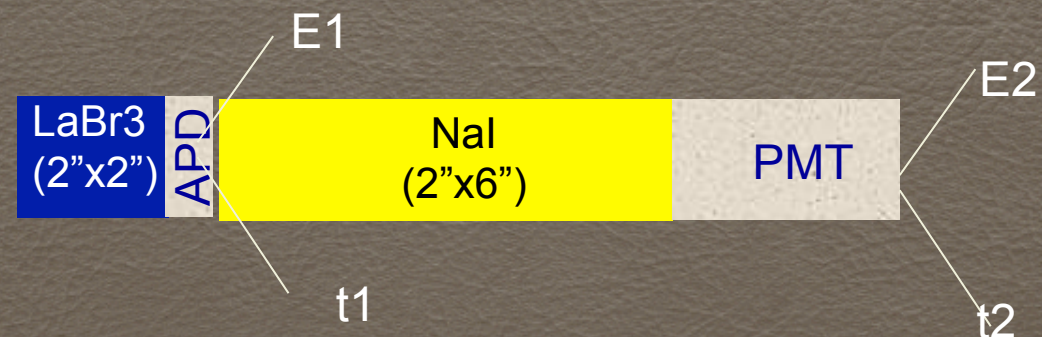
- ❑ be **modular** (to be connected with other detectors: **AGATA**, **EXOAM**, **GALILEO**, **GASPARD**, **NEDA**, **FAZIA**, **ACTAR**, **HECTOR/HECTOR+**, **EAGLE**, **ORGAM**, **CORSET**...)
- ❑ have **high granulation** (multiplicity measurement, Doppler correction,...)
- ❑ have very **high efficiency for high-energy γ -rays** (5-30 MeV)
- ❑ stand **high counting-rate** (ca. 50MHz)
- ❑ have **good timing** resolution (ca. 500 ps)
- ❑ have **energy resolution** as good as possible (ca. 4%)
- ❑ have some **position sensitivity**
- ❑ be **transportable** (**SPIRAL2/GANIL** will be the primary site, but experimental campaigns are planned also in other facilities: **IPN Orsay**, **HIL Warsaw**, **CCB Krakow**, **SPES/LNL**, **HIE-ISOLDE**, **Mumbai**,...)

4 POSSIBILITIES FOR A „GAMMA-TELESCOPE” ELEMENT

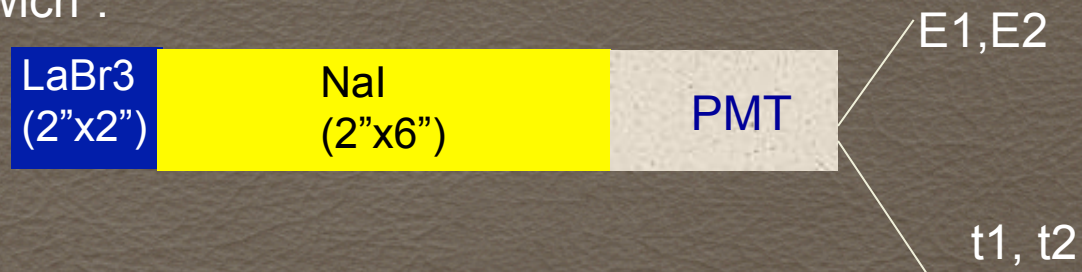
Possibility 1.



Possibility 2.



Possibility 3 – „phoswich”.

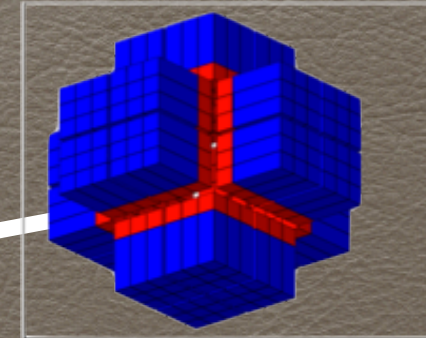
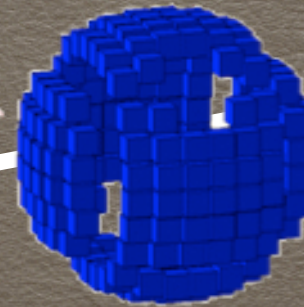
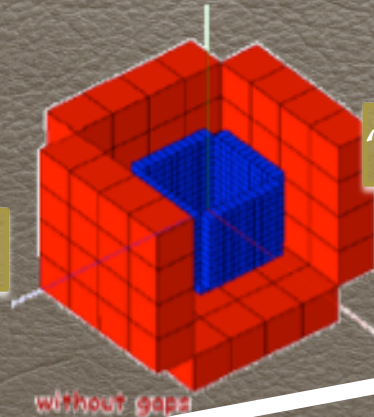


Several geometries studied

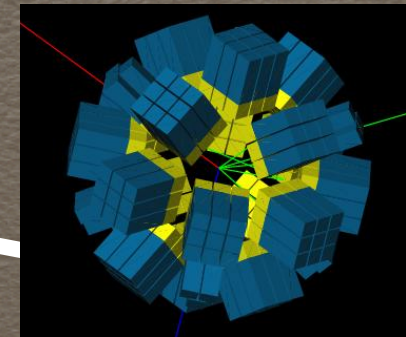
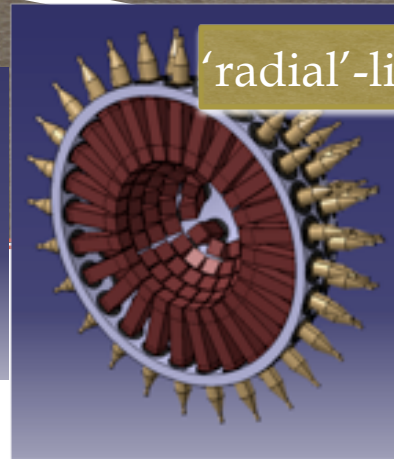
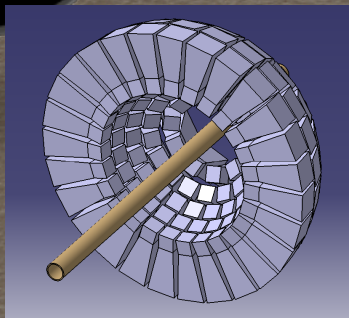
'Ideal' - spherical



'cubic' -like



'radial' -like



CONCLUSION:

PARIS to be made of clusters:

Cluster = 9 phoswiches

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

Institutions actively working for PARIS

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

FRANCE (coord.: I. Matea): INP3: IPN Orsay, IPHC Strasbourg, IPN Lyon;
GANIL

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

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

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

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

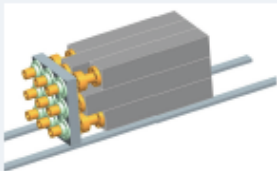
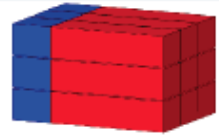

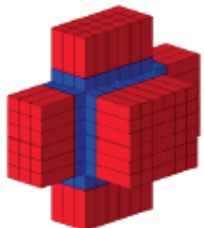
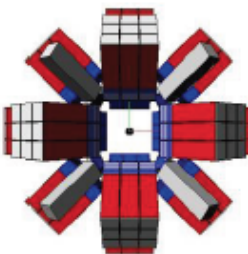
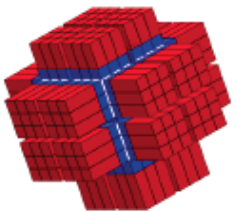
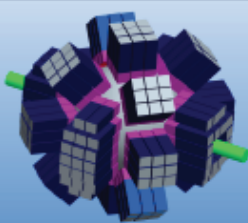
ROMANIA (coord.: F. Negoita) IFIN-HH Bucharest

PARIS Demonstrator MoU 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), Bulgaria, 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 2018 PARIS Demonstrator	5 clusters: 45 phoswiches			1100 k€	Only if Phase1 validated Funds: MoU Ph1Day1 exp@S3
2020 PARIS 2π	12 clusters: 108 phoswiches			≈ 2 M€	Only if Phase2 validated Funds: MoU, PARIS consortium Ph2Day1 exp. with AGATA and GASPARD Other exp.
Phase 4 2022? PARIS 4π	≥24 clusters: ≥216 phoswiches			≈ 4 M€	Only if Phase3 validated Funds: PARIS consortium Regular experim in various labs

IPN Orsay
·
AGATA@GANIL
·
S3@GANIL
·
CCB Krakow
·
LNL/SPES
·
SPIRAL2 phase2

**Since 2012 (after MoU was signed)
New organization of PARIS**

PARIS Steering Committee

(by nominations of the MoU partners):

- **IN2P3 France: F. Azaiez**
- **GANIL France: M. Lewitowicz**
- **COPIN Poland: B. Fornal (dep.chair)**
- **India: V. Nanal (chair)**
- **Italy: A. Bracco**
- **Romania: F. Negoita**
- **UK: D. Jenkins**
- **Turkey: S. Erturk**
- **Bulgaria: D. Balabanski**

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

Working Groups and their Coordinators
(proposed by PPM and approved 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)

Campaign Spokesperson

(nominated by lab directors):

GANIL: C. Schmitt

IPN Orsay: I. Matea

PARIS Management Board:

PARIS Project Manager + WG coordinators

**PARIS Collaboration Council – representing each institution interested in PARIS.
Chair is elected for 2 years term**

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)

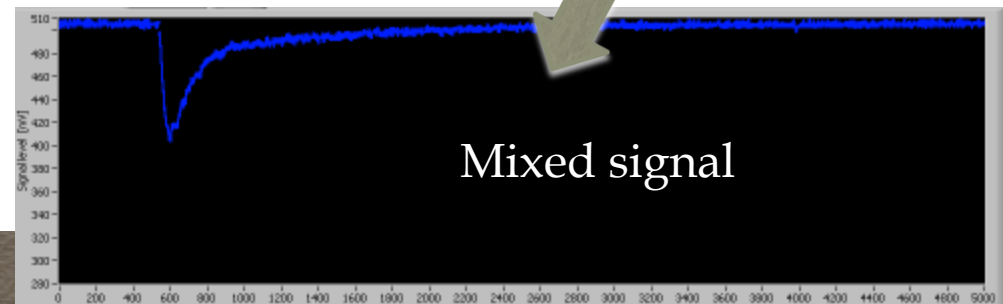
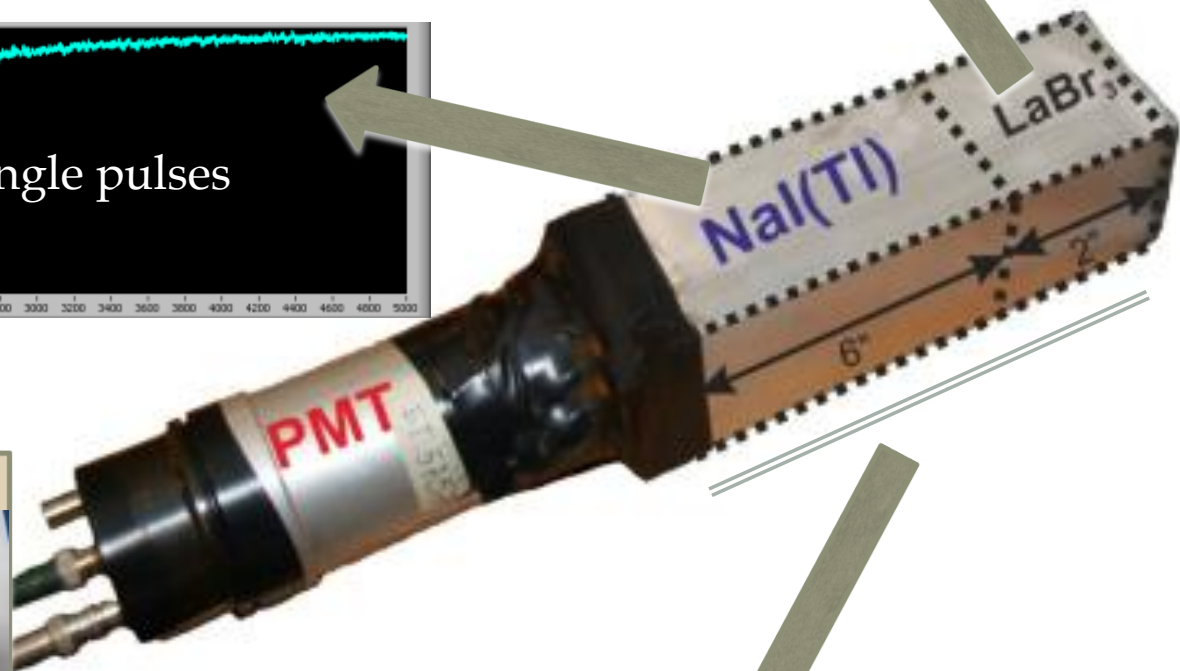
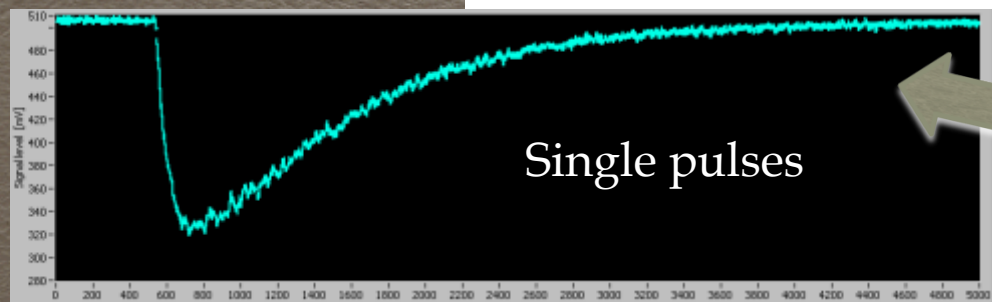
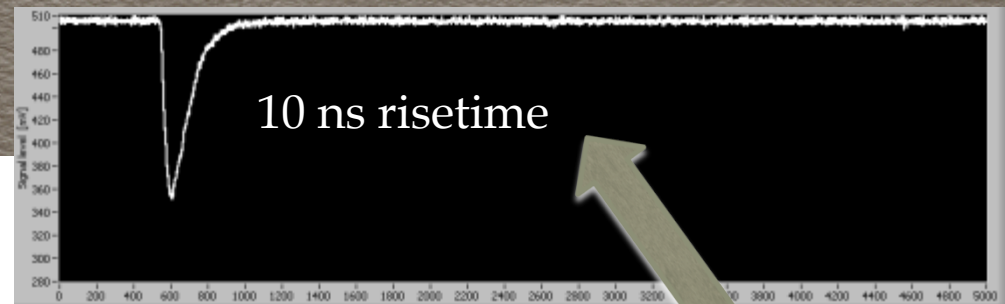
Pawel Napiorkowski (HIL Warsaw, Poland)

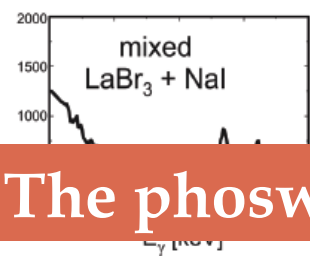
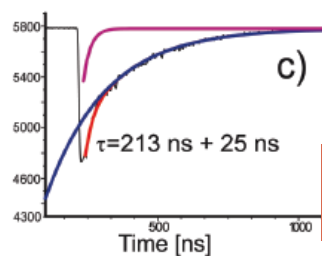
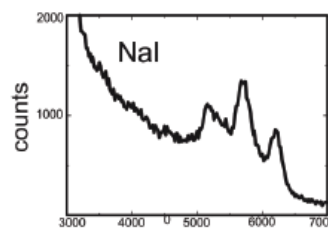
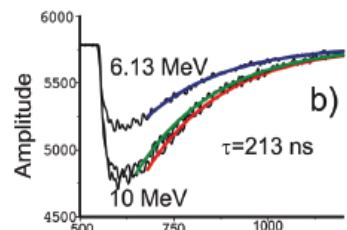
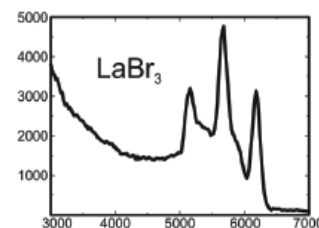
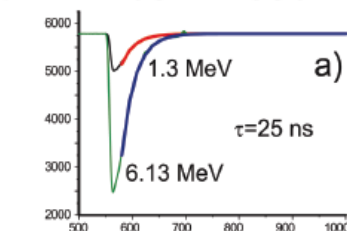
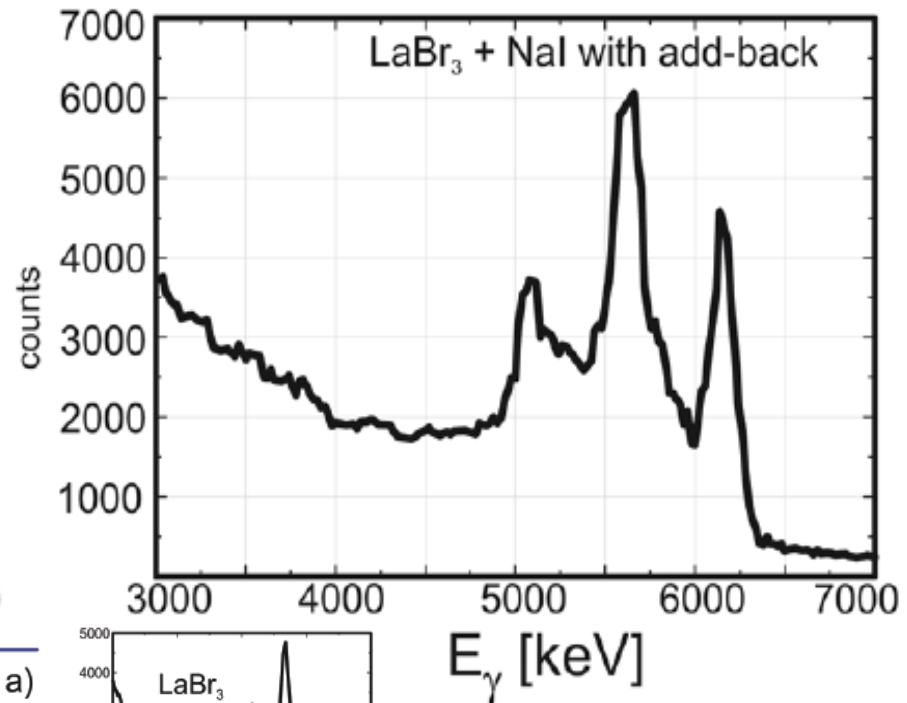
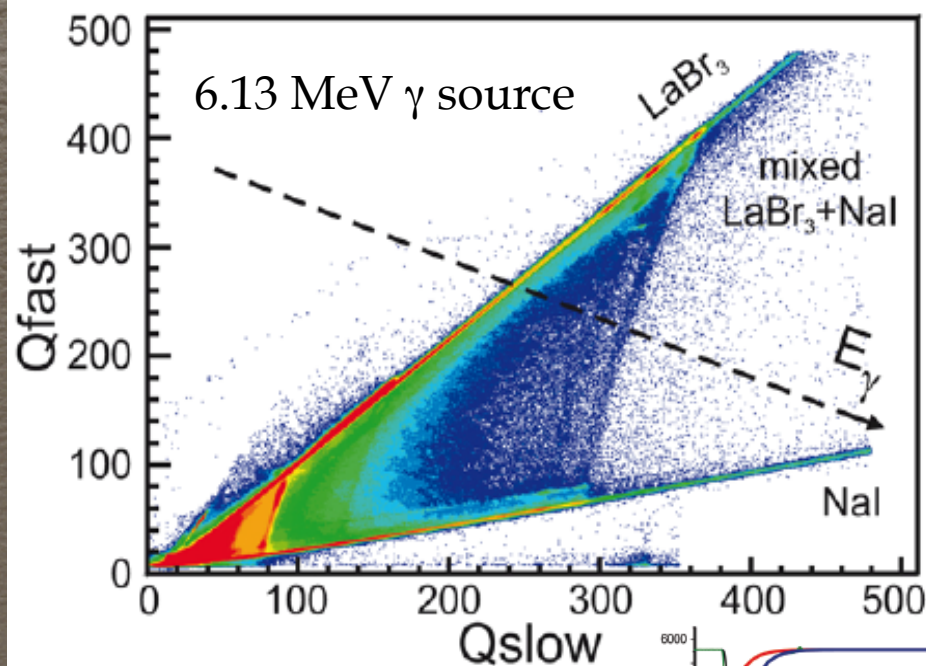
Marek Ploszajczak (GANIL, France)

Mihai Stanoiu (IFIN-HH Bucharest, Romania)

Jonathan Wilson (IPN Orsay, France)

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 Nal): ca. 4%

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

The phoswich concept works!

PARIS Cluster ready – First in-beam test (Matea/Maj) , May 2013, Tandem-ALTO, IPN Orsay



$^{11}\text{B}(p, \gamma)^{12}\text{C}$ at 7.2 MeV

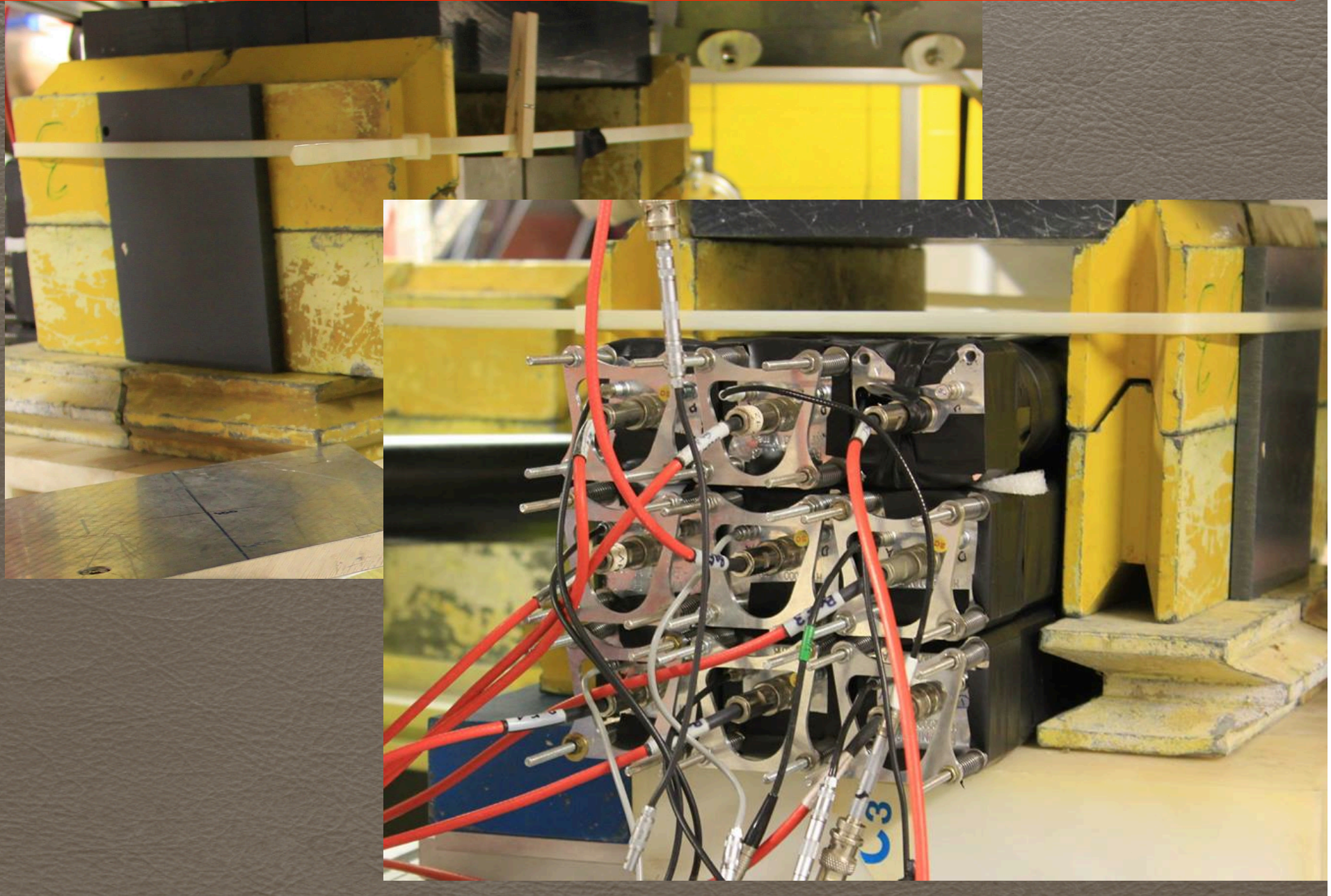
E_γ : ..., 18.12 , 22.56 MeV

Goal:
testing addback
capabilities at high
energies

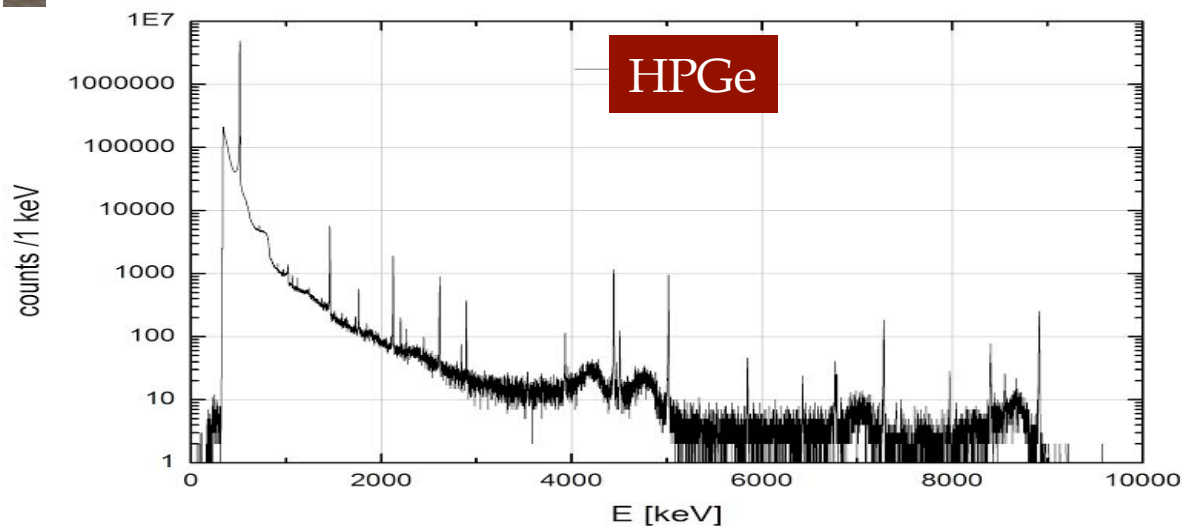
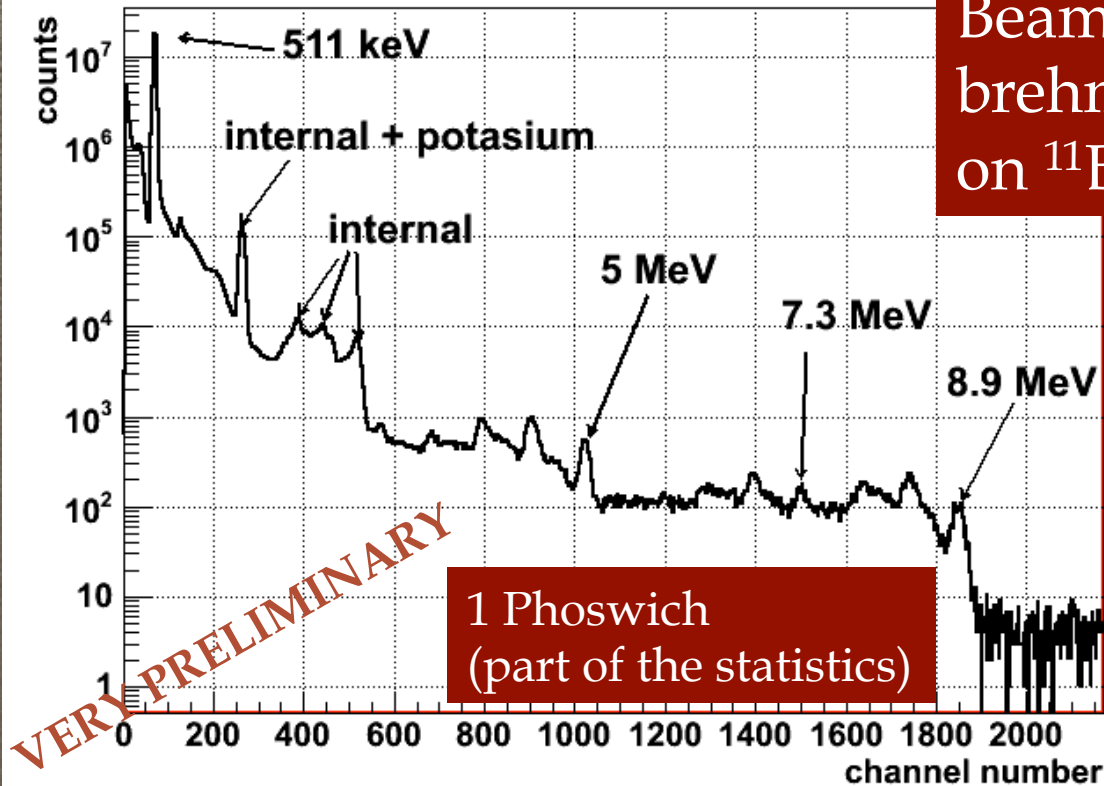


ELBE facility, Dresden 10-12 December, 2013

Nuclear Resonance Fluorescence experiment (Mazumdar, Maj, Schwengner)



Beam 15 MeV electrons:
brehmstallung gamma beam
on ^{11}B target



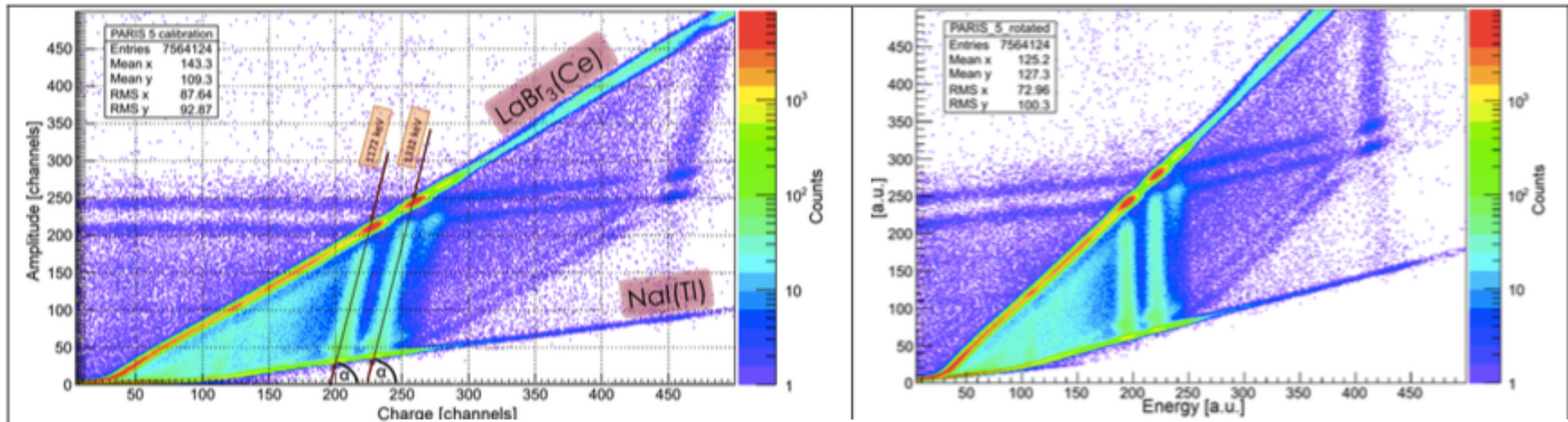


Fig. 4) Example of charge vs calibration run. Lines of even energy was deposited in one same energy deposited and

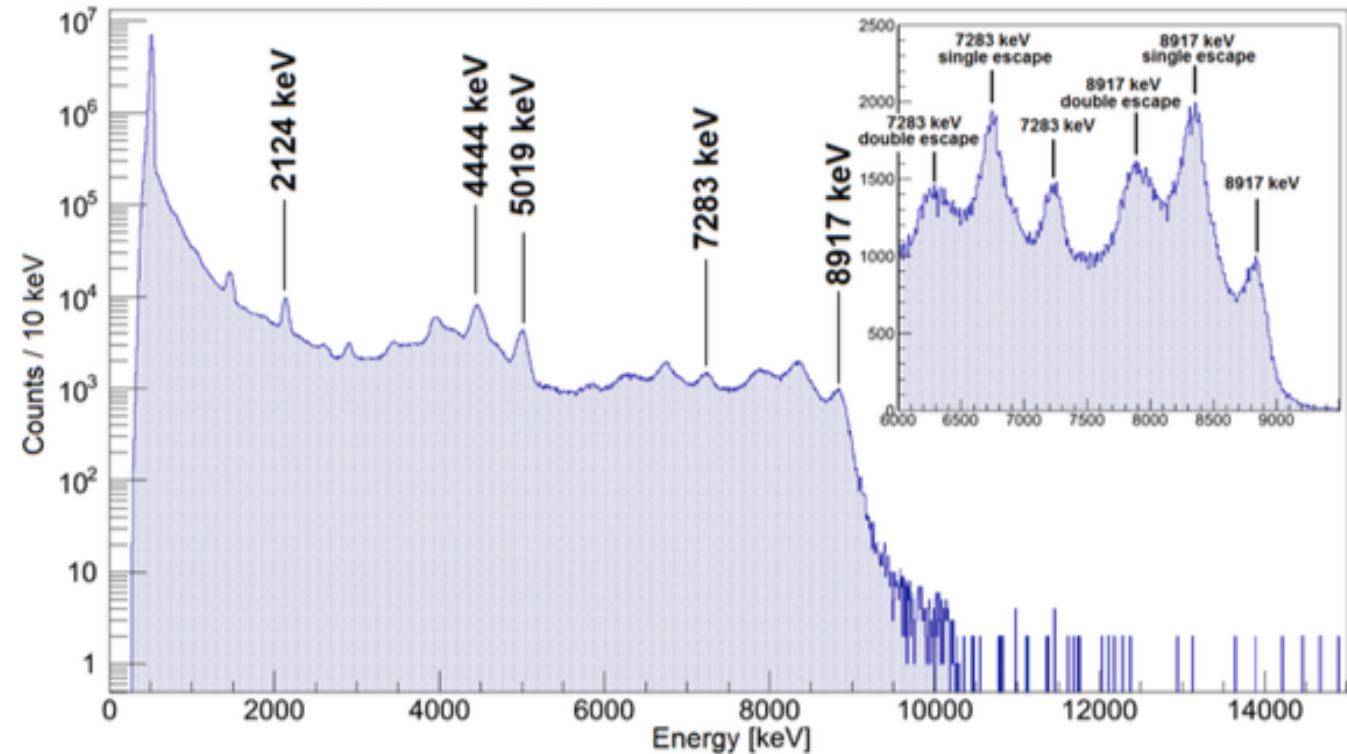


Fig. 6) Energy add-back spectrum of the PARIS cluster.

B. Wasilewska et al.,
paper in
preparation

Other PARIS cluster/phoswich tests performed

- ❑ Milano, April 2015 – testing PARIS_Pro modules with full cluster, S. Brambilla, F. Camera
- ❑ IPN Orsay, May 26-29, 2015, „Measurement of the neutron response of PARIS cluster between 0.5 to 12 MeV (LICORNE)”, J. Wilson, I. Matea
- ❑ Coulex experiment at HIL Warsaw, June 2015

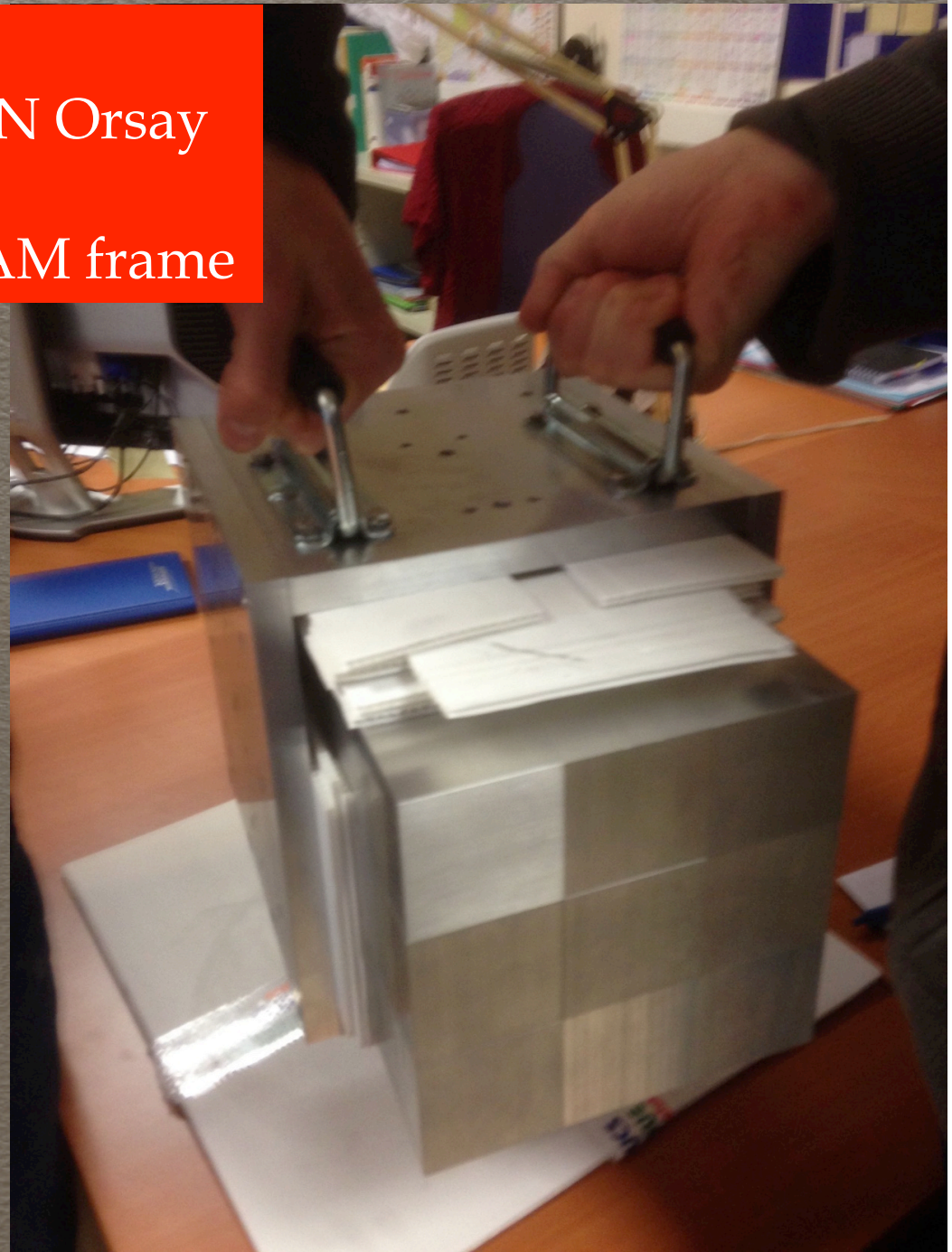
Next tests: depending of availability

- ❑ CCB Krakow, 2016 ?

Cluster holding structure

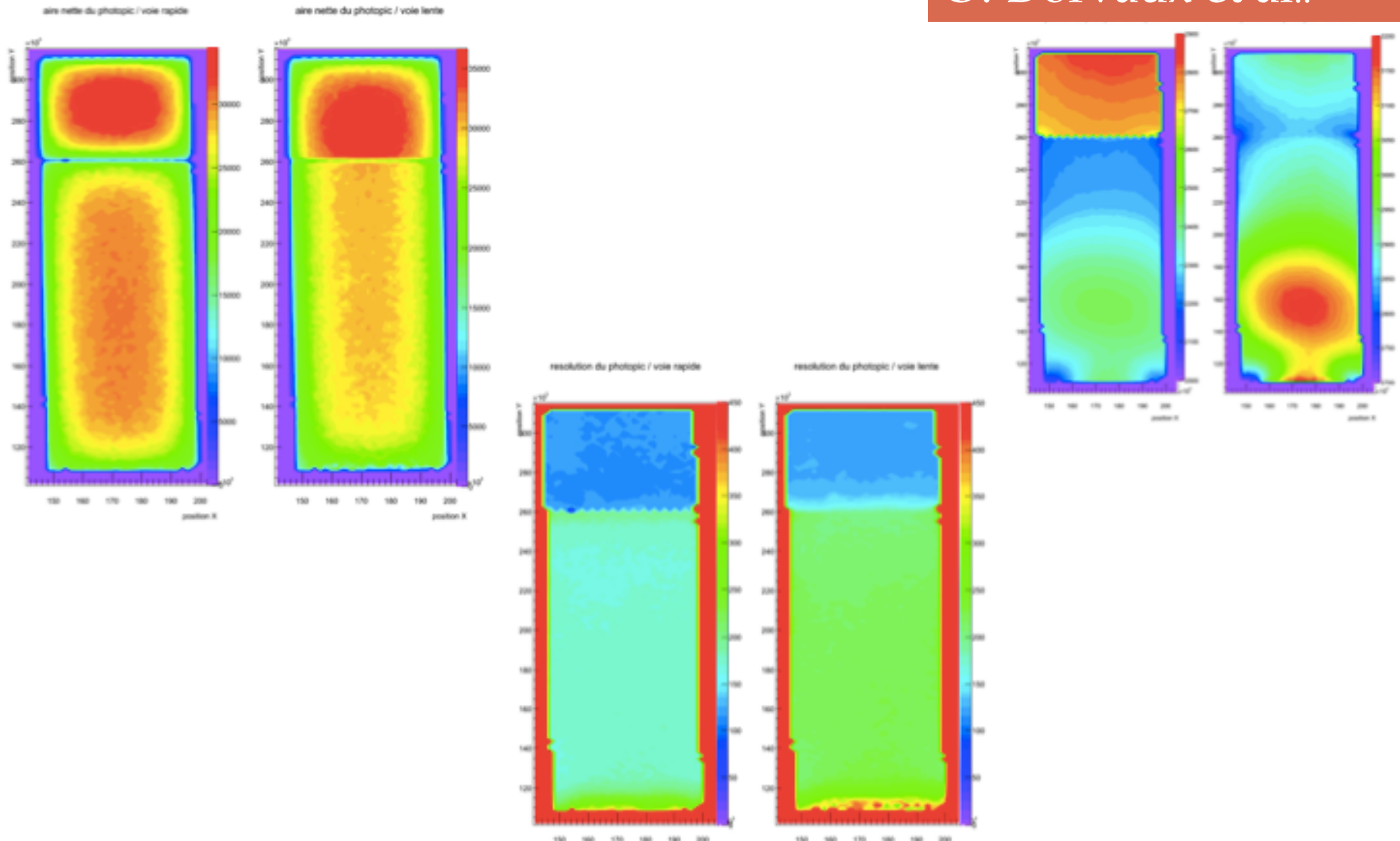
Designed and produced by IPN Orsay

It will be connected to EXOGAM frame



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

IPHC Strasbourg
O. Dorvaux et al..



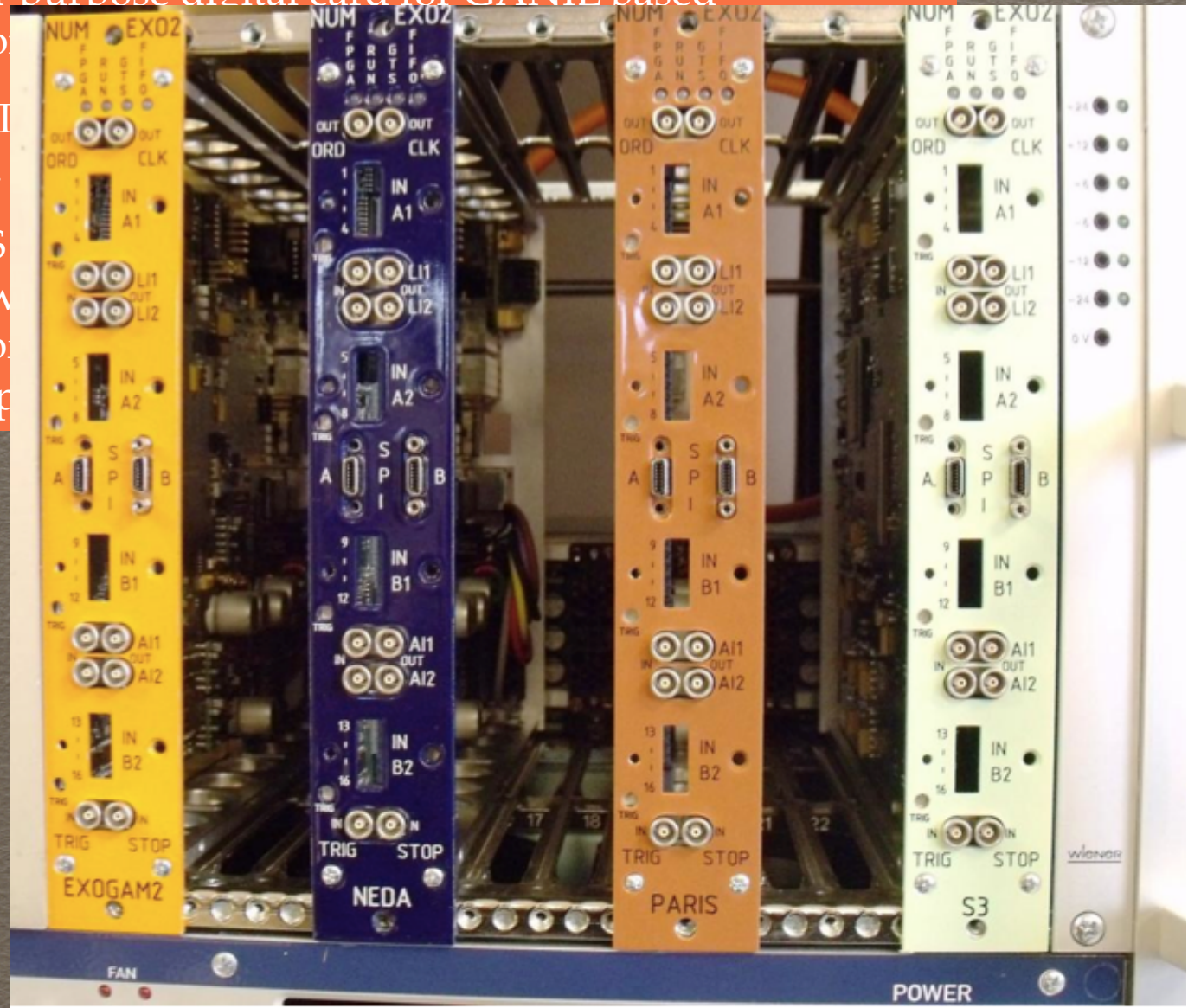
IPHC Strassbourg: Database of all PARIS phoswiches

Options of electronics for PARIS

1) NUMEXO2 - a general-purpose digital card for GANIL based experiments (collaboration)

Implementation of the GT currently being finalized.

A dedicated PARIS FADS designed. The digitizer w board. Implementation of Virtex6LX platform is in p



Options of electronics for PARIS

1) **NUMEXO2** - a general-purpose digital card for GANIL based experiments (collaboration with **EXOAM2** 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.

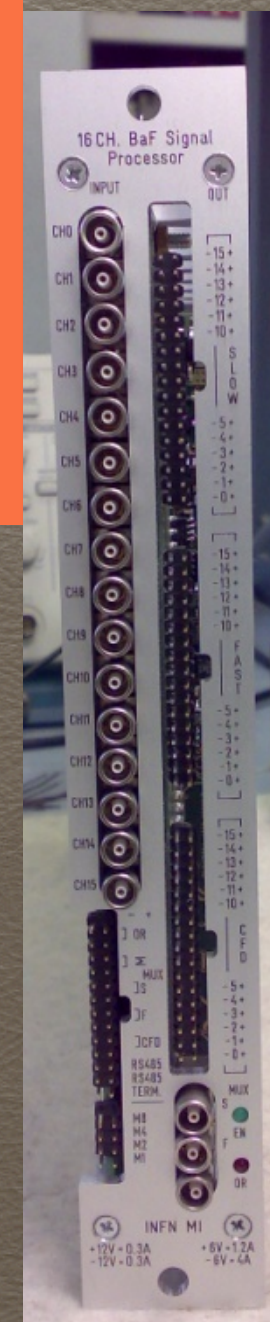
2) **Analogue electronics** based on **Milano "PARIS_Pro"** cards (S. Brambilla et al.) + **AGAVA** interface (A. Czermak et al.):

Already tested in AGATA LNL and GSU campaigns!

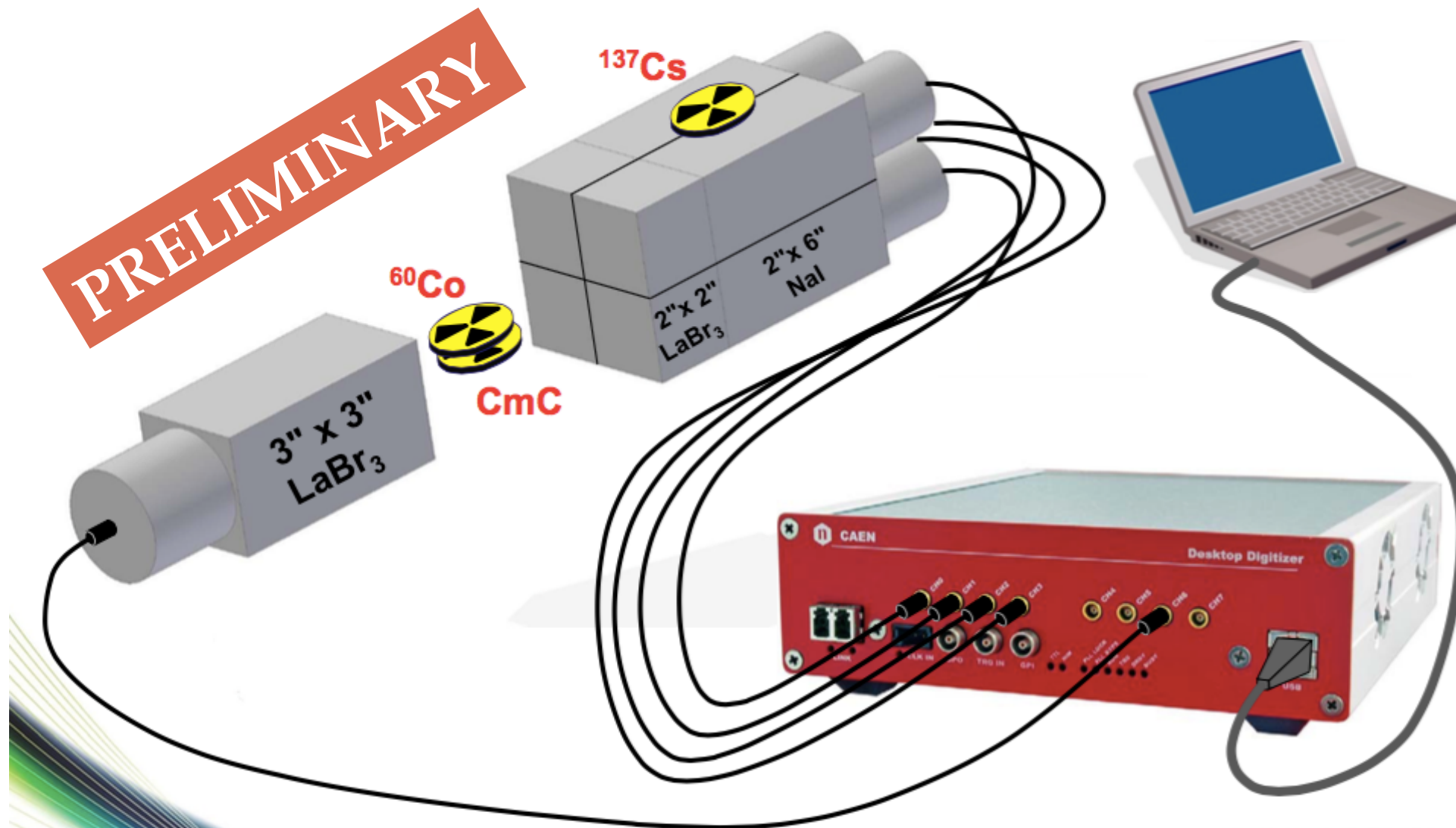
**Will be used for first experiments with AGATA.
(integrated to the VAMOS branch)**

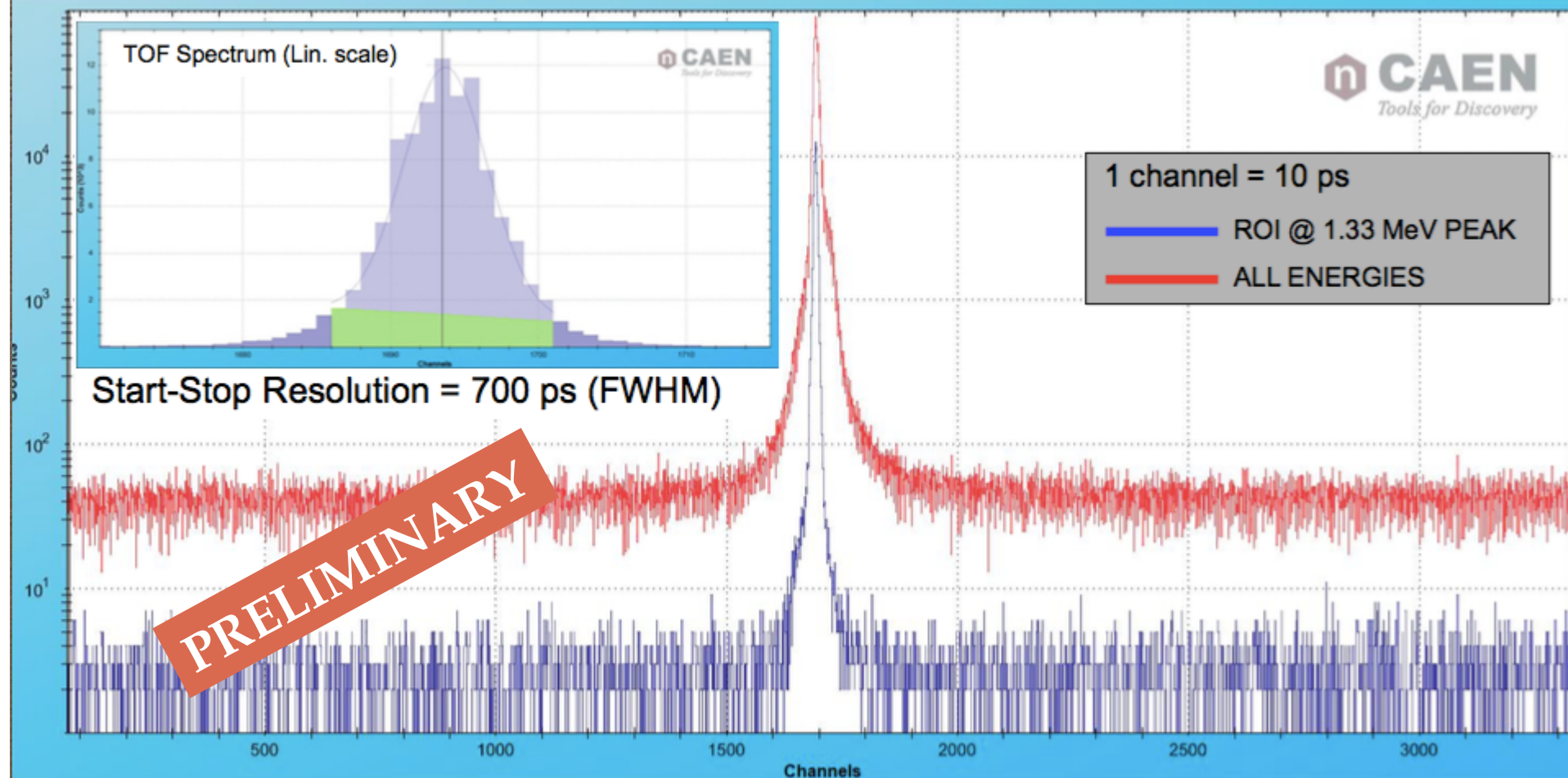
3) **Commercial digitizers** (V1730, 16 channel, 500 MS/s, 12/14 bit CAEN digitizer)

Tested in Krakow, July 2015 – works very well (good time resolution, time resolution – 0.7ns, low deadtime)



PRELIMINARY





TOF from pure 3"x3" LaBr₃ to Phoswitch-LaBr₃

First experiments

IPN/ALTO Orsay (PARIS campaign, 2016)

PARIS campagne manager: I. Matea

6 proposals accepted by the Orsay PAC

Requiring at least **one cluster**:

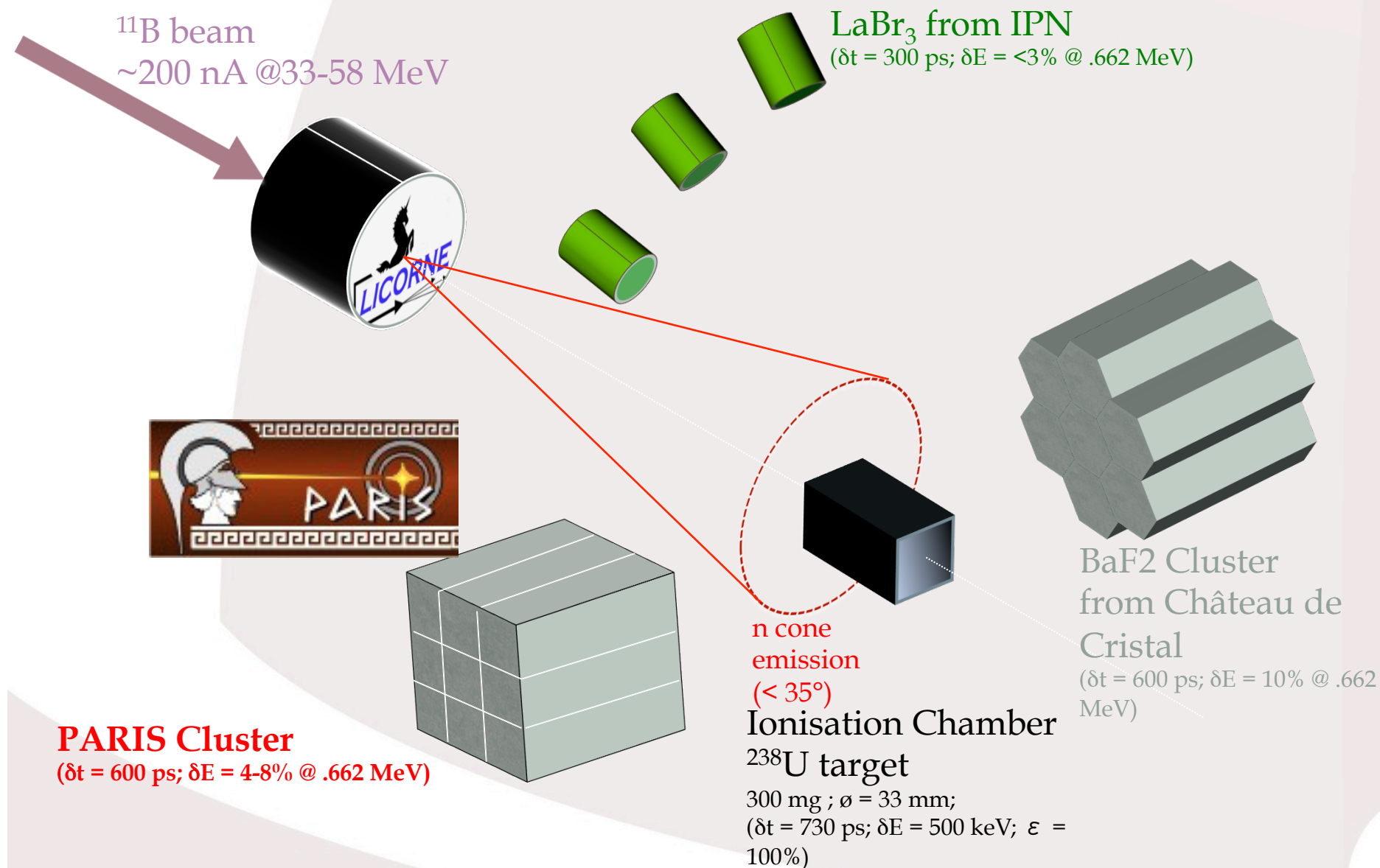
- M. Lebois - Prompt gamma and neutron emission for ^{238}U fast neutron induced fission as a function of incident neutron energy - **Done in April 2016!**
- A. Kozulin - Prompt γ -rays as a probe of nucleardynamics - **to be done end of June 2016**

Requiring **2-4 clusters**:

- B. Blank - Measurement of the super-allowed branching ratio of ^{10}C
- O. Kirsebom - A new probe of alpha-cluster structure in ^{12}C
- M. Wiedeking - Coulomb Excitation of ^{14}C
- P.J. Napiorkowski - Coulomb excitation of super-deformed band in ^{40}Ca

Possible campagne winter 2016/2017

EXPERIMENTAL SETUP: MEASUREMENT OF PROMPT γ FROM ^{238}U FAST NEUTRON INDUCED FISSION

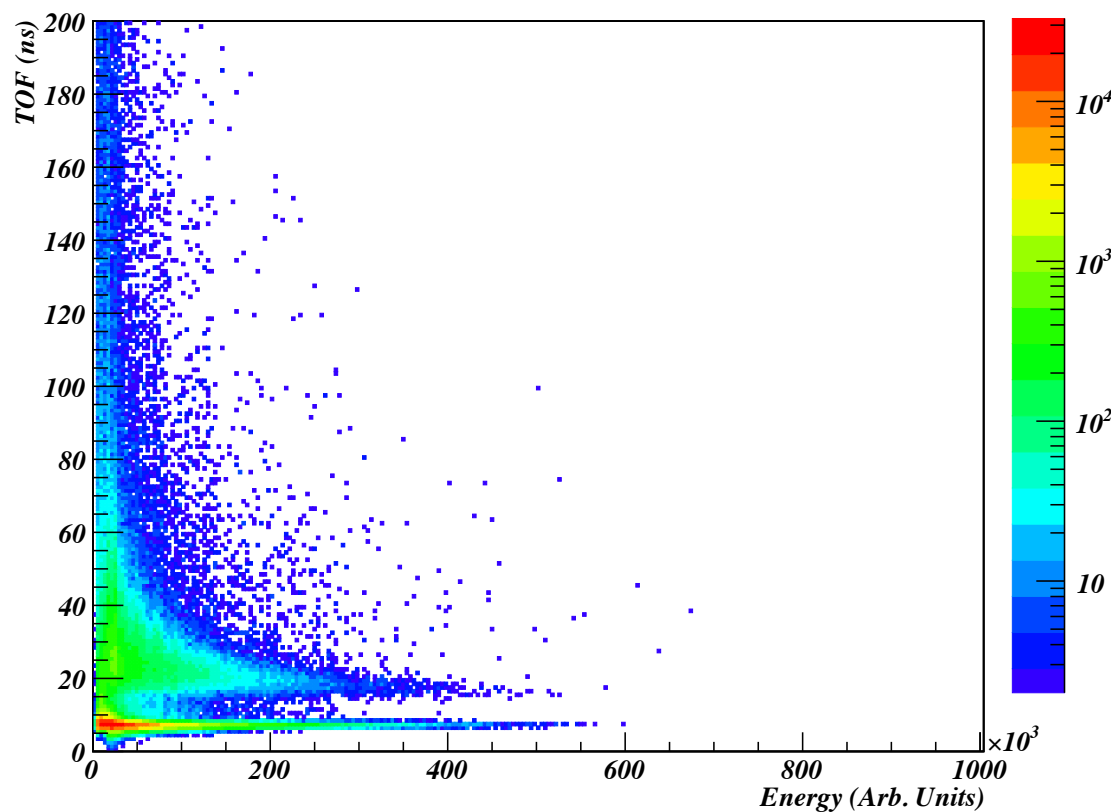




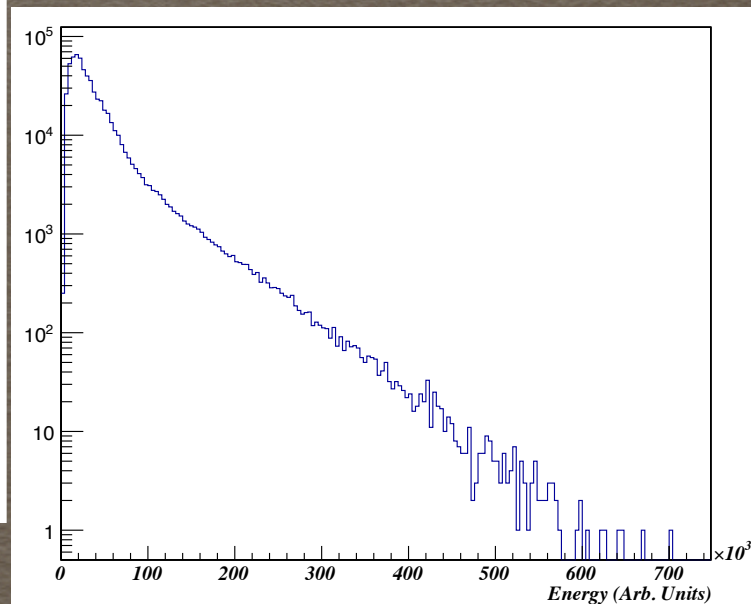
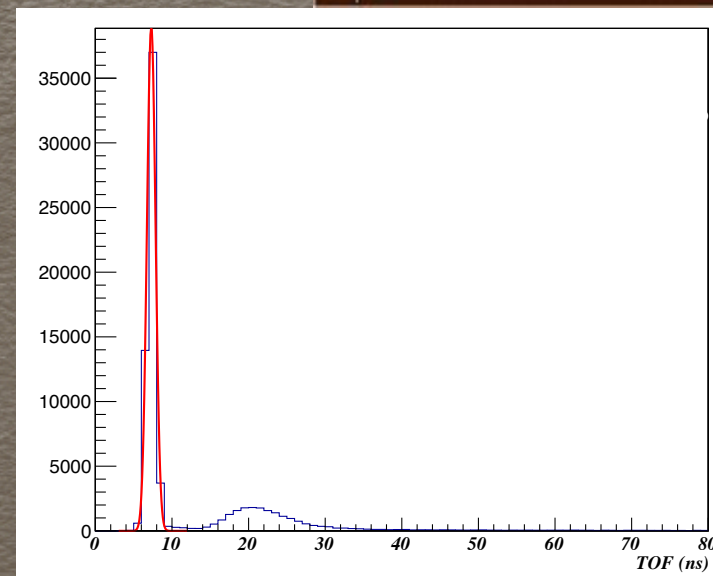
Preliminary Results for N-SI-86 Experiment With PARIS



^{252}Cf γ and neutrons from
spontaneous fission



Courtesy of Q. Liqiang & M. Lebois



AGATA@GANIL (ca. 2017)

PARIS campagne manager: Ch. Schmitt

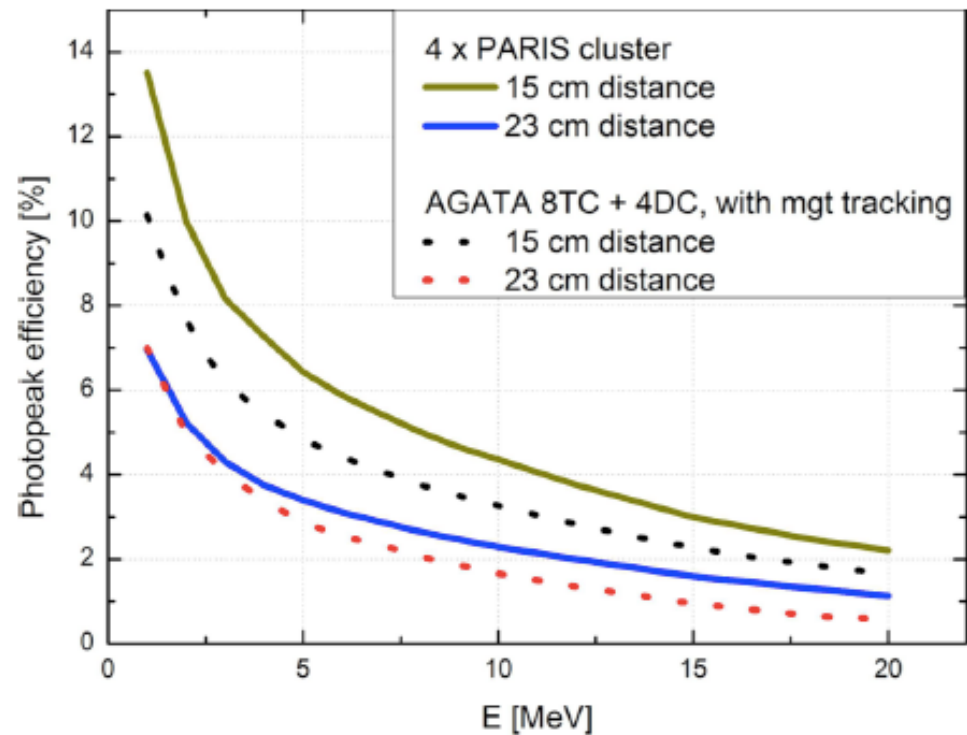
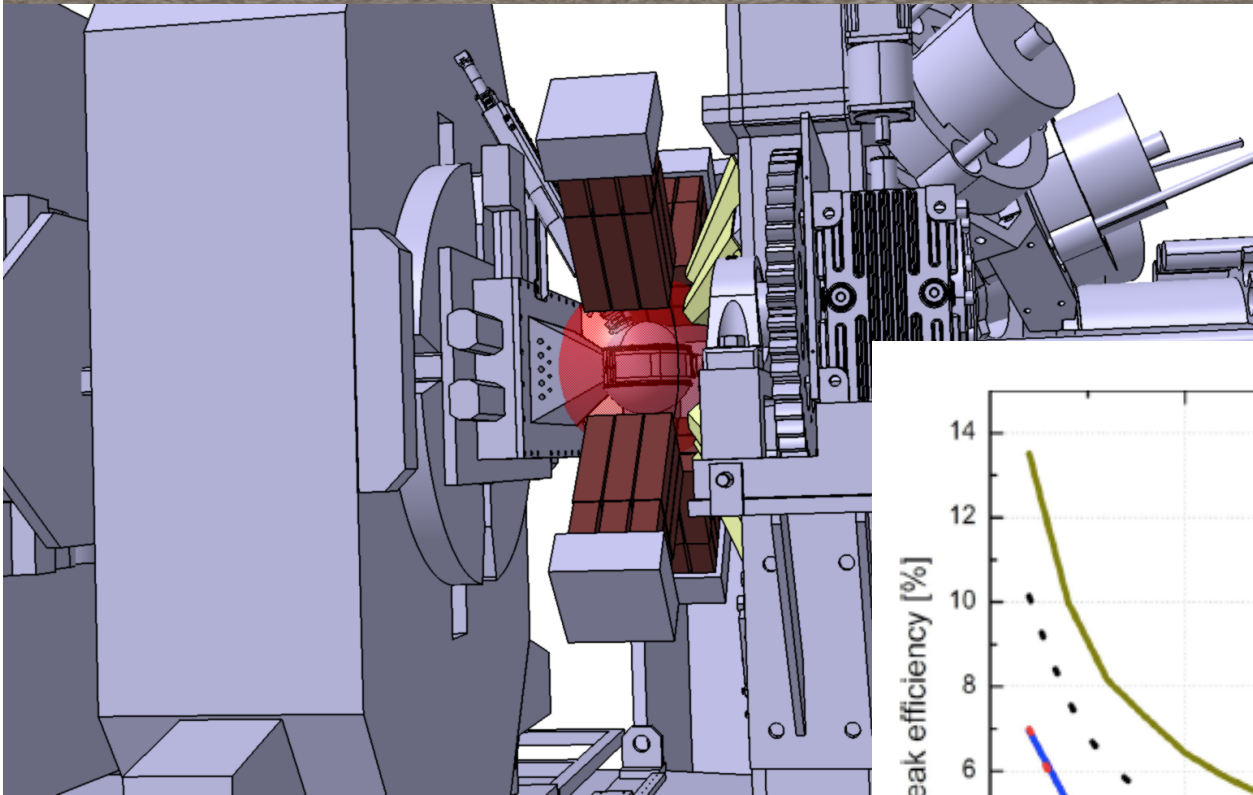
2 proposals accepted by the GANIL PAC

- S. Leoni, B. Fornal, M. Ciemala, **Lifetimes in A=18 region measured with PARIS** (at least 2 clusters), AGATA, VAMOS, Plunger
- P. Bednarczyk, A. Maj, **Investigation of a high spin structure in ^{44}Ti via discrete and continuum γ -spectroscopy** with AGATA, PARIS (4 clusters) and DIAMANT

2 proposals submitted recently for AGATA@GANIL (ca. 2018)

- S. Leoni, B. Fornal, M. Ciemala, „**Gamma decay from near-threshold states in ^{14}C : a probe of clusterization phenomena in open quantum systems**”, AGATA, PARIS, NEDA, DIAMANT, DSSD
- B. Cederwall, A. Maj, **Complete spectroscopy of extremely deformed nuclei in the A \approx 90 region at high angular momentum**” AGATA, PARIS, NEDA, DIAMANT

PARIS and VAMOS and AGATA @GANIL



Standard geometry:
4 PARIS clusters at 23 cm from the target

1 LoI for LISE@GANIL (ca. 2018)

- M. Vanderbrouck, „Study of giant and pygmy resonances in exotic nuclei at LISE”, ACTART TPC, Chateau de Cristall, CATS, PARIS

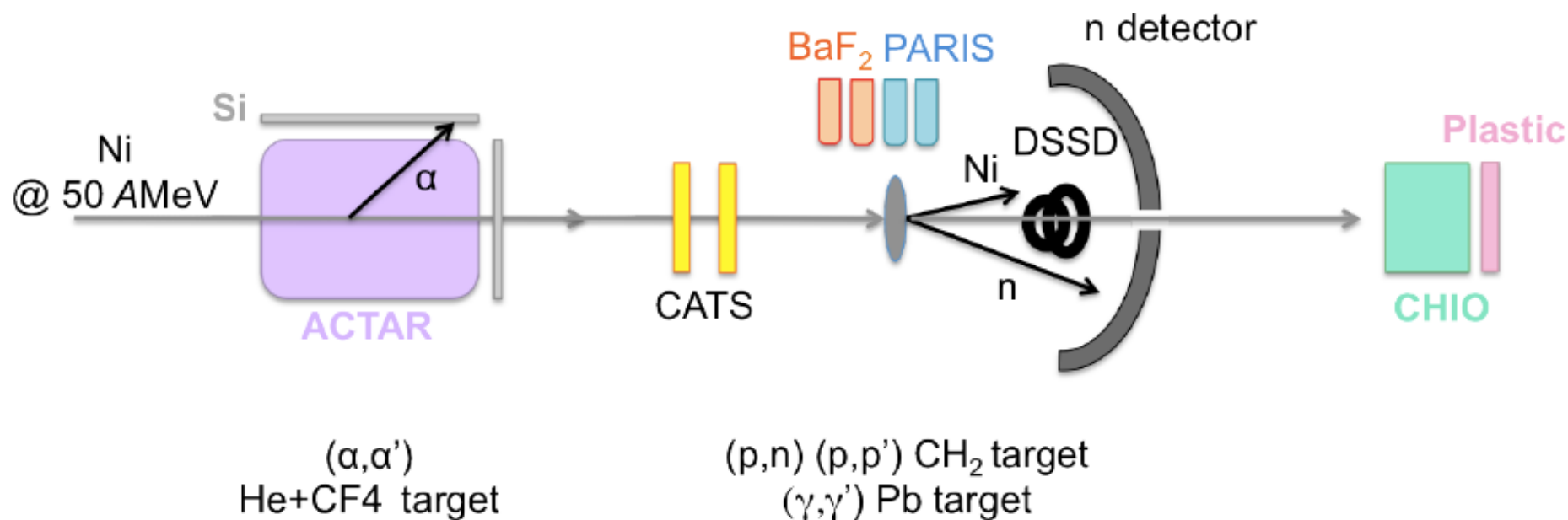


Figure 4: Proposed experimental setup.

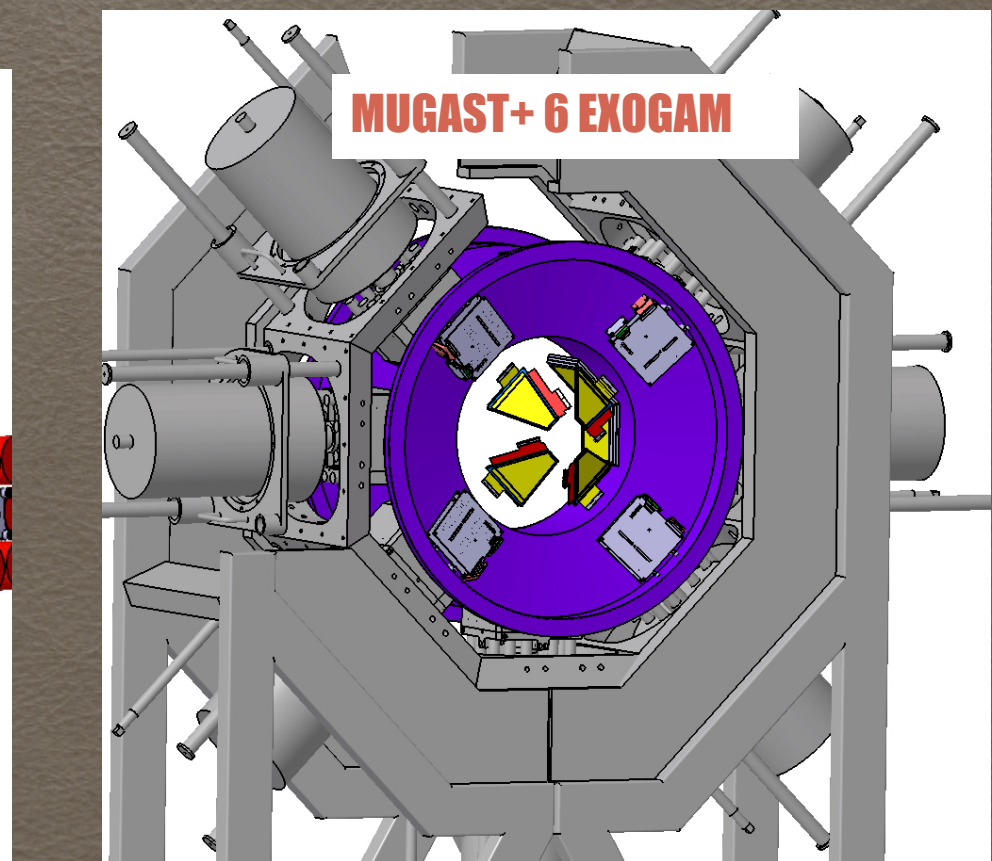
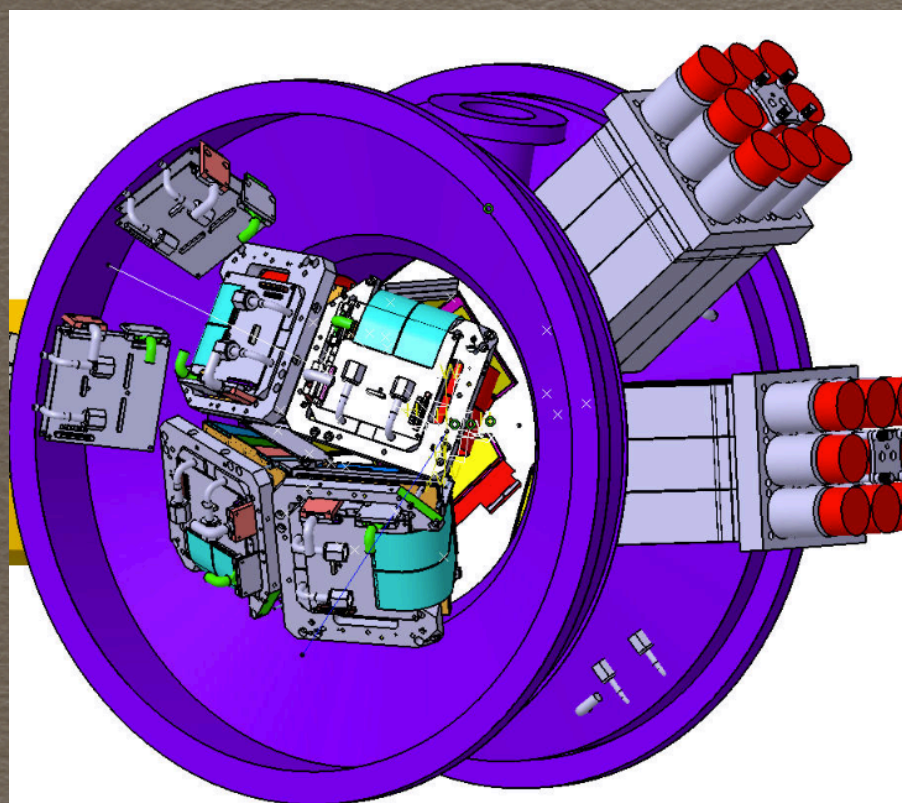
- 1 LoI for MUGAST@GANIL
- G. De Angelis, C. Domingo Pardo, „The $^{79}\text{Se}(n, \gamma)$ capture cross section via the surrogate $^{79}\text{Se}(d, p)^{80}\text{Se}$ reaction”, MUGAST, PARIS

« MUGAST » configuration = MUST2 + GASPARD (trapeze) +TRACE (square)
available for AGATA campaign at GANIL (2017)

read by MUST2 electronics (MUFEE+MUVI)

Possible gamma detector's configurations :

- 6 PARIS clusters (if available)
- 6 EXOGAM



1 proposal for NFS@SPIRAL2/GANIL

- **Eric Bonnet, „Measurement of the absolute neutron detection efficiency of FAZIA telescopes“, FAZIA (+ eventually PARIS cluster)**

**Next PARIS campaigns under
consideration**

CCB Krakow (2016/2017, campaign manager tbc)

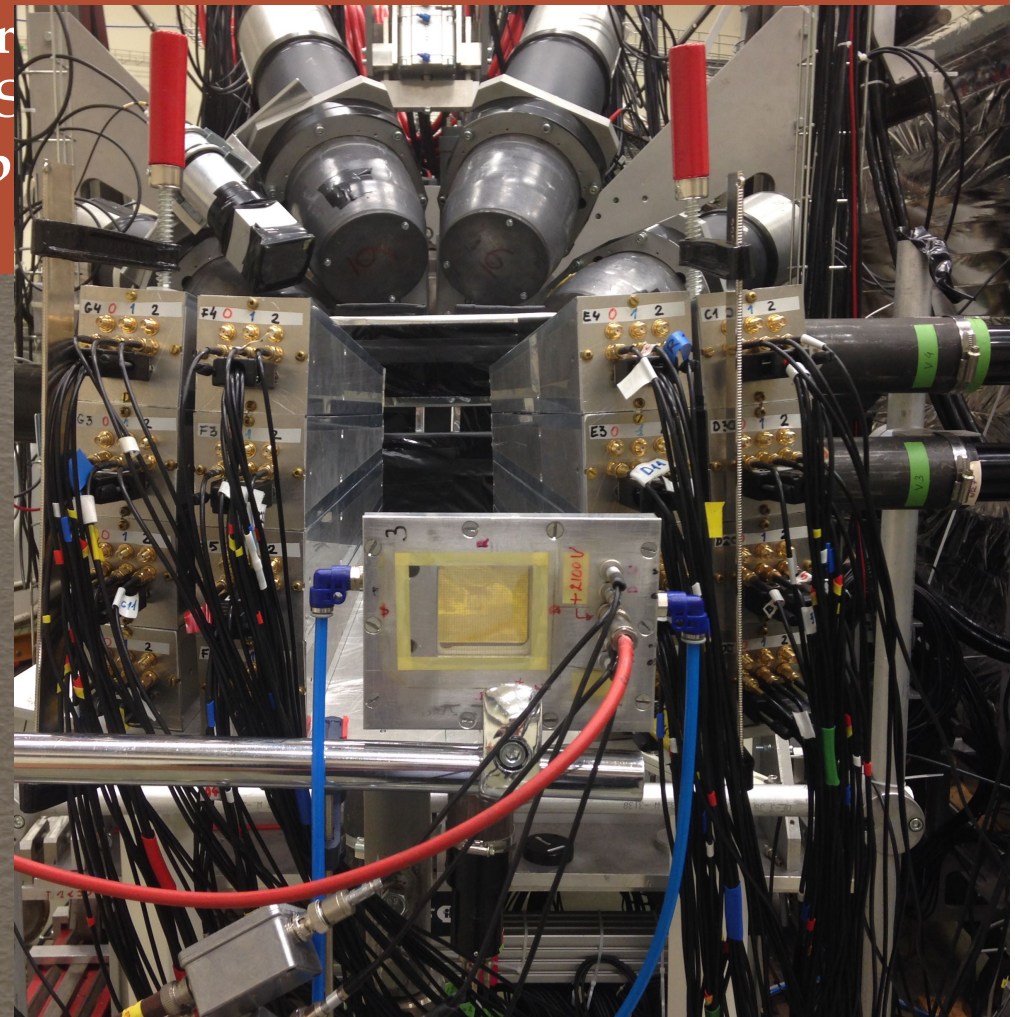
4 LoIs accepted by IAC:

- **Studies of resonance states in nuclei using high-energy proton beam in p,p' reactions** (Crespi, Kmiecik): HECTOR, PARIS, KRATTA,
- Investigations of $(p,2p)$ reactions in order to identify deep single-particle proton-hole states (Bracco, Fornal) HECTOR, PARIS, KRATTA
- Gamma-decay of GDR in proton in (Camera, Kmiecik) HECTOR, PARIS
- Investigation of proton induced sp HECTOR, PARIS, KRATTA

SETUP

HECTOR: 8 large BaF₂'s
1 large LaBr₃
1 small LaBr₃
1 PARIS phoswich

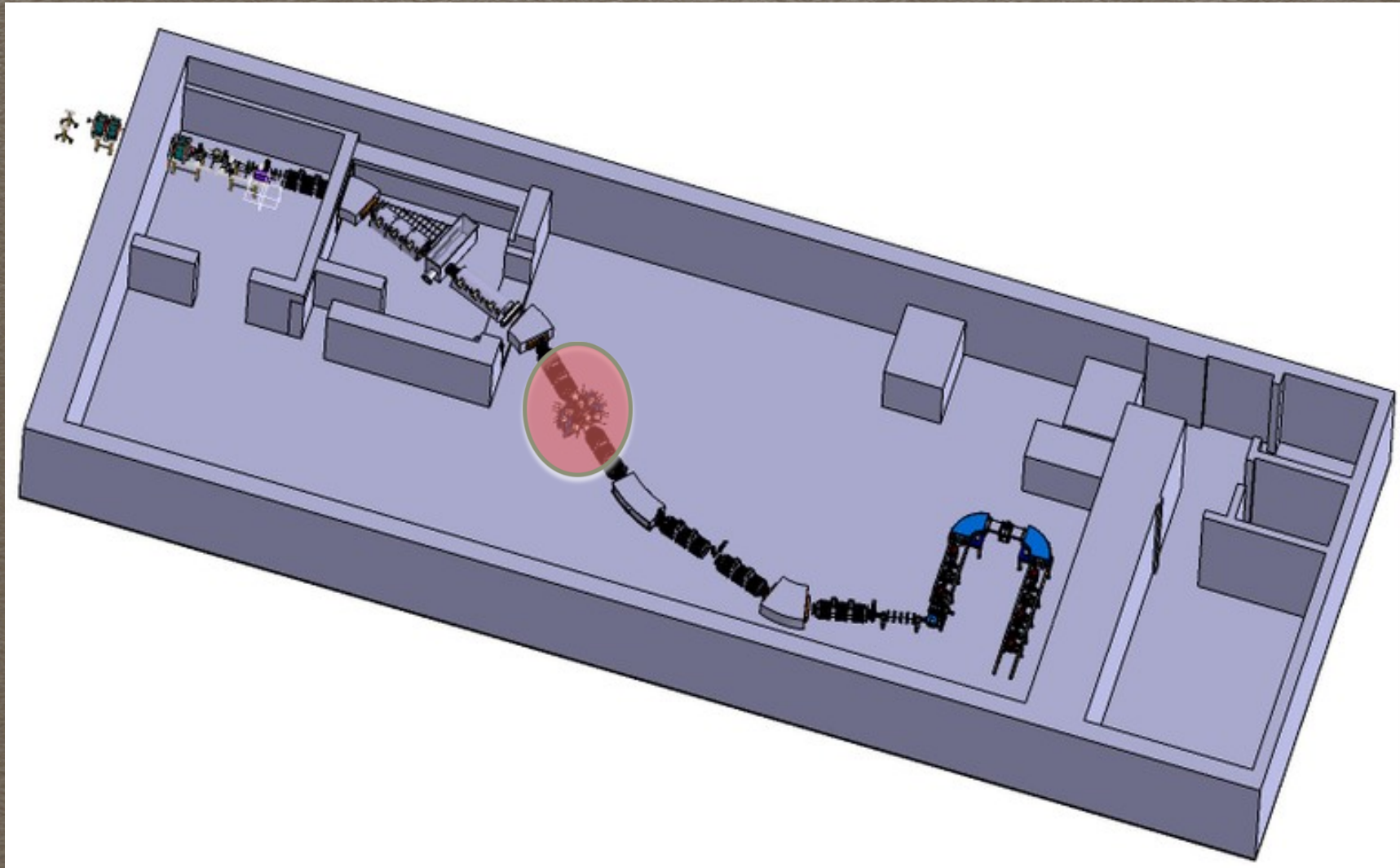
KRATTA tripple telescope array



7 LoIs for PARIS4SPES campaign (2018?)

- **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 $A \sim 90$ Rb radioactive beams at SPES** (Bednarczyk): GALILEO
- **GDR feeding of the SD bands in $A=30-60$ region** (P. Bednarczyk, M. Kmiecik, F. Camera)

Near future: Ideas of mechanical coupling of PARIS clusters to S^3 middle focal plane



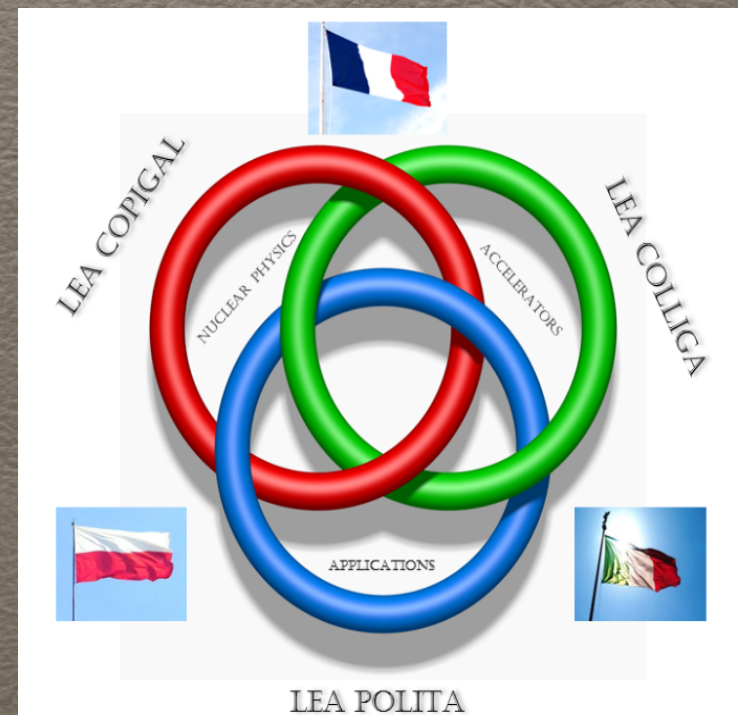
Summary



PARIS

PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

- LaBr₃+NaI phoswich is a viable solution for the elements of the PARIS calorimeter, in terms of it meeting the requirements for energy and timing resolution
- Presently we explore the performance of a cluster of 9 phoswich detectors. Source and in-beam testing of this cluster were done recently.
- Electronics for AGATA experiments based on analogue PARIS-Pro + AGAVA, data stream via VAMOS branch. Commercial digitizer is under tests, which looks very promising
- The next phase will be to complete the PARIS Phase2 (Demonstrator) of 4 clusters, each of 9 phoswich detectors. *(Some delay, due to the delays in delivery time of phoswiches)*
- First PARIS physics experiments are coming in
FRANCE: AGATA@GANIL and IPN Orsay;
POLAND: CCB Krakow and HIL Warsaw;
FRANCE: LNL/SPES Legnaro (Italy).
- **PARIS is a very good example of a coherent (and succesful despite all problems) collaboration within COPIGAL+CallAGAIN+POLITA**



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F. Azaiez, I. Matea – **IPN Orsay**; O. Dorvaux, S. Kihel – **IPHC Strasbourg**;

M. Lewitowicz, Ch. Schmitt – **GANIL**; O. Stezowski – **IPN Lyon**;

A. Bracco, S. Leoni, F. Camera, S. Brambilla, B. Million, O. Wieland, A. Giaz – **INFN & U. Milano**;

V. Nanal, I. Mazumdar – **TIFR Mumbai**; D. Jenkins – **York**; and many others

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