PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

Status of PARIS

Adam Maj
IFJ PAN Krakow
for the PARIS collaboration

GASPARD-HYDE-TRACE Workshop
IPN Orsay, 23-24.01.2017

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 (LaBr3(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 (BaF2 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) ***
$^{130\text{-}142}$Ba, $^{116\text{-}120}$Cd, $^{88\text{-}98}$Mo, ^{71}Zn
(**A. Maj, J. Dudek, K. Mazurek** et al.)

b) **Studies of shape phase diagrams of hot nuclei – GDR differential methods**
$^{186\text{-}193}$Os, $^{190\text{-}197}$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**
$^{214\text{-}222}$Ra, $^{118\text{-}226}$Th, $^{229\text{-}234}$U
(**Ch. Schmitt, O. Dorvaux** et al.)

g) **Heavy ion radiative capture ***
^{24}Mg, ^{28}Si

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 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 S^3) ***
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.

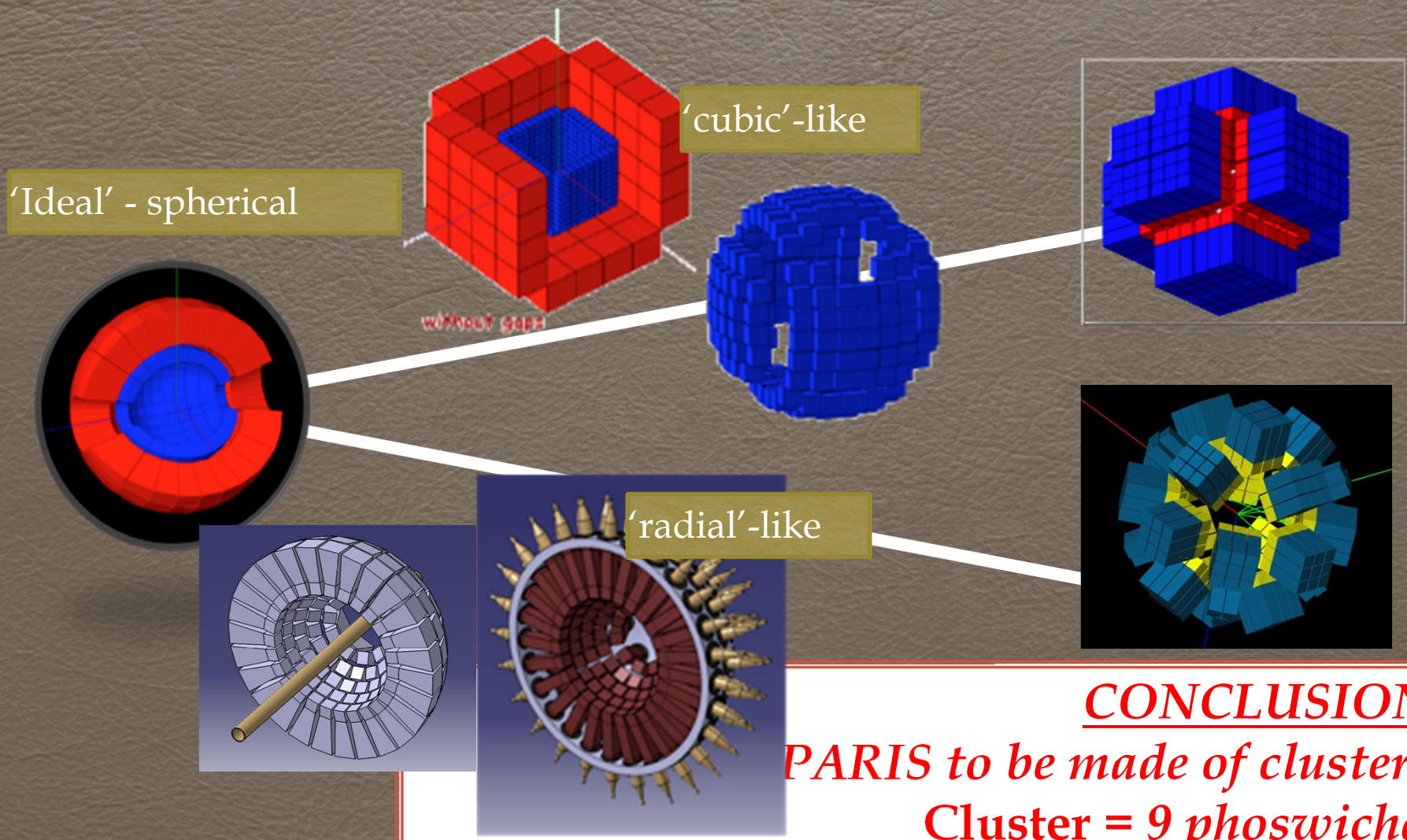
o) **Onset of chaotic regime: PARI+AGATA**
S. Leoni et al.

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**, EXOGAM, **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,…)

Several geometries studied



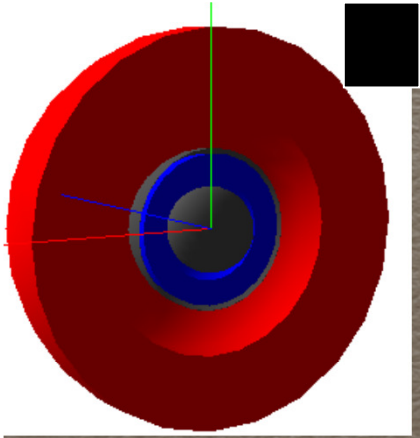
CONCLUSION:

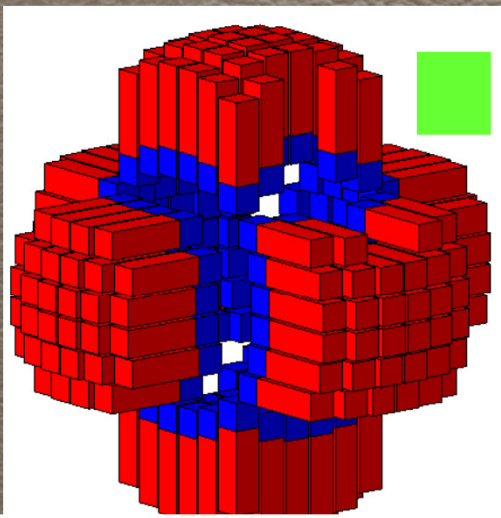
PARIS to be made of clusters:

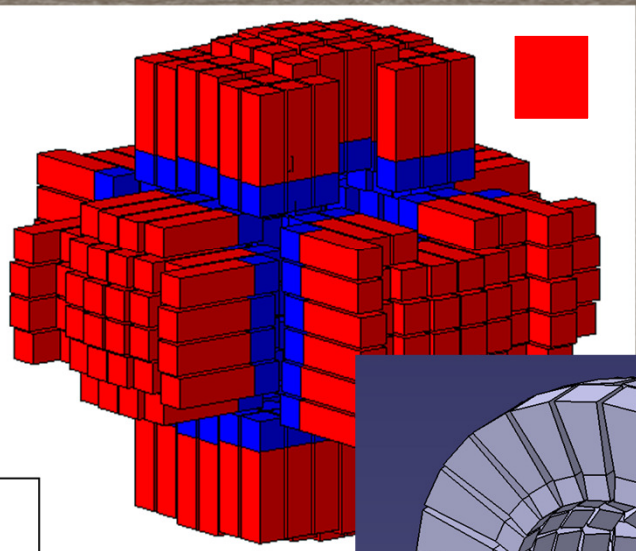
Cluster = 9 *phoswiches*

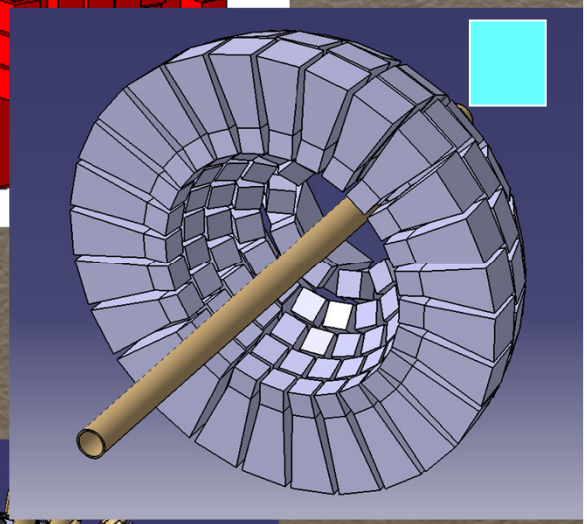
This allows *cubic* or *semi-spherical* geometry with 24 clusters (216 phoswiches)

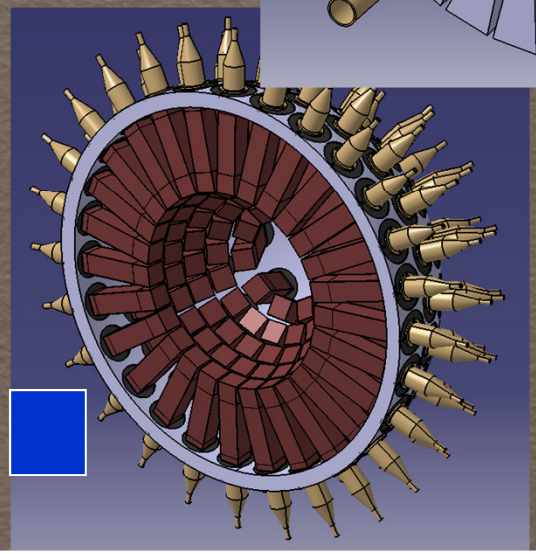
Cubic vs. Radial geometry

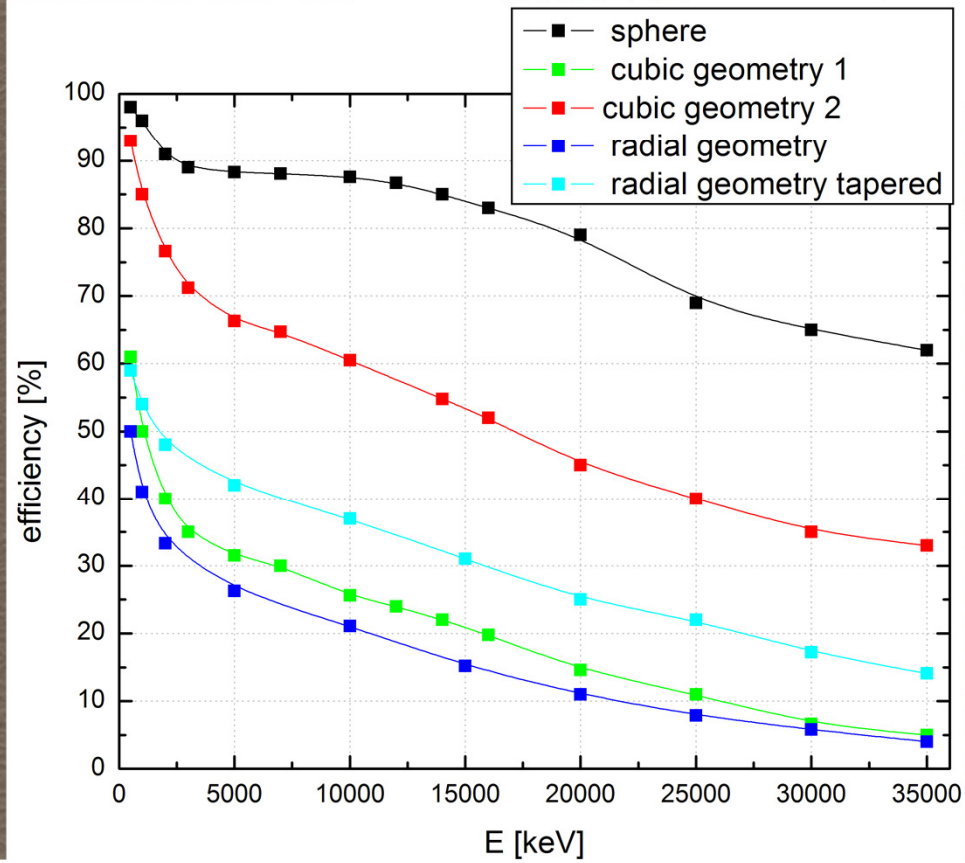












Institutions actively working for PARIS

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

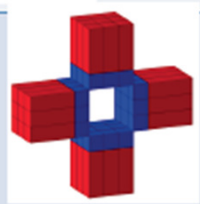
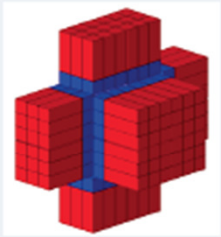
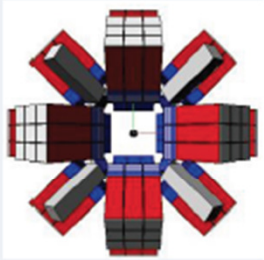
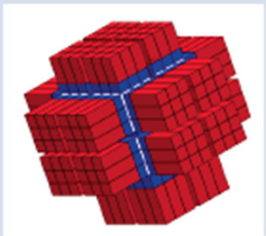
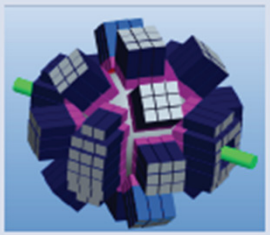
TURKEY (coord.: S. Ertürk): U. Istanbul, U. Nigde, U. Kayseri, U. Akteniz

ROMANIA (coord.: M. Stanoiu) 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), 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. wit AGATA and GASPARD Other exp.
Phase 4 2022? **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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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: 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

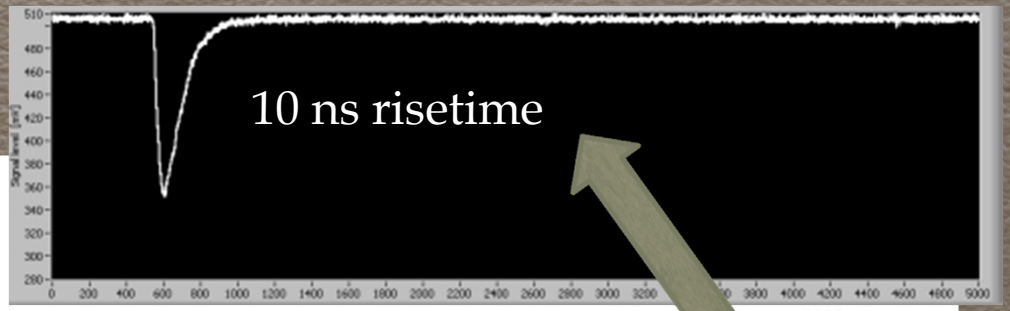
Campaign Spokesperson
(nominated by lab directors):
GANIL: C. Schmitt
IPN Orsay: I. Matea

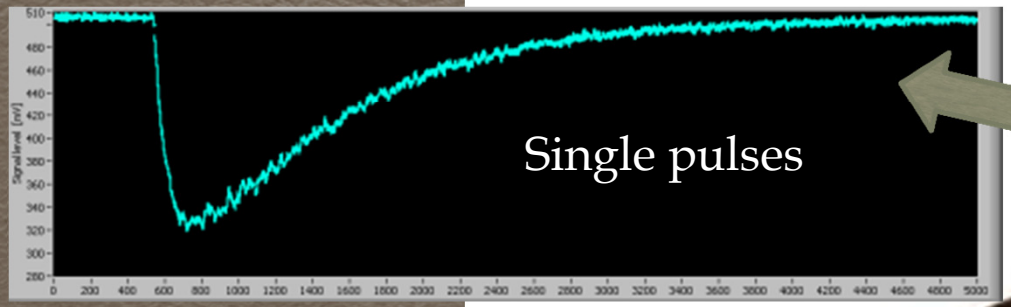
PARIS Collaboration Council – representing each institution interested in PARIS. Chair is elected for 2 years term

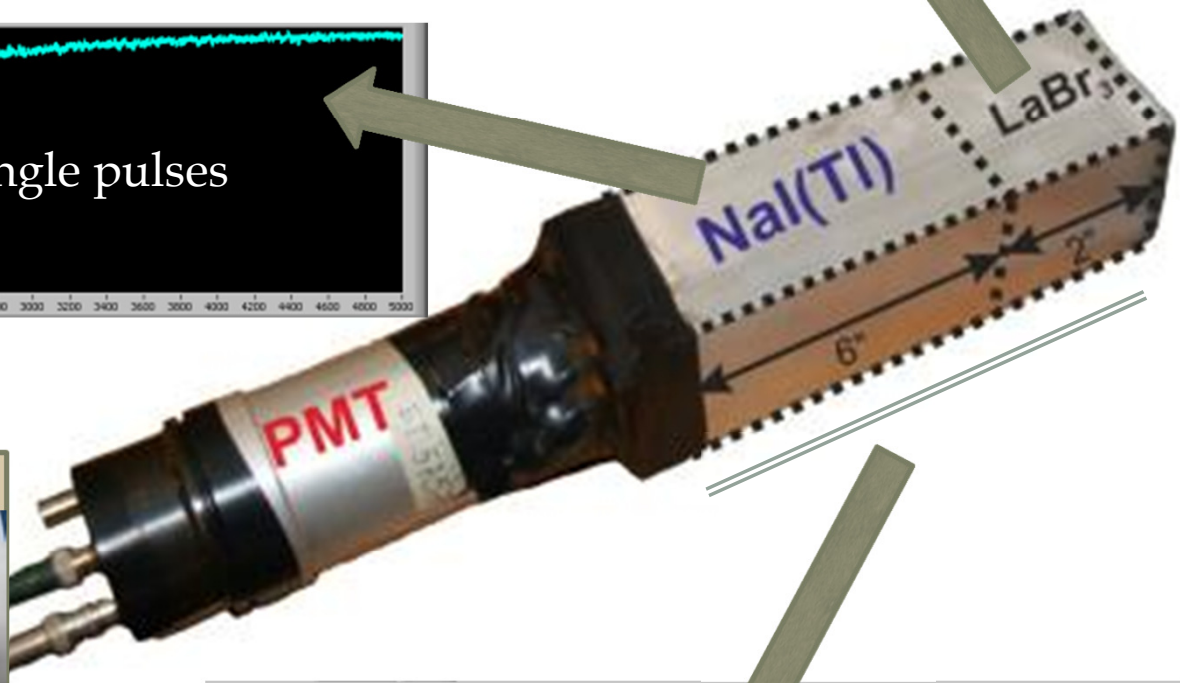
PARIS Collaboration Council:

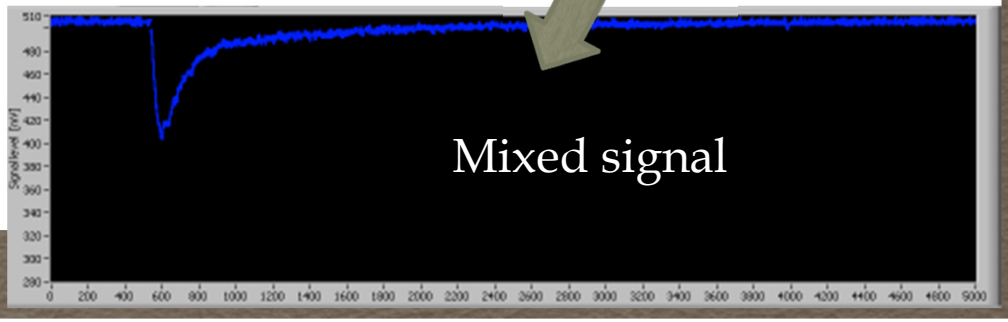
David Jenkins (University of York, UK) - chair and PARIS spokesman
Sudhee R. Banerjee (VECC Kolkata, India)
Franco Camera (INFN and University of Milano, Italy)
Wilton N. Catford (University of Surrey, UK)
Marco Cinausero (LNL Legnaro, Italy)
Sandrine Courtin (IPHC Strasbourg, France)
Zsolt Dombradi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

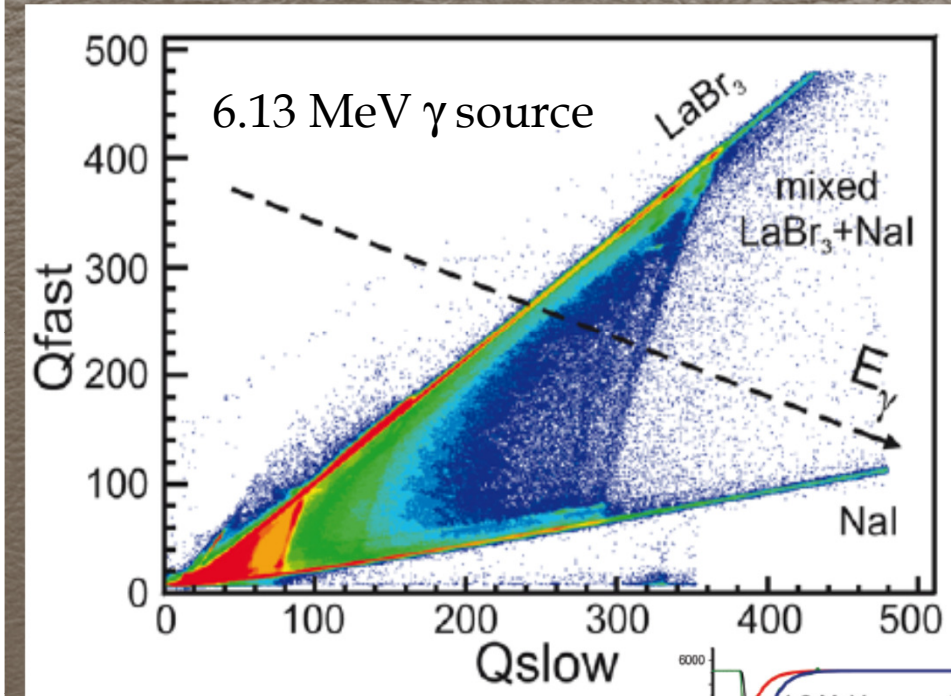
The PARIS PHOSWICH at work

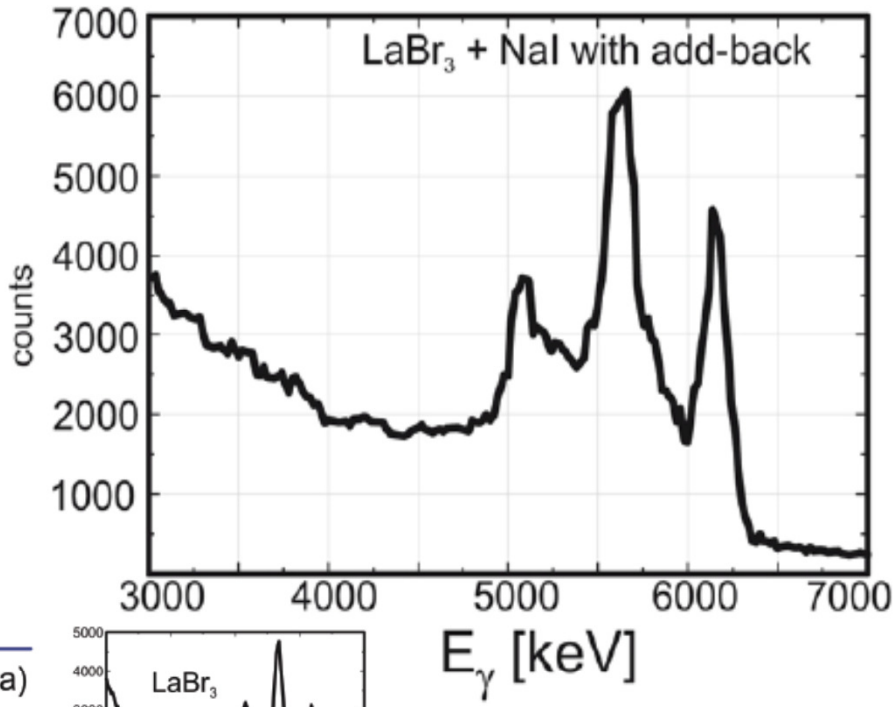


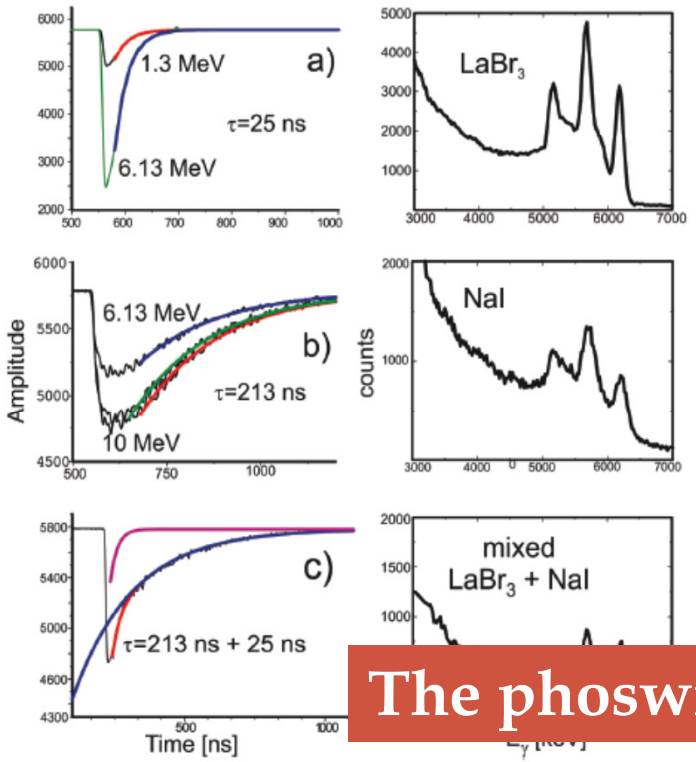












A test measurement at IFJ PAN, Kraków (2011) with BafPro module from Milano

- Sources
- proton beam

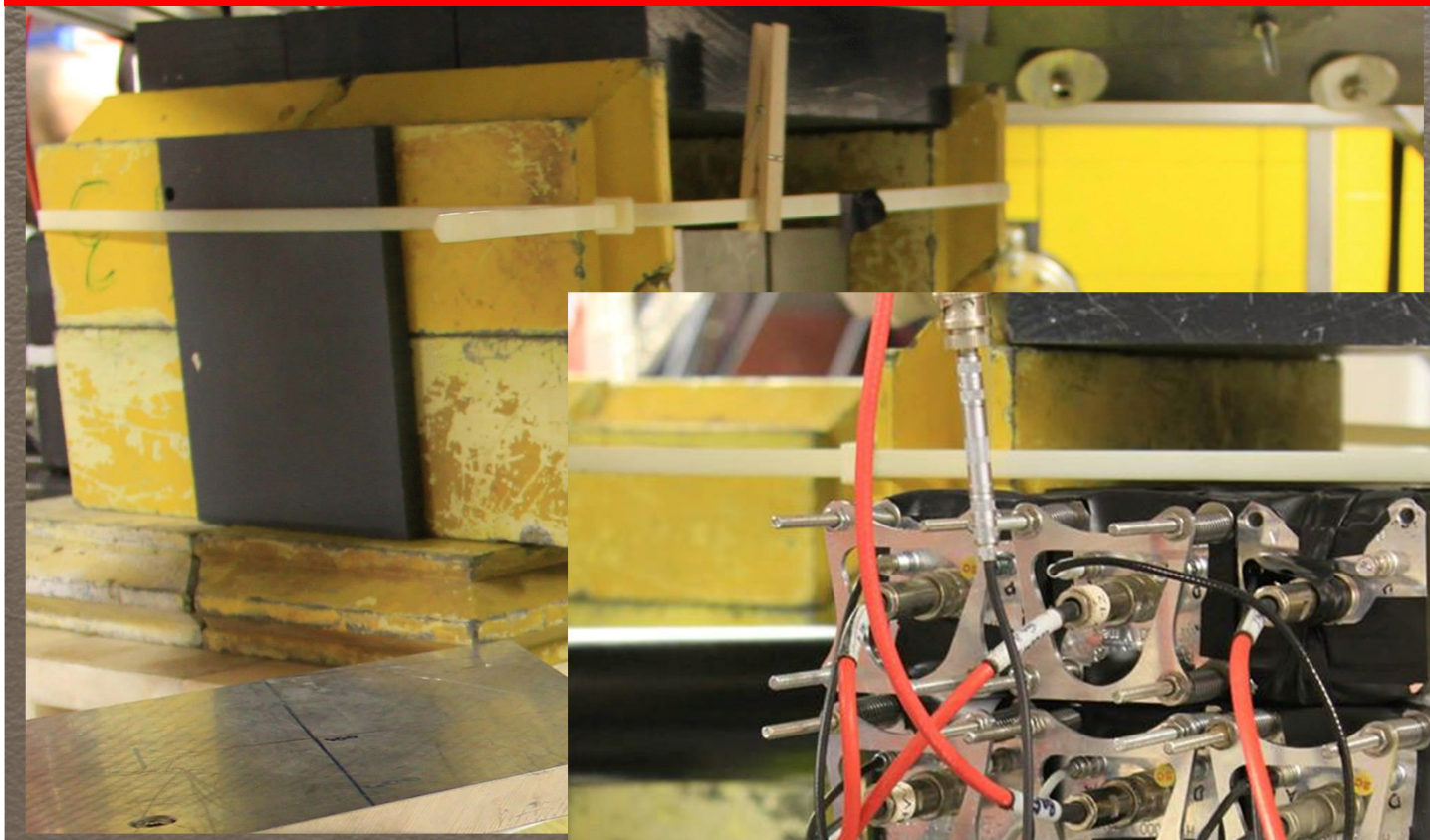
LaBr3 resolution (seen through 6" long NaI): ca. 4%

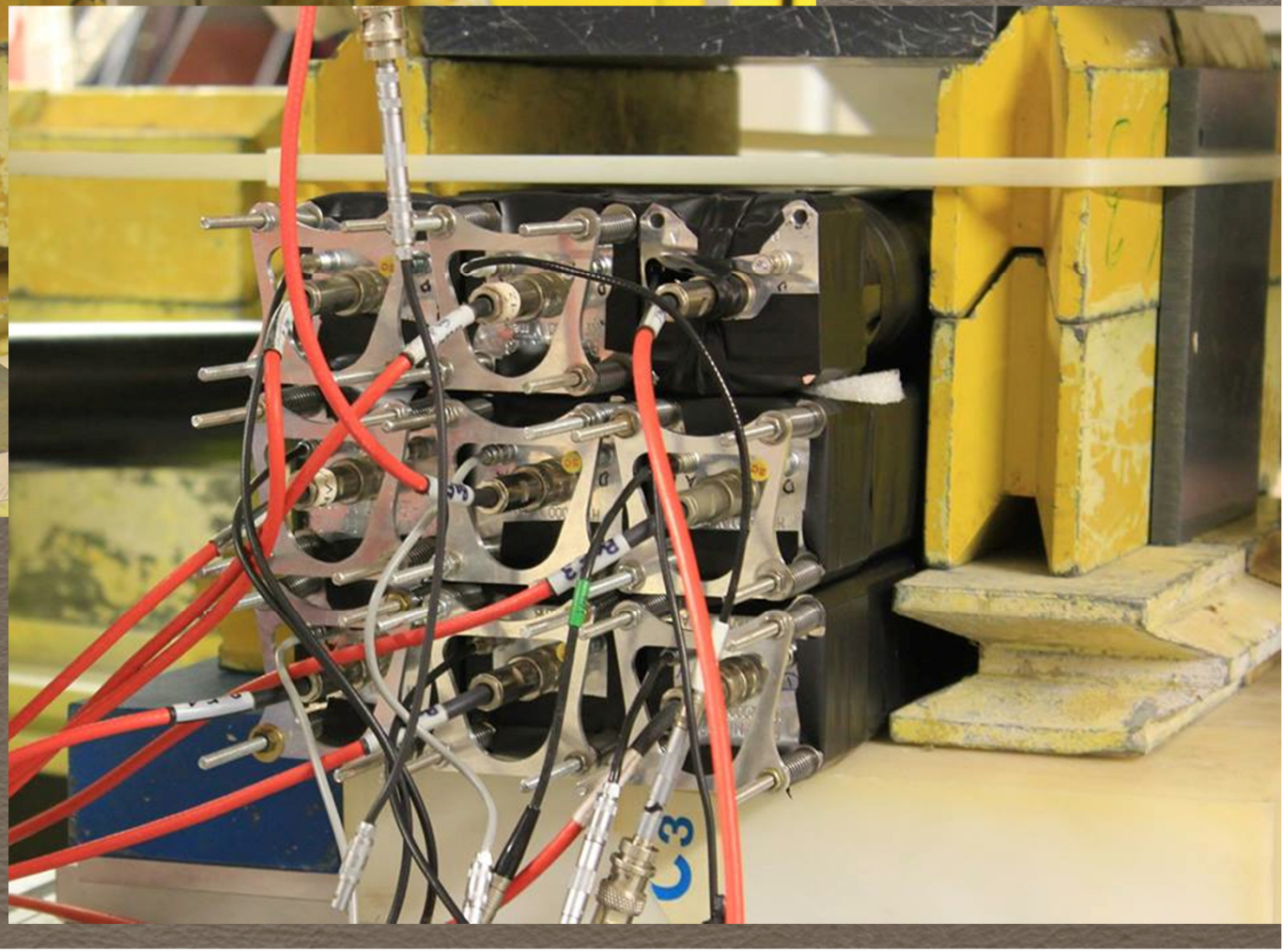
M. Zieblinski et al., Acta Phys.Pol. B44, 651 (2013)

The phoswich concept works!

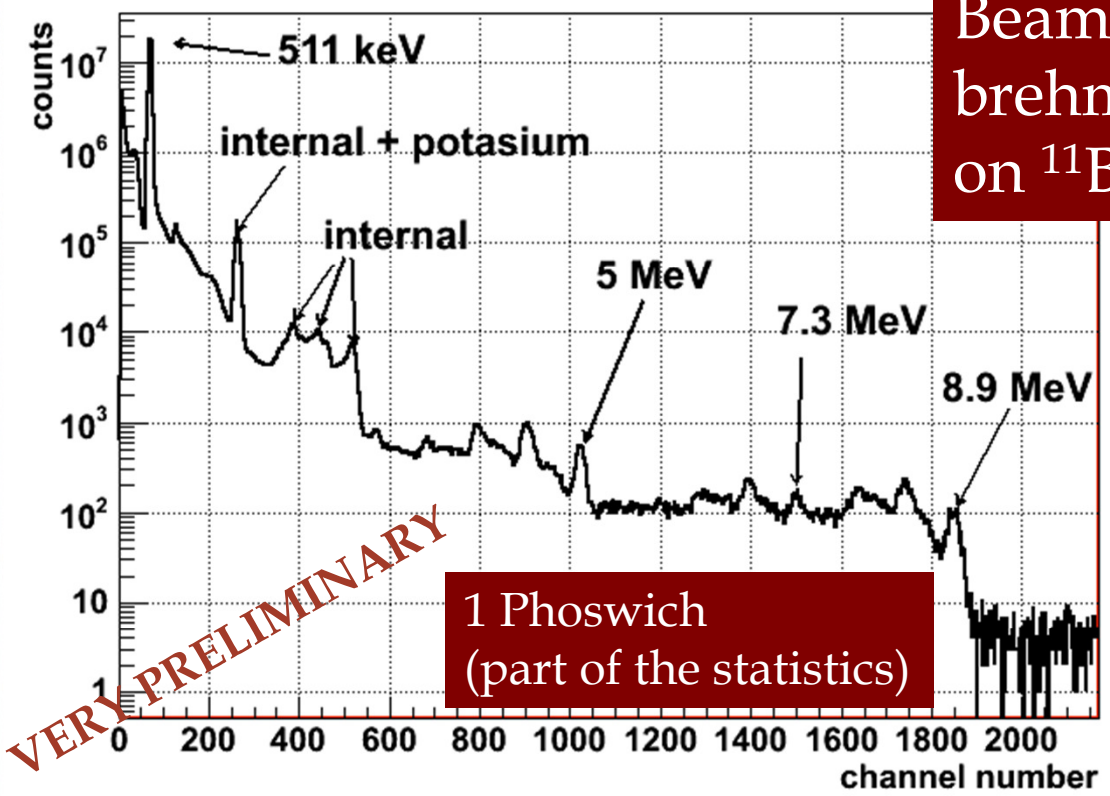
ELBE facility, Dreseden 10-12 December, 2013

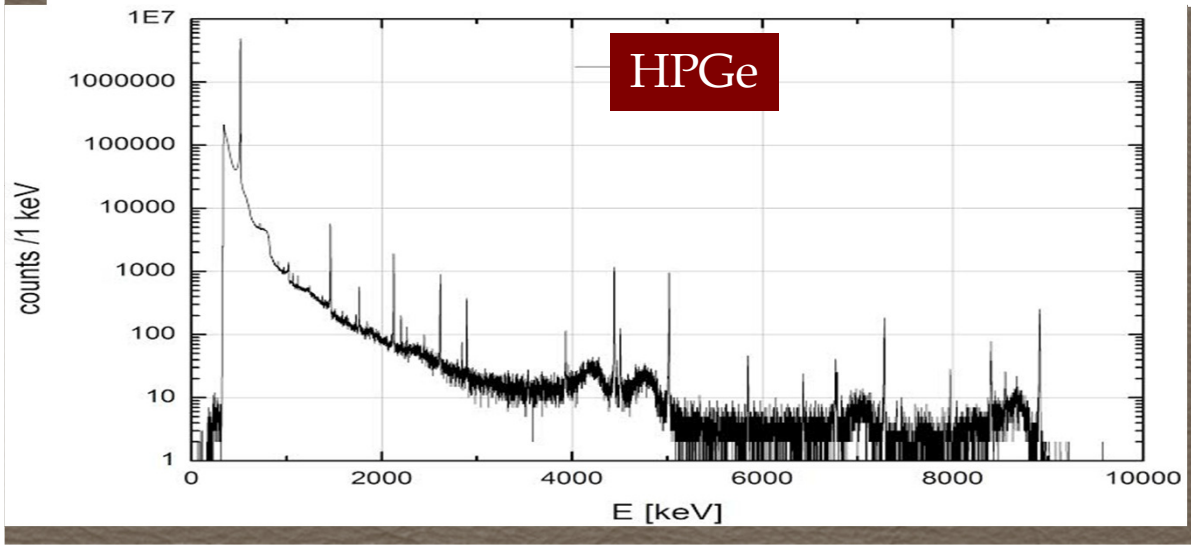
Nuclear Resonance Fluorescence experiment (Mazumdar, Maj, Schwengner)





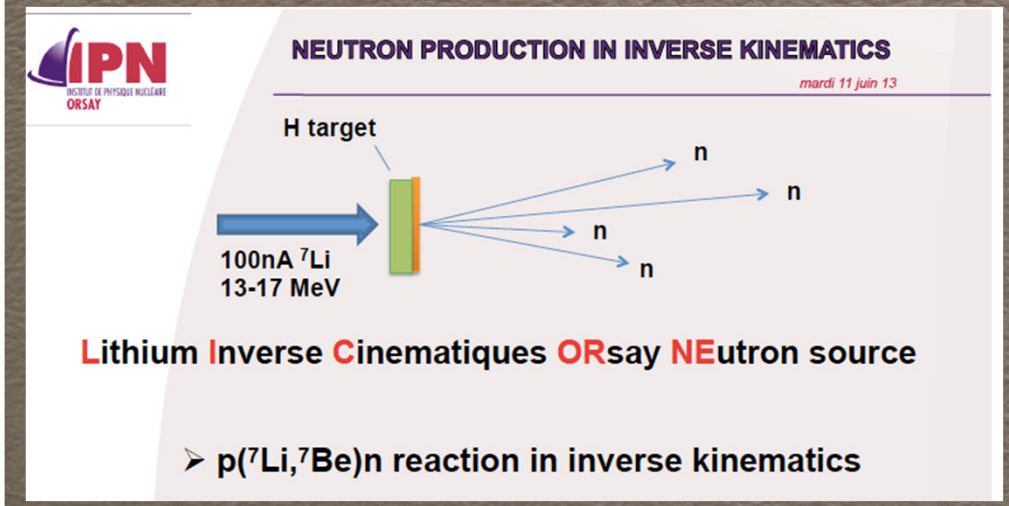
Beam 15 MeV electrons: brehmstallung gamma beam on ^{11}B target

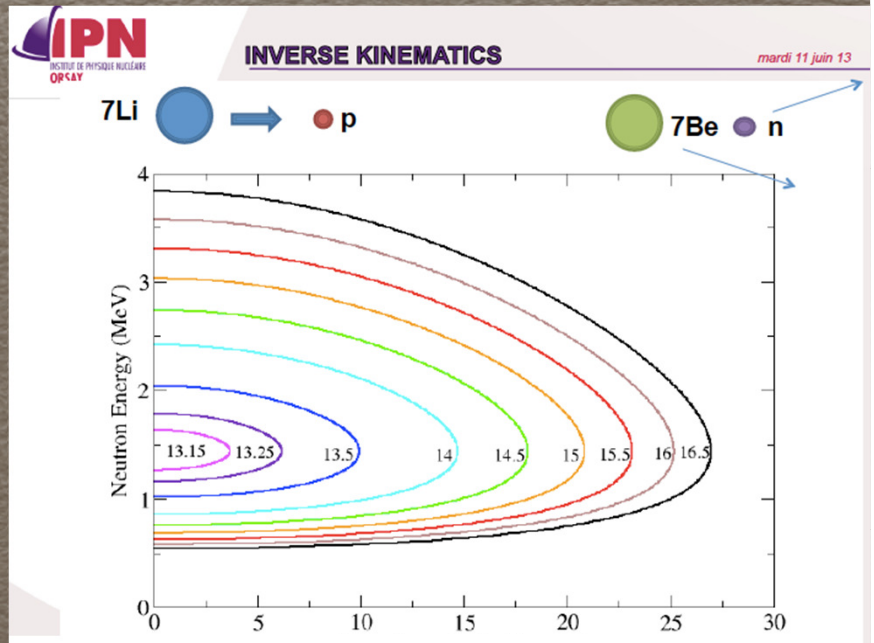


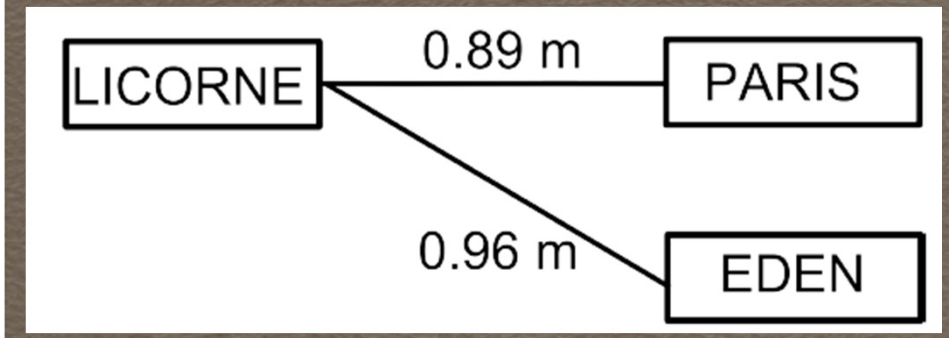


Testing the PARIS cluster at LICORNE@IPNO

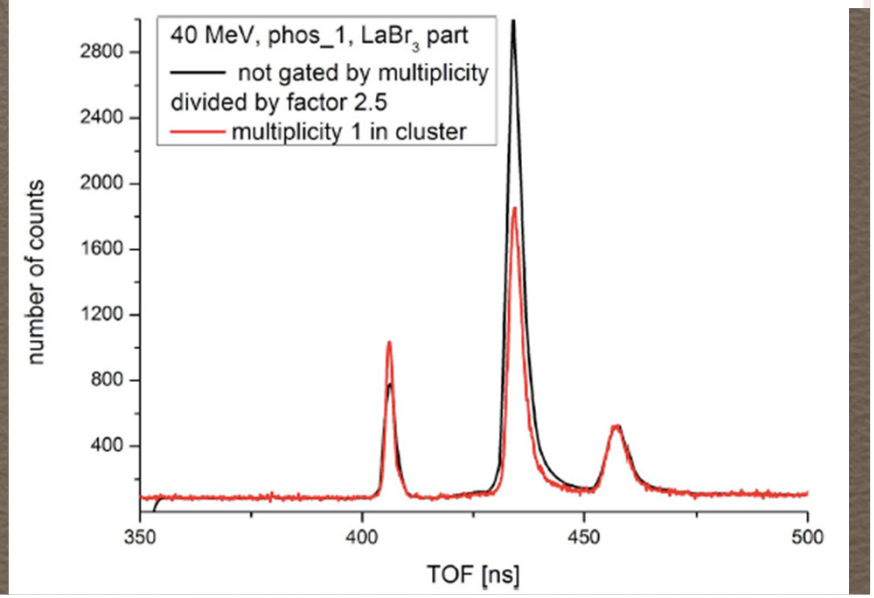
(J. Wilson, I. Matea et al.)



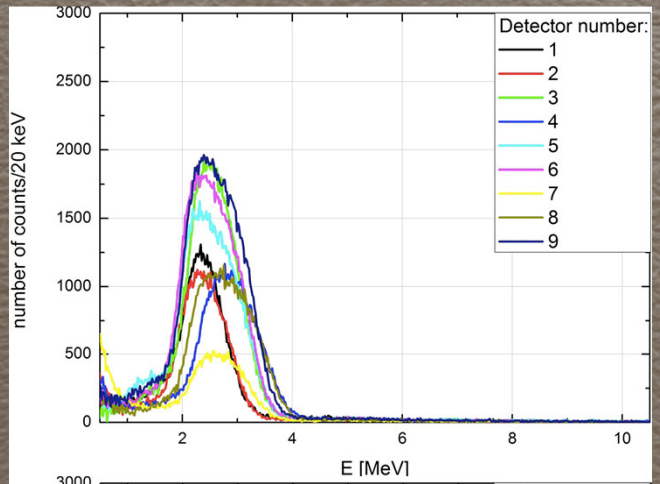




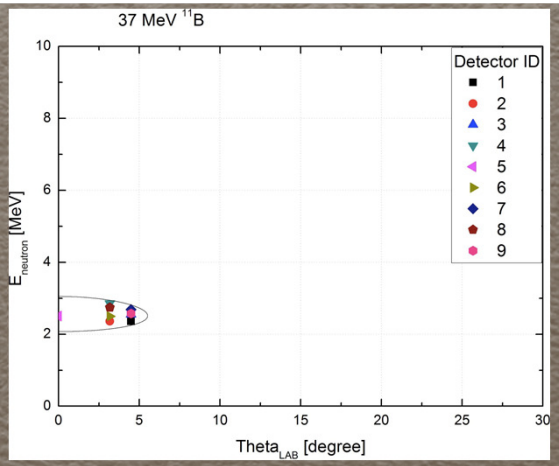
^{11}B was used as a beam instead of ^{7}Li

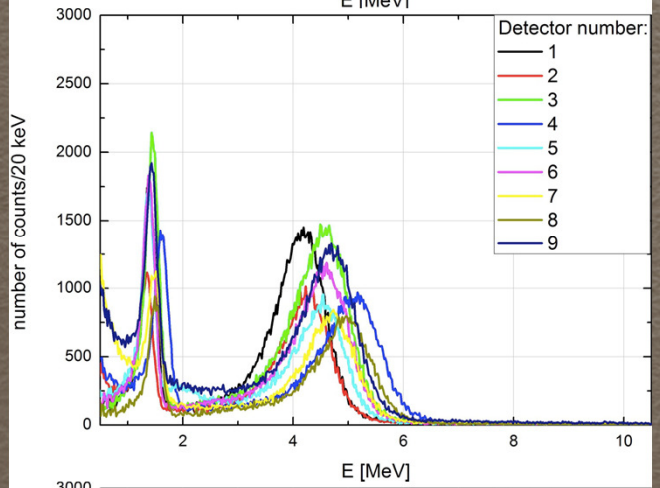


Analysis: M. Ciemała et al.. (to be published)

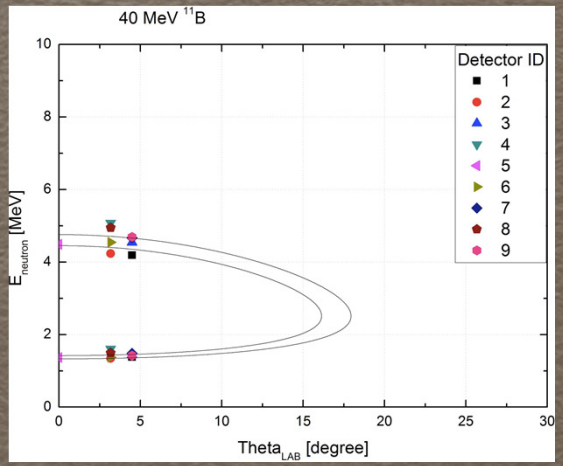


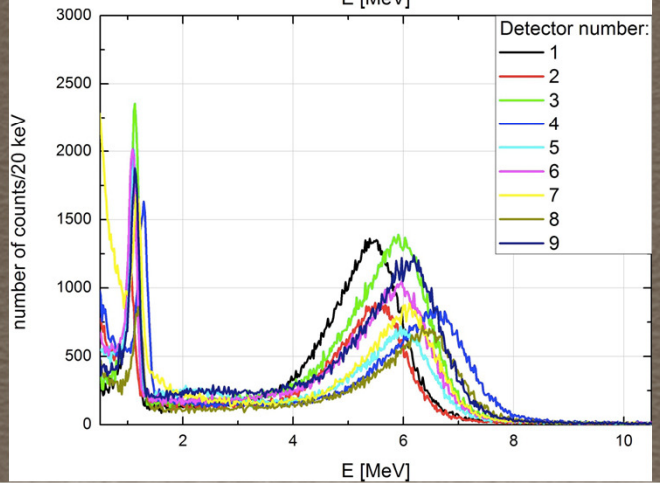
37 MeV



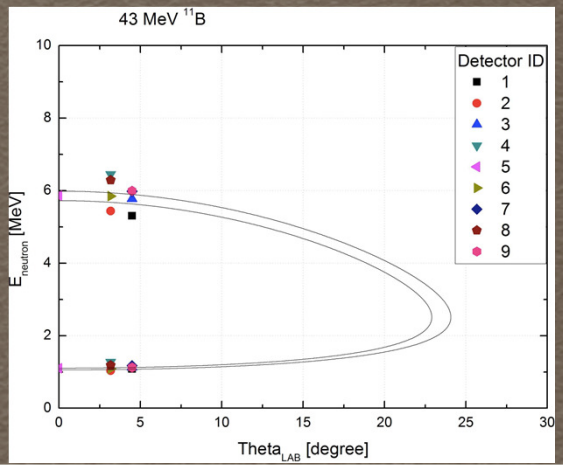


40 MeV



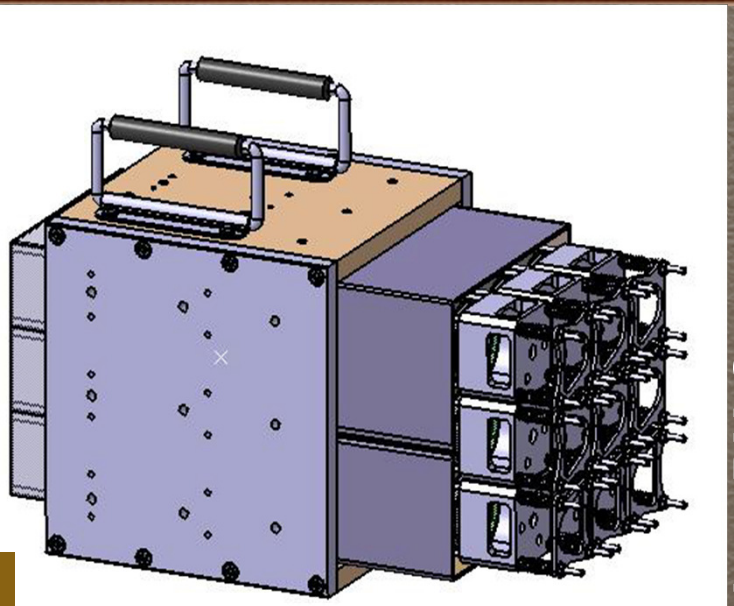


43 MeV

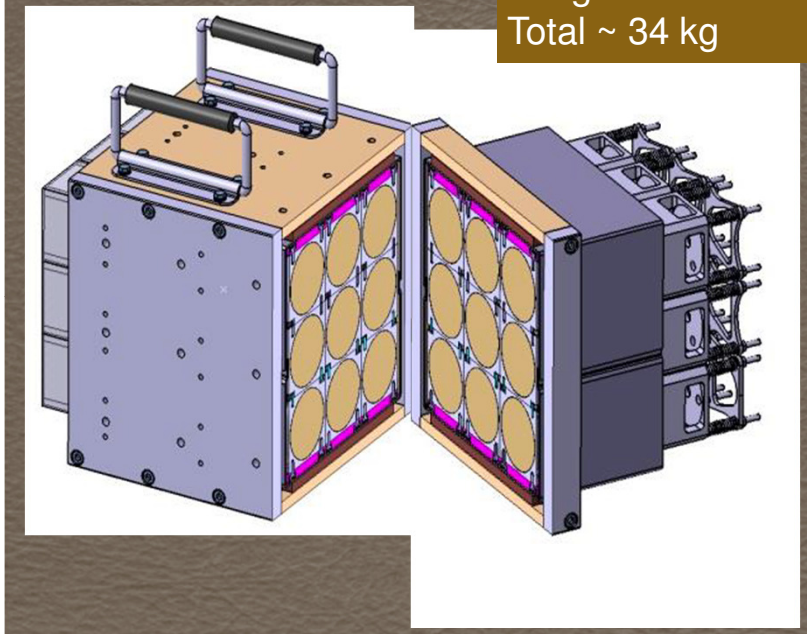


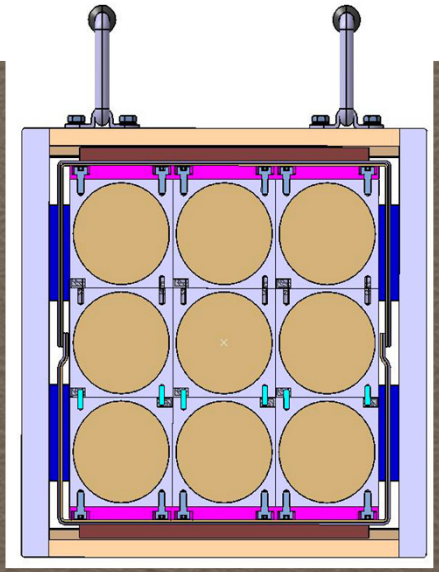
the mechanical design

- **Special mechanical design to ensure the optical coupling and compatible with the assembly in a "cluster" configuration of 9 phoswiches**



Weight 9 cristal LaBr3+NaI ~ 23 kg
Weight cluster ~ 11 kg
Total ~ 34 kg



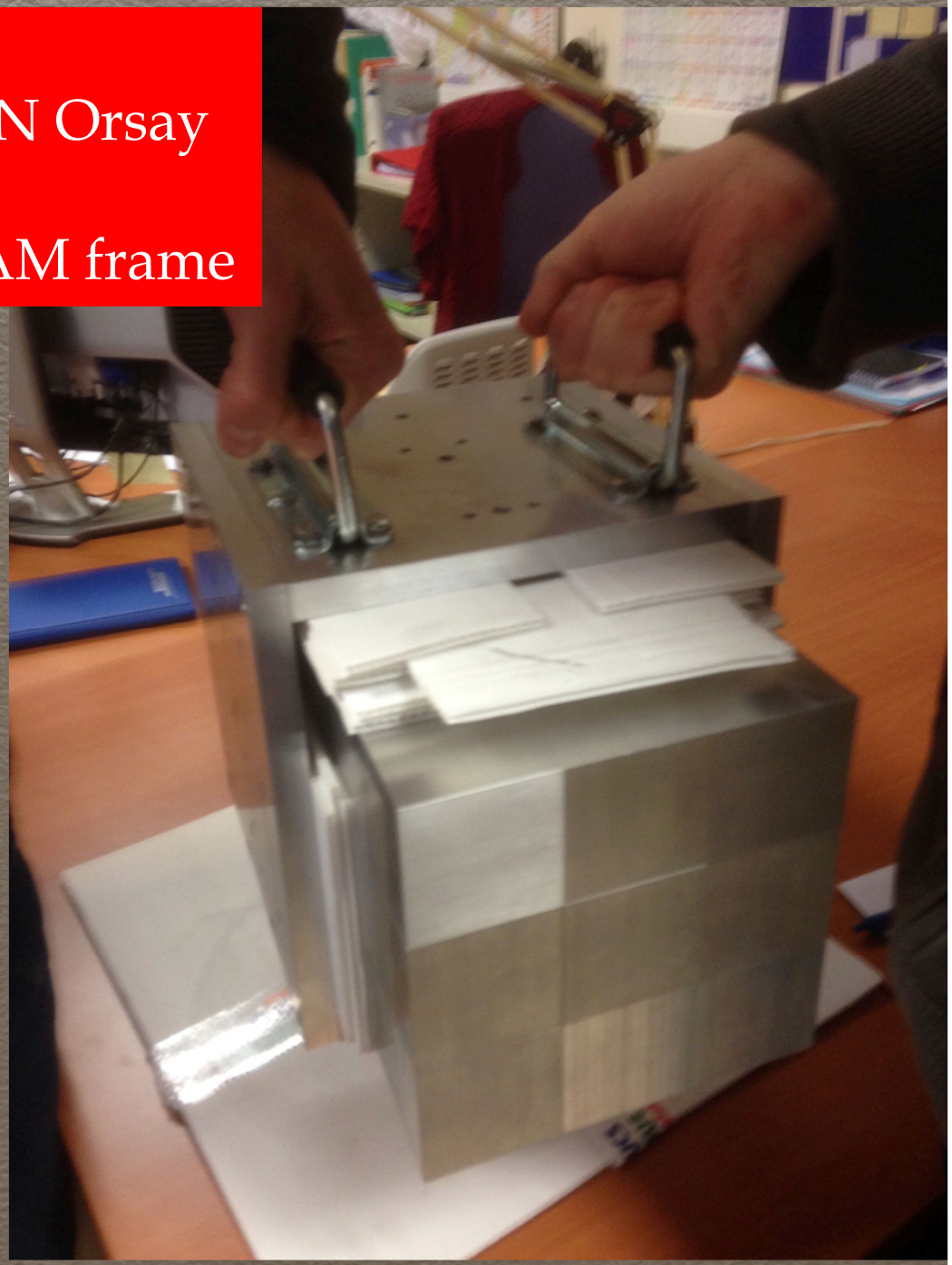


Courtesy of G. Minier, IPN Orsay

Cluster holding structure

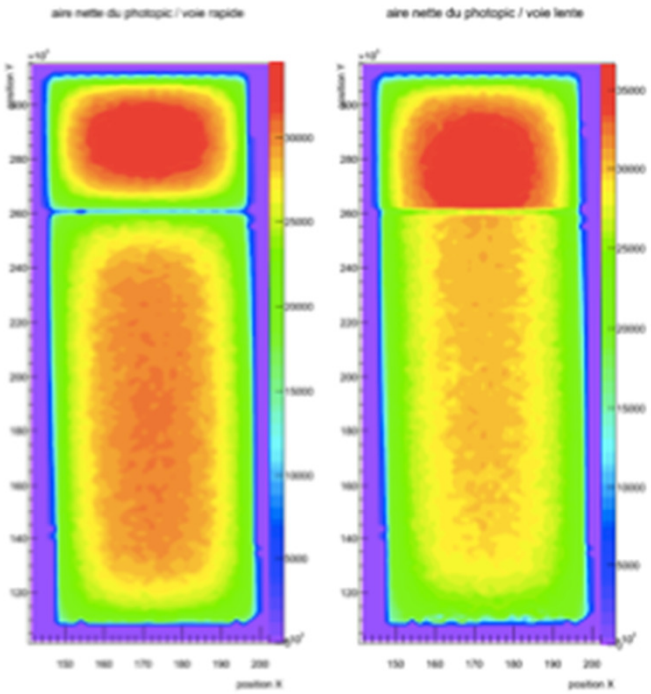
Designed and produced by IPN Orsay

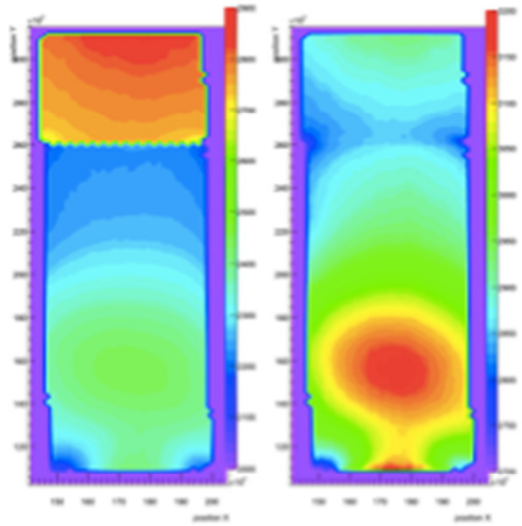
It will be connected to EXOGAM frame

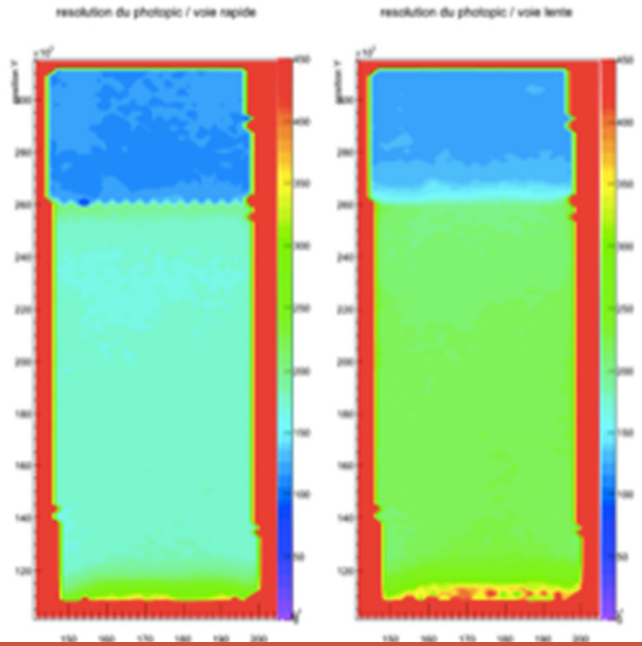


A example of scanning detector using the AGATA scanning table (1500 points)

IPHC Strasbourg
O. Dorvaux et al..







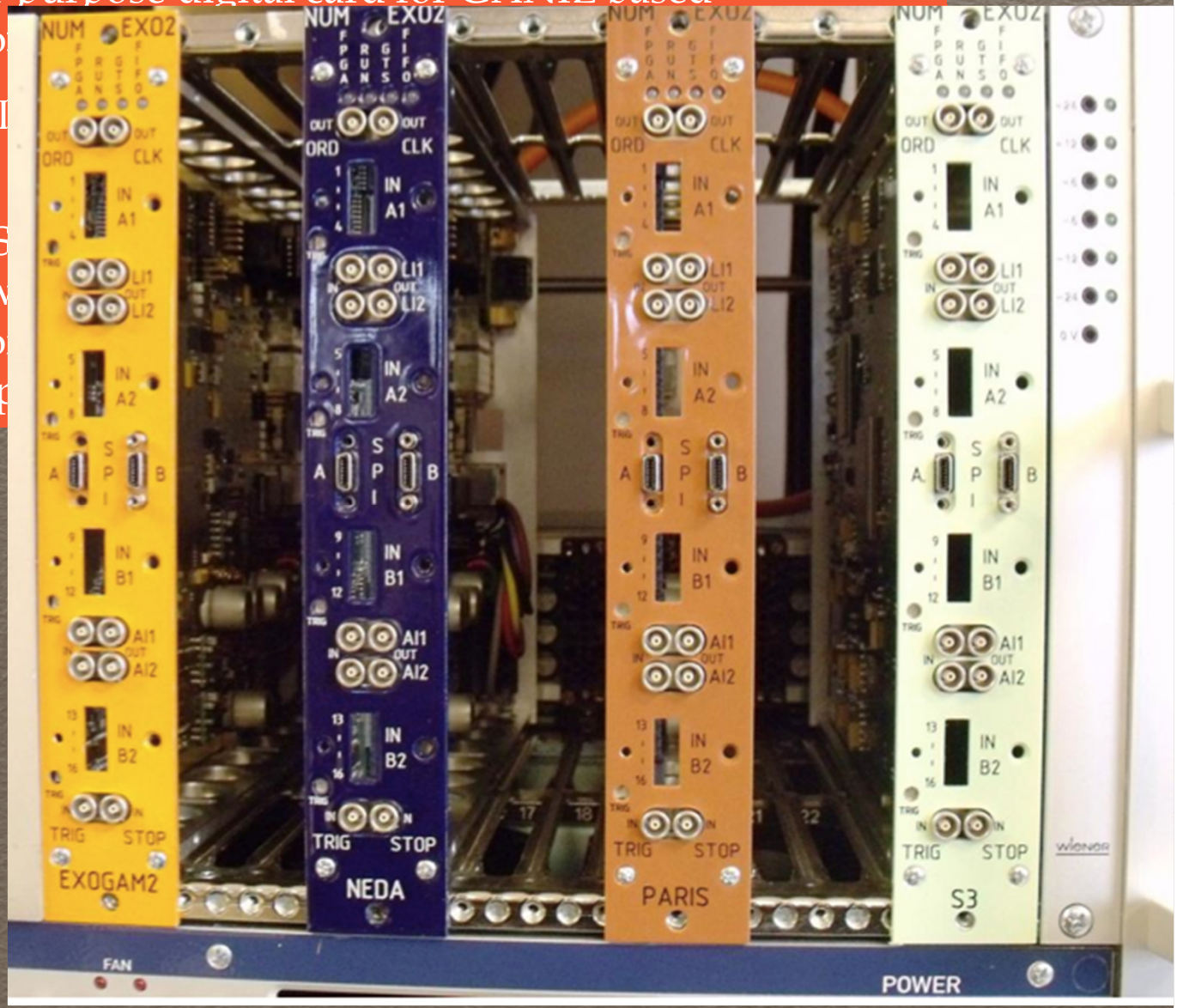
IPHC Strassbourg: Database of all PARIS phoswiches

Options of electronics for PARIS

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

Implementation of the GT currently being finalized.

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



Options of electronics for PARIS

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

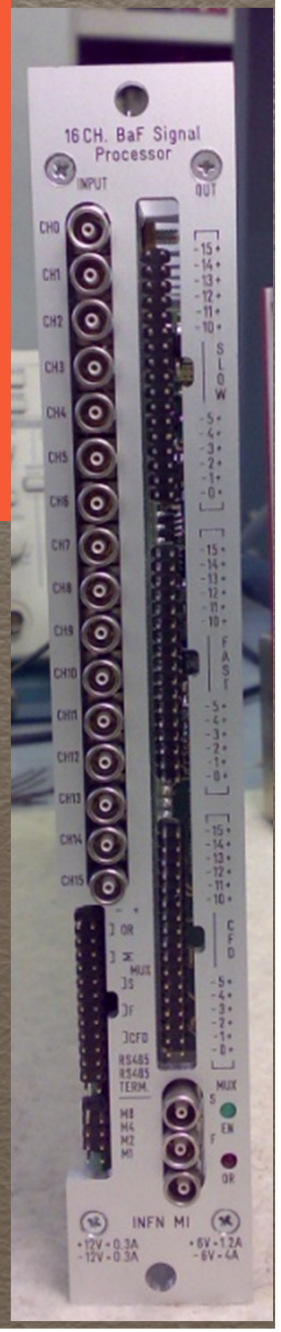
Implementation of the GTS interface into the NUMEXO2 VIRTEX 5 FPGA is currently being finalized.

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 fir first experiments with AGATA. (integrated to the VAMOS branch)

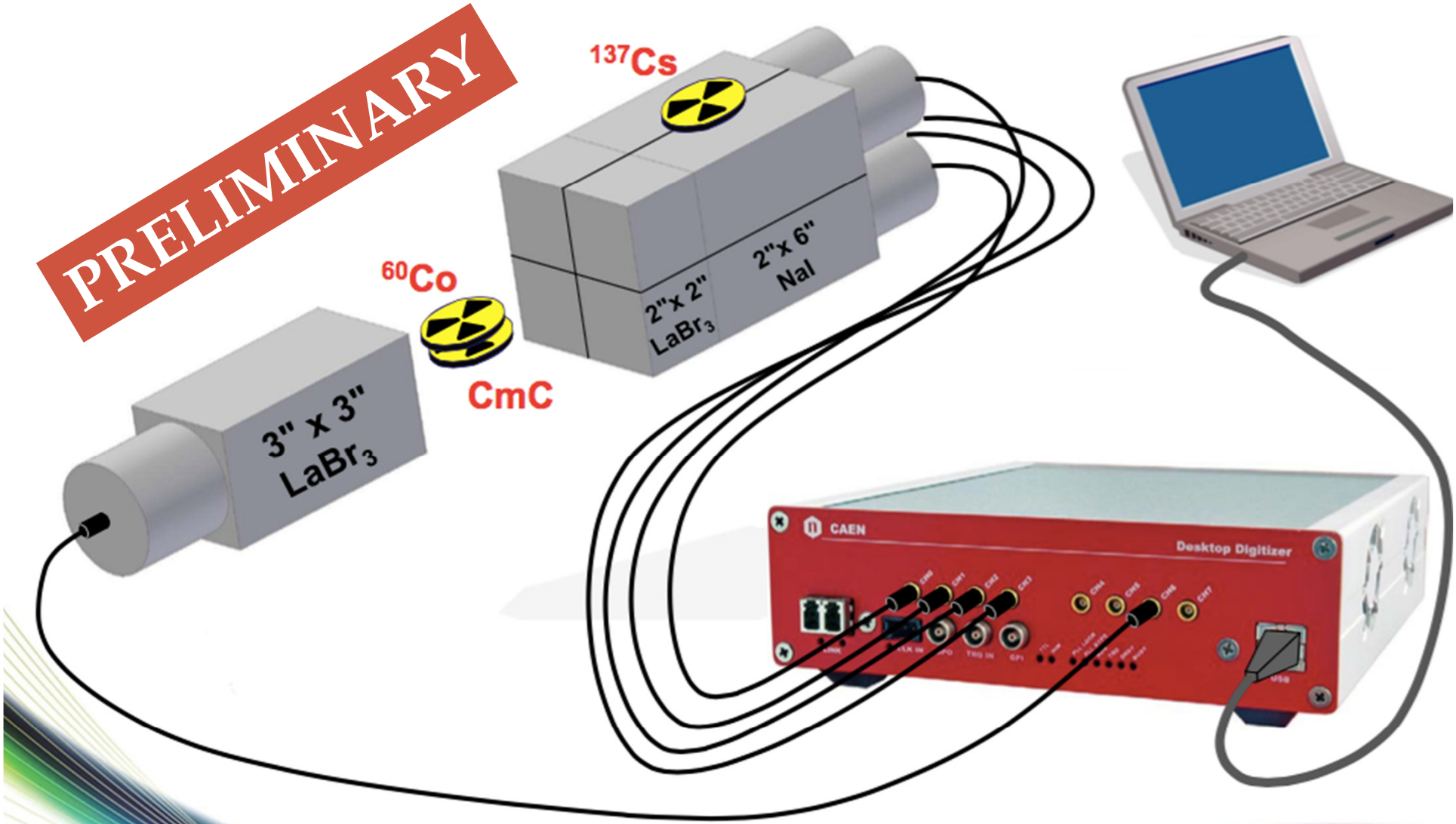
3) Comercial digitizers (V1730, 16 channel, 500 MS/s, 12/14 bit CAEN digitizer)

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



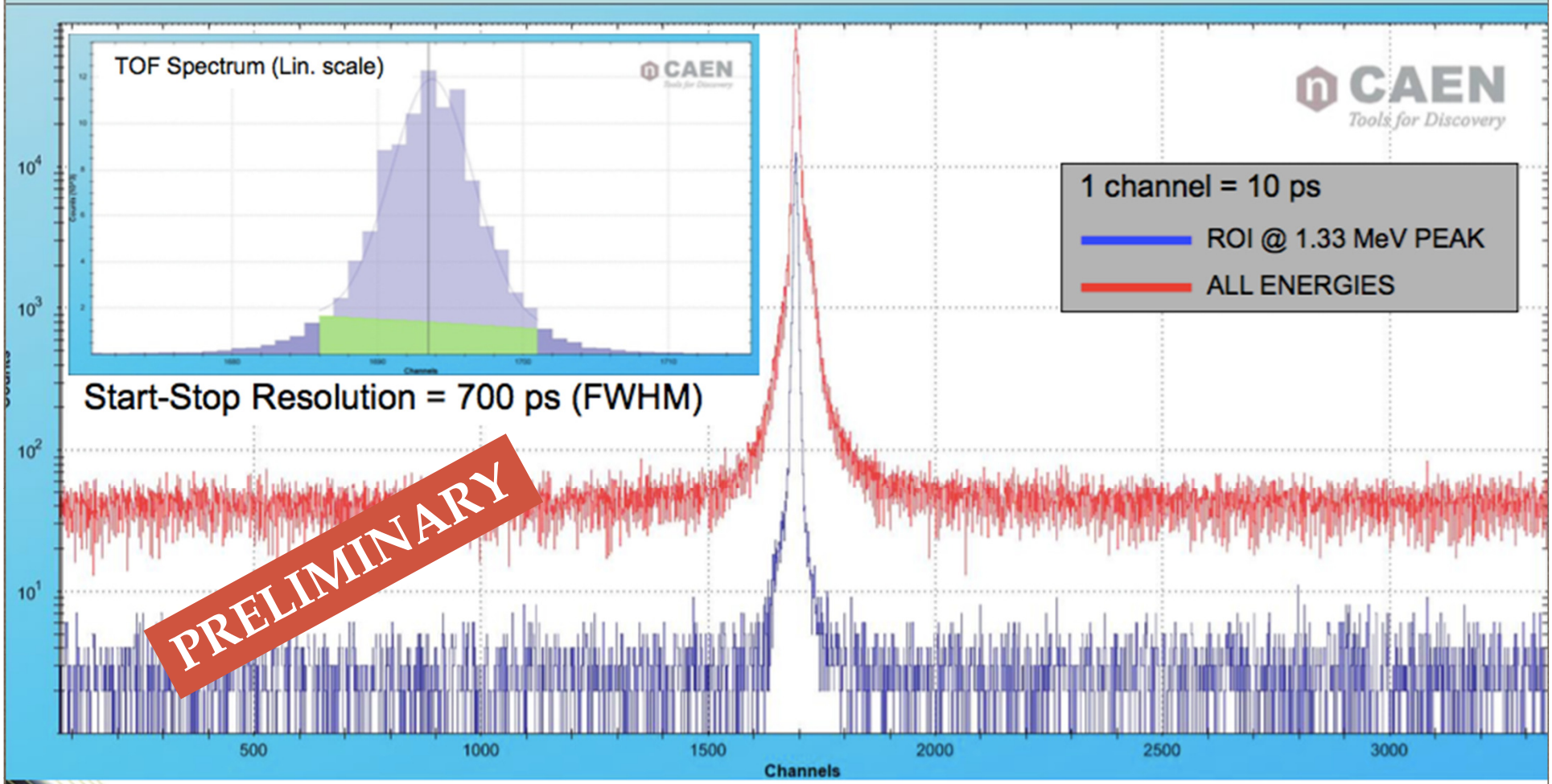
CAEN
Tools for Discovery

Test Setup for high energy gammas



CAEN
Tools for Discovery

Timing Resolution



TOF from pure 3"x3" $LaBr_3$ to Phoswitch-$LaBr_3$

First experiments

IPN/ALTO Orsay (PARIS campaign, *2016*)

PARIS campaigne 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 and November/December 2016**
- A. Kozulin - **Prompt γ-rays as a probe of nucleardynamics – Done in June 2016** (first results are coming…)

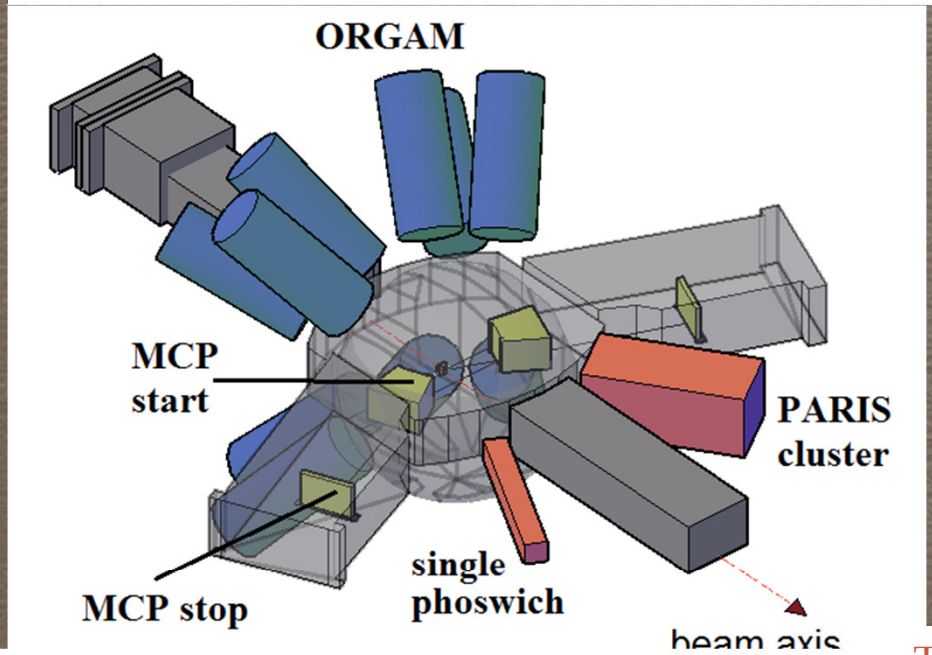
Requiring 2-4 clusters:

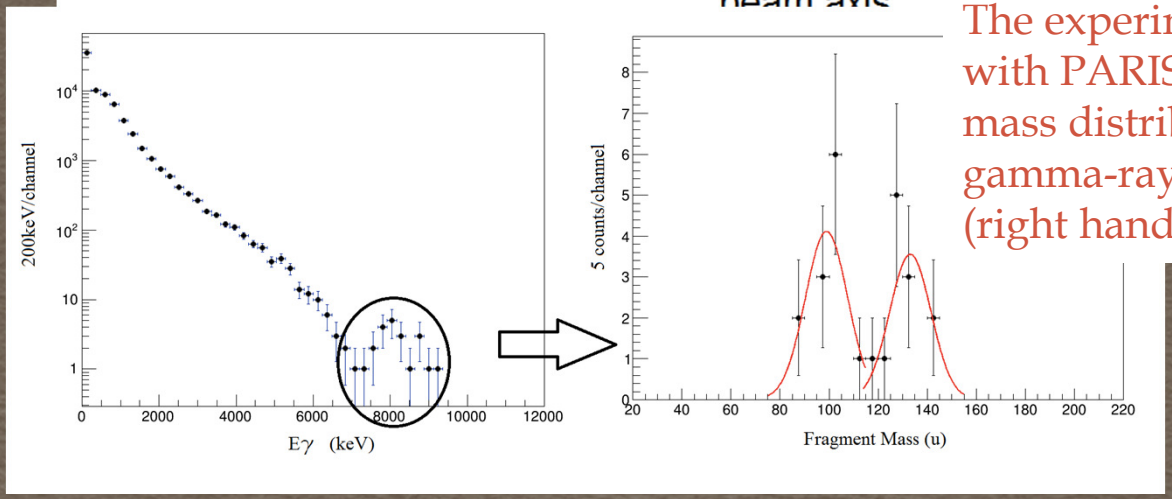
- B. Blank - **Measurement of the super-allowed branching ratio of ^{10}C**
- O. Kirsebom - **A new probe of alpha-cluster structure in ^{12}C**
- M. Wiedeking - **Coulomb Excitation of ^{14}C (????)**
- P.J. Napiorkowski - **Coulomb excitation of super-deformed band in ^{40}Ca**

Possible campaigne - 2017

A. Kozulin - **Prompt γ-rays as a probe of nucleardynamics – preliminary results**

„THE REACTION 32 S + 197 AU NEAR THE INTERACTION BARRIER:
I.M. Harca, E. Kozulin et al., proceeding of the EXON2016 conference





The experimental-ray energy spectrum collected with PARIS alone (left hand-side), and the FF mass distribution fo the events coincident with gamma-rays having energy higher than 7MeV (right hand side).

AGATA@GANIL (from mid 2017)
PARIS campaigne manager: Ch. Schmitt

3 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* (to be done 1st half of 2017?)

- P. Bednarczyk, A. Maj**, Investigation of a high spin structure in ^{44}Ti via discrete and continuumγ-spectroscopy** with *AGATA, PARIS* (4 clusters) and *DIAMANT*

- B. Fornal, S. Leoni, M. Ciemala, „**Gamma decay from near-threshold states in 14C: a probe of clusterization phenomena in open quantum systems", AGATA** (4 clusters) **, PARIS, NEDA, DIAMAND, DSSD**

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**

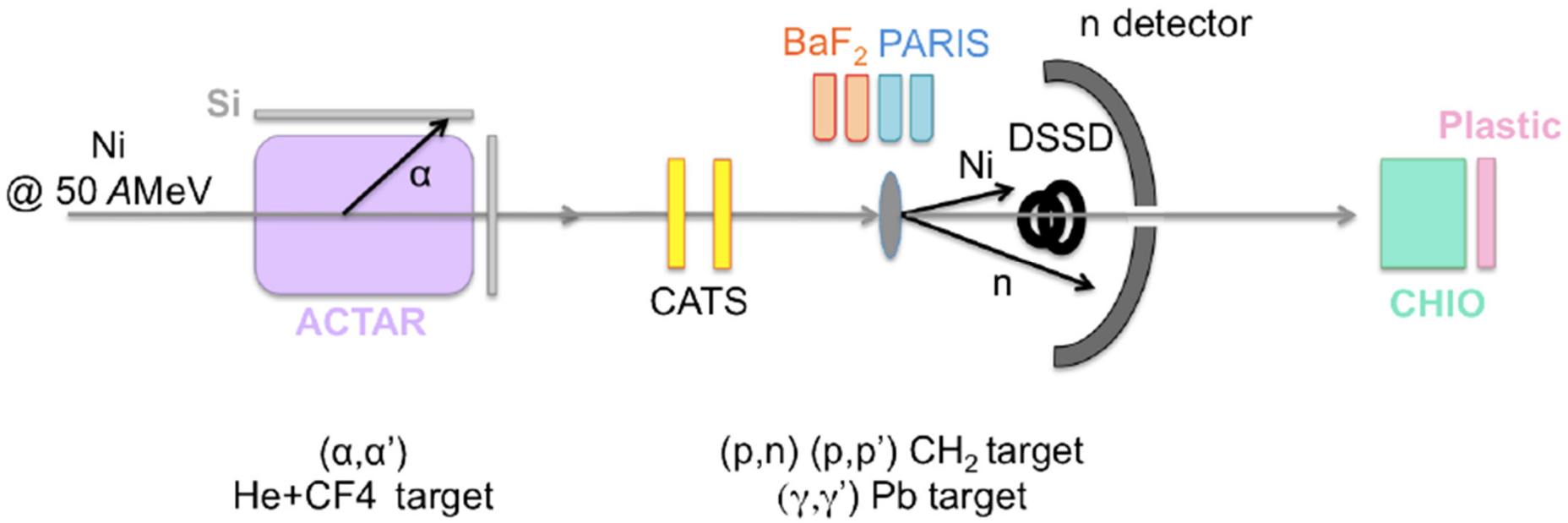


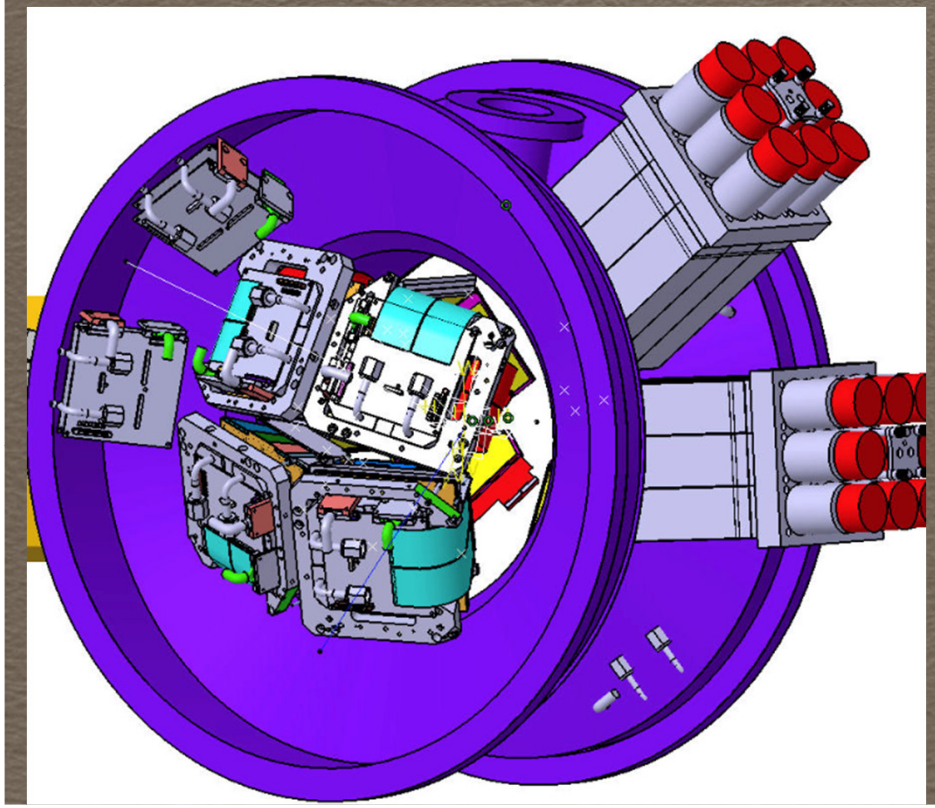
Figure 4: Proposed experimental setup.

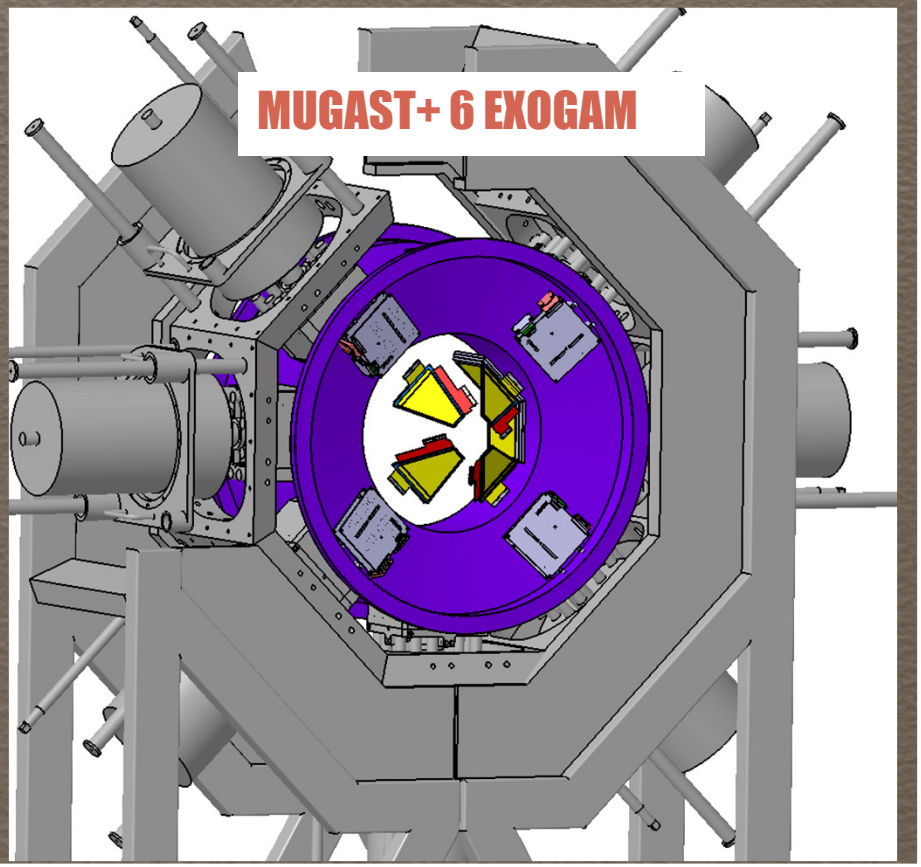
- **1 LoI for MUGAST@GANIL**
- G. De Angelis, C. Domingo Pardo, **„The 79Se(n,γ) capture cross section via the surrogate 79Se (d,p) 80Se reaction", MUGAST, PARIS**

« 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**





Next PARIS campaignes under consideration

CCB Krakow (2017/2018, campaign manager tbc)

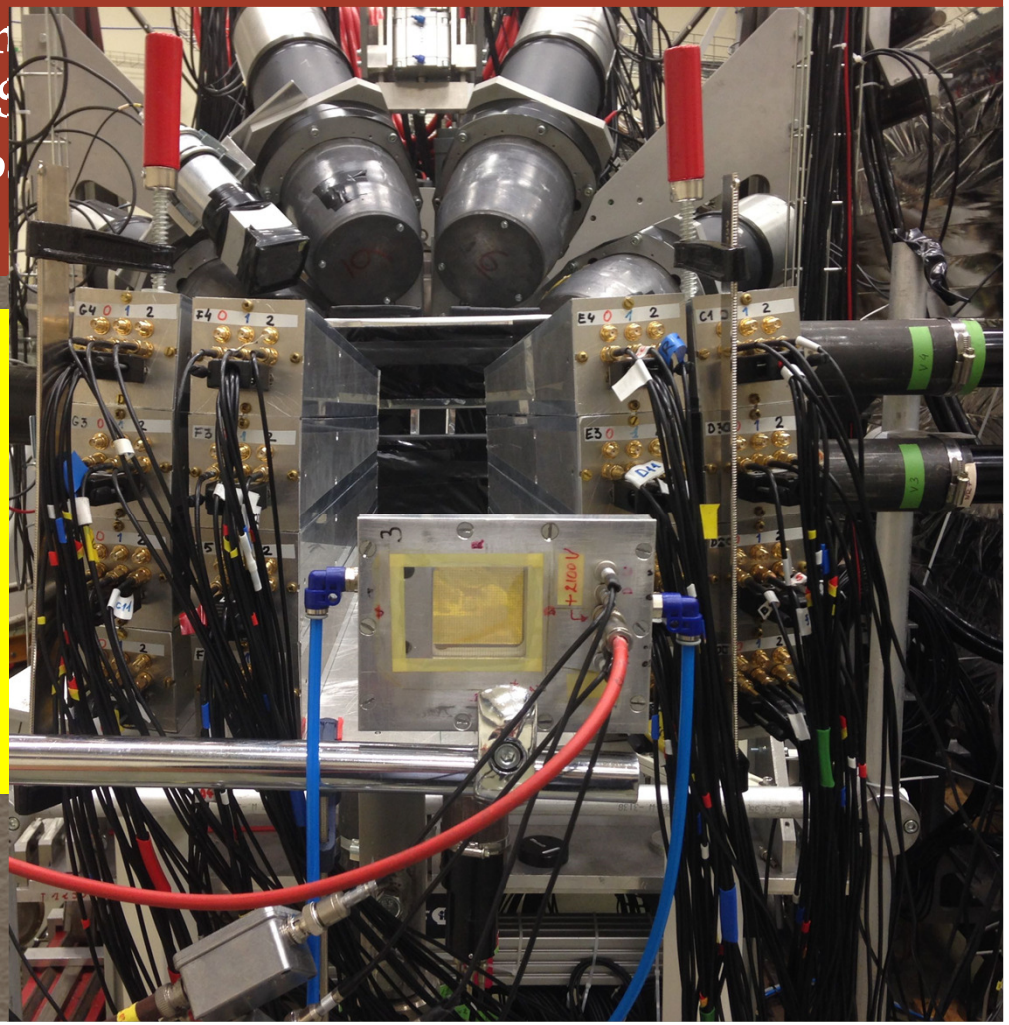
4 LoIs accepted by IAC:

- **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 ir**
  (Camera, Kmiecik) HECTOR, PARI
- **Investigation of proton induced sp**
  HECTOR, PARIS, KRATTA

Present SETUP

HECTOR: 8 large BaF2's (from Milano)
1 large LaBr3
1 small LaBr3
1 PARIS phoswich

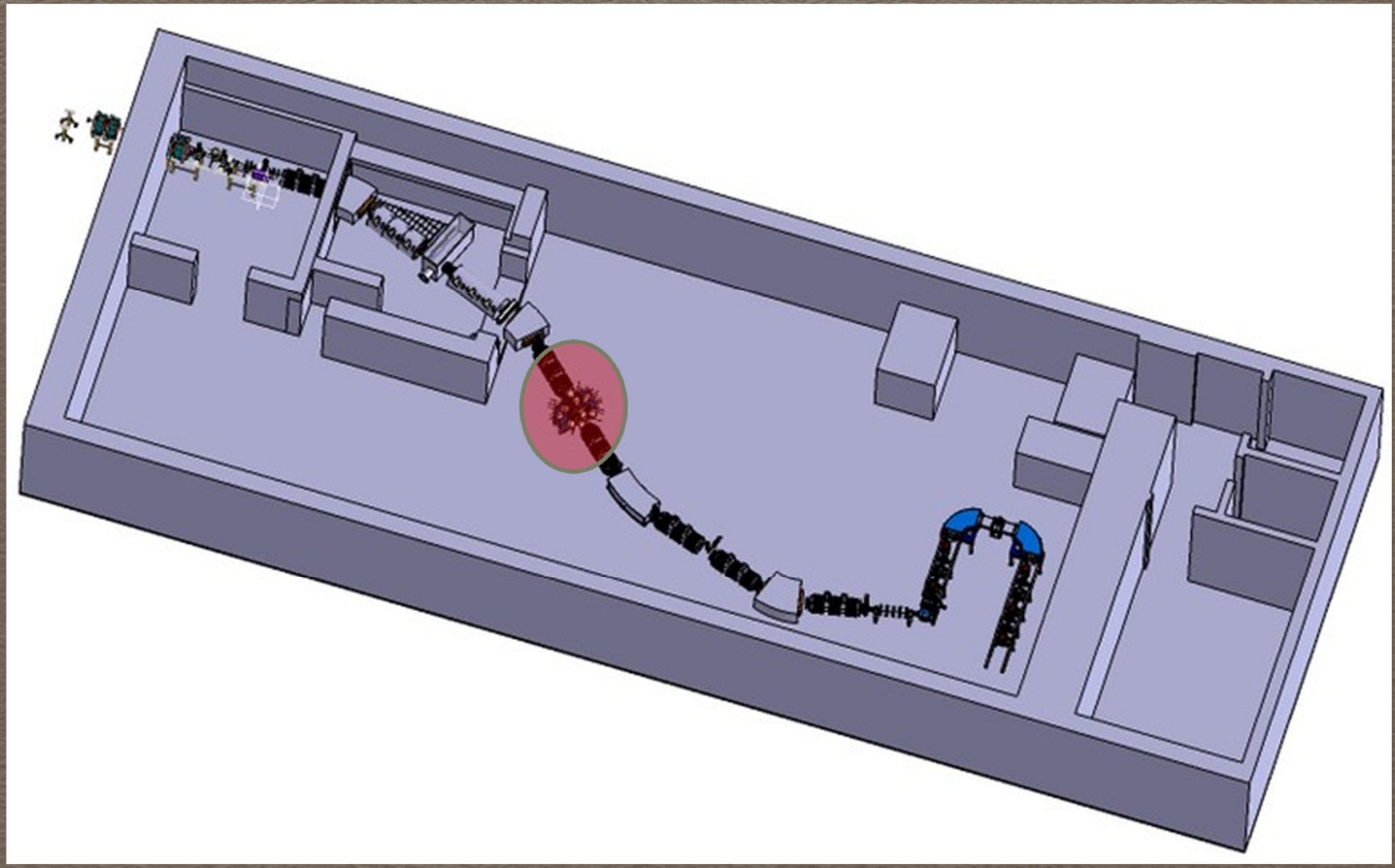
KRATTA tripple telescope array



7 LoIs for PARIS4SPES campaign (2019?)

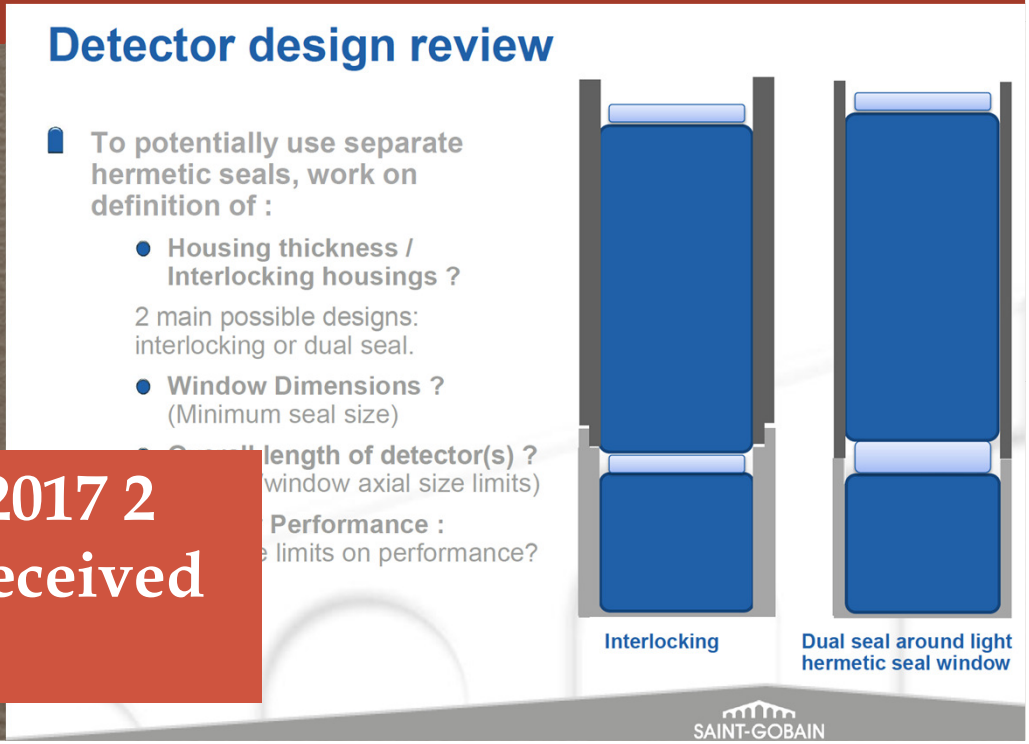
- **GDR decay of hot rotating nuclei in A=130 mass region** (Maj, Leoni): GALLILEO, RFD
- **Measurement of Isospin Mixing in N=Z medium mass nuclei** (F. Camera): HECTOR+, GALLILEO
- **Measurement of the Dynamical Dipole emission** and the symmetry term of the EOS (F. Camera, G. Casini): HECTOR+, fusion_evaporation 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)

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



Problems with Saint Gobain phoswiches!!!

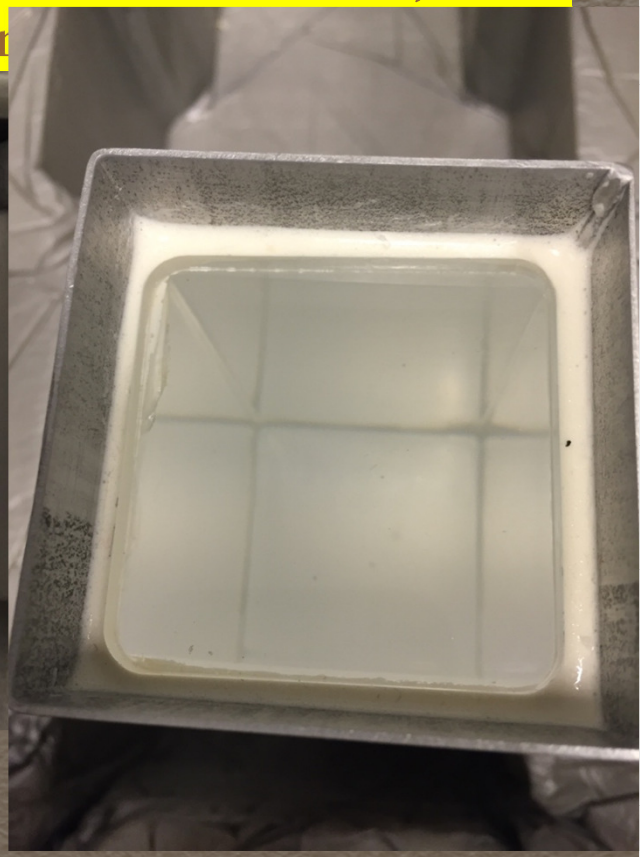
- Saint Gobain announced in 2014 that the phoswiches produced recently by them are having problems with getting worse resolution after treatment. They decided to hold the production (and reparation of the old ones) until solution is found.
- Recently, spring 2015, SG decided to stop the production with current desing and proposed a new design, **with LaBr3 and NaI separately hermetically sealed**.
- A prototype shall be delivered
  until end of 2015
  beginning of March 2016
  mid 2016?
  (*production moved to US*)



Recent news – in December 2017 2 new type phoswiches were received – they perform OK!

Paralel approach:
Changing LaBr3 to another scintillator, but keeping the phoswich concept

Phoswich made of CeBr3+NaI: discussion with Scionix undertaken, a prototype was ordered by GANIL and delivered en



Energy and time resolution seem to be acceptable so the ***CeBr3/NaI phoswich*** *might be an alternative or parralel solution for PARIS concept*

PARIS construction time line

Within PARIS Demonstrator MoU

- **Presently PARIS has 16 operational LaBr3_NaI phoswiches (one cluster + 7 modules), additional 4 are sent to SaintGobain for replacements/repair; 6 additional phoswiches were ordered and are on hold ;**
- **One CeBr3-NaI phoswich cluster beginning 2017 (we have already 5 such phoswiches)**
- **Until mid of 2017 3 clusters are very probably, and 4th one until end of 2017**
- **Analoque electronics PARIS-Pro implemented, mechanical integration to AGATA ready**
- **CAEN V1730 electronics verified**

End of PARIS Demonstrator MoU: 2015 It will be extended by 3 years

2018: New PARIS 2π MoU to be agreed and signed

- **2019** (maybe)**: 8 clusters**
- **2021:** (hopefully) **12 clusters (2π PARIS)**

SUMMARY

- 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 analoque PARIS-Pro + AGAVA, data stream via VAMOS branch. Commercial digitizer is under tests, which looks very promising
- Presently we are completing 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;

  ITALY: LNL/SPES Legnaro.

PARIS is ready for new experiments, also with GASPARD