

Adam Maj
IFJ PAN Krakow
for the PARIS collaboration

The PARIS array: the concept, status and first experiments



NUSPIN 2016 Workshop of the Nuclear
Spectroscopy Instrumentation Network and
AGATA Physics Workshop

from 27 June 2016 to 01 July 2016 (Europe/Rome) San Servolo, Venice



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. Guenther 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

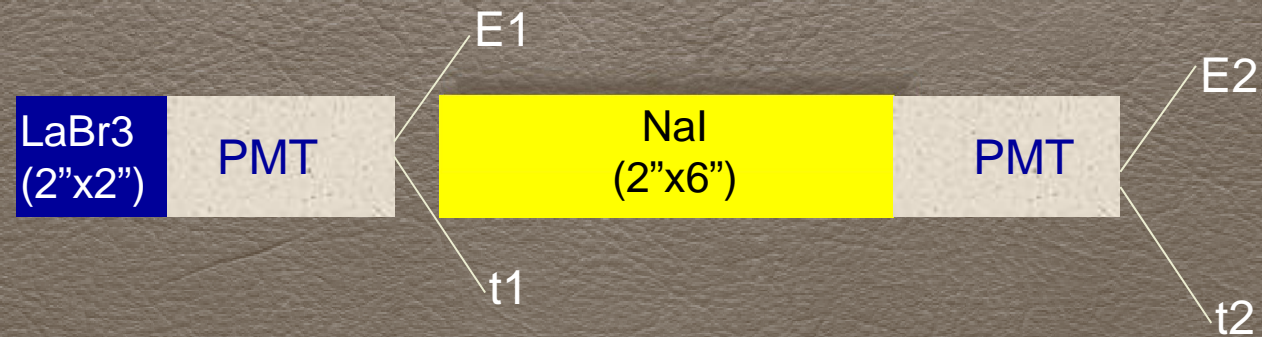
G.F. Grinyer et al..

Main physics cases require that PARIS has to

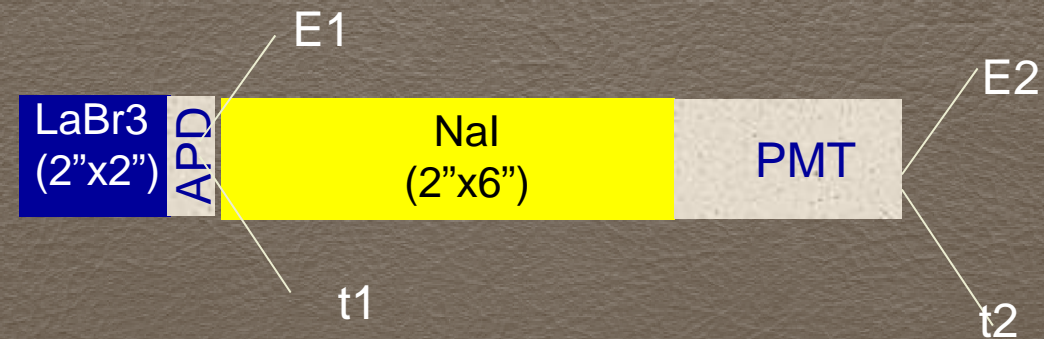
- ❑ be **modular** (to be connected with other detectors: AGATA, EXOGAM, GALILEO, GASPARD, NEDA, FAZIA, ACTAR, HECTOR/HECTOR+, EAGLE, ORGAM, CORSET...)
- ❑ have **high granulation** (multiplicity measurement, Doppler correction,...)
- ❑ have very **high efficiency for high-energy γ -rays** (5-30 MeV)
- ❑ 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,...**)

4 POSSIBILITIES FOR A „GAMMA-TELESCOPE” ELEMENT

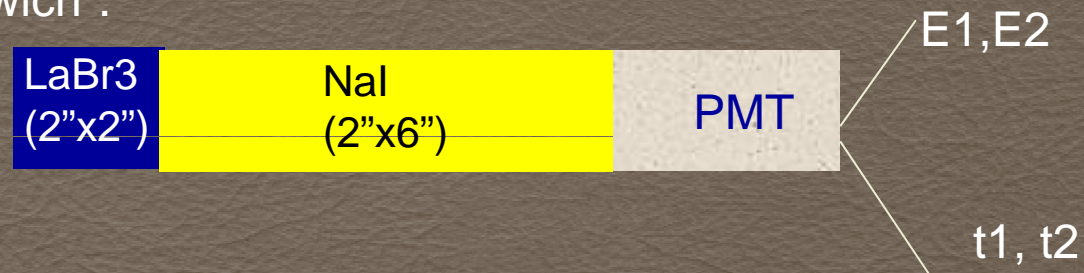
Possibility 1.



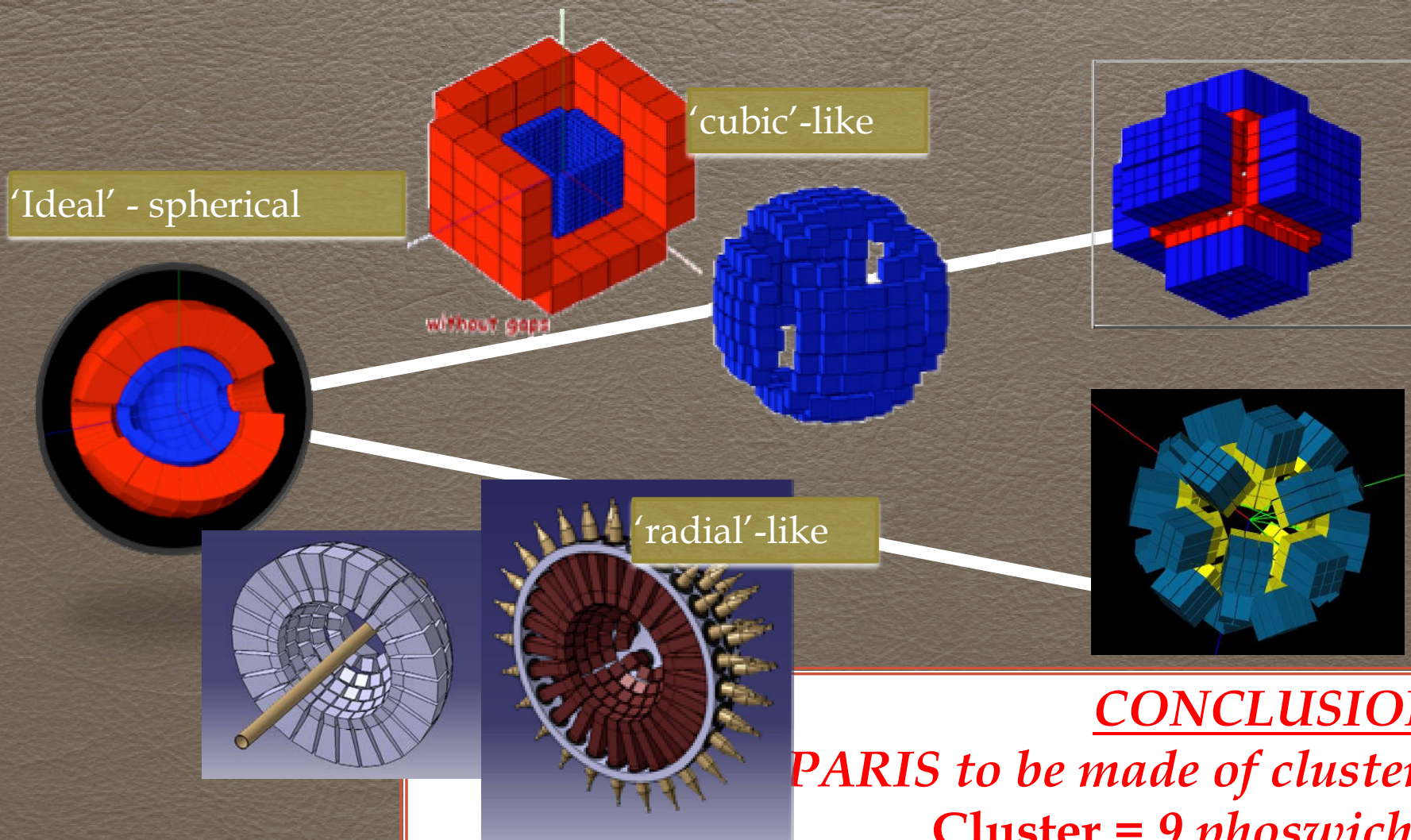
Possibility 2.



Possibility 3 – „phoswich”.



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)**

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

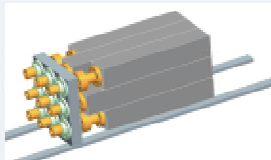
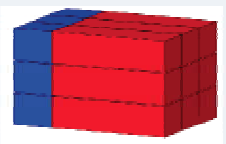
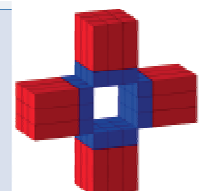
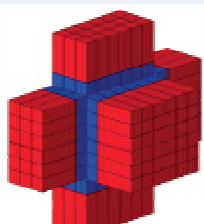
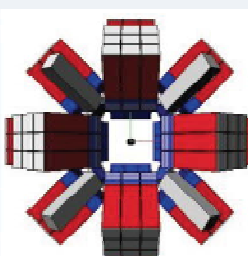
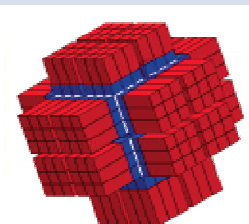

ROMANIA (coord.: F. Negoita) IFIN-HH Bucharest

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), 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
Phase 3 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 experiments 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 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 Nair (TIFR Mumbai, India)

Pawel Napiorkowski (IFJ PAN Krakow, Poland)

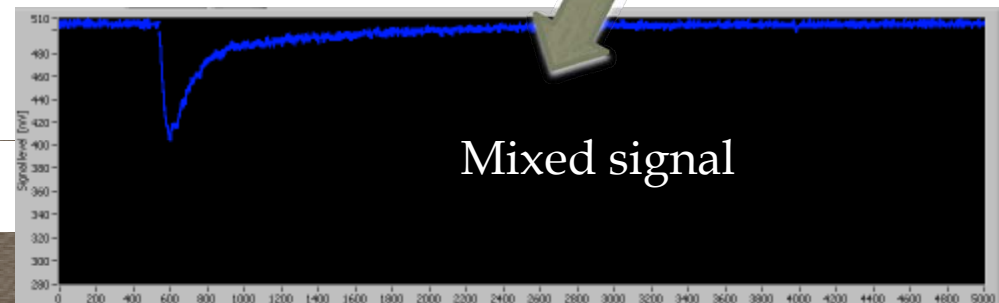
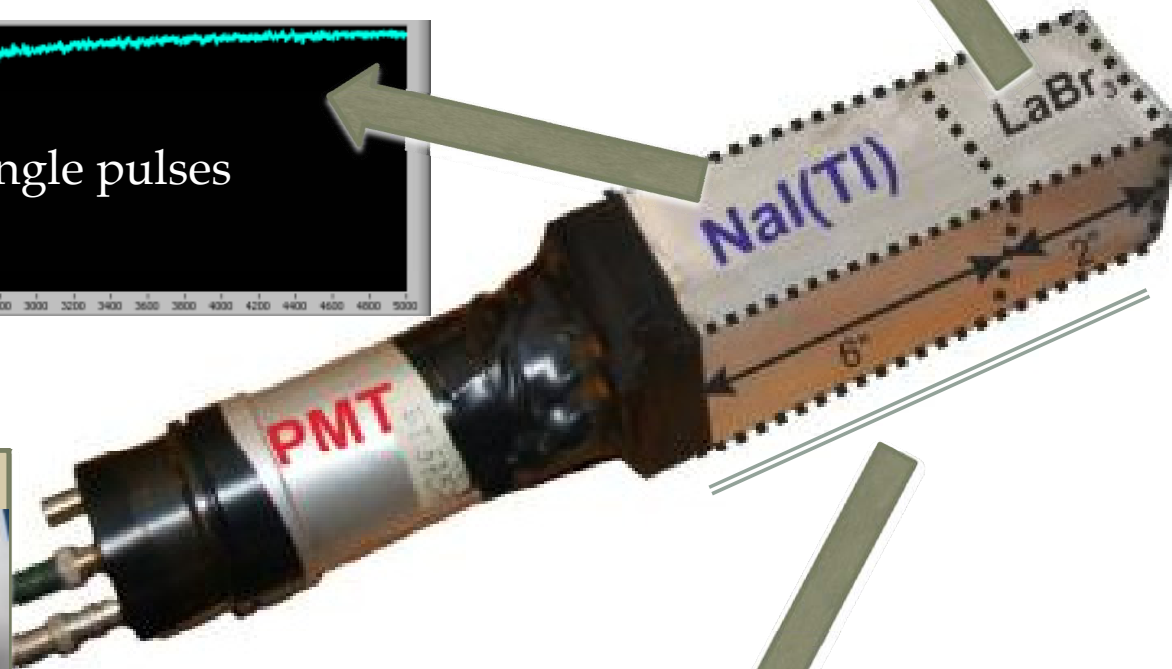
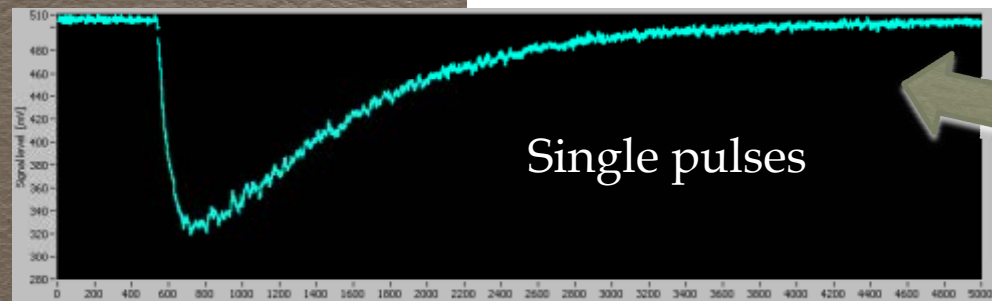
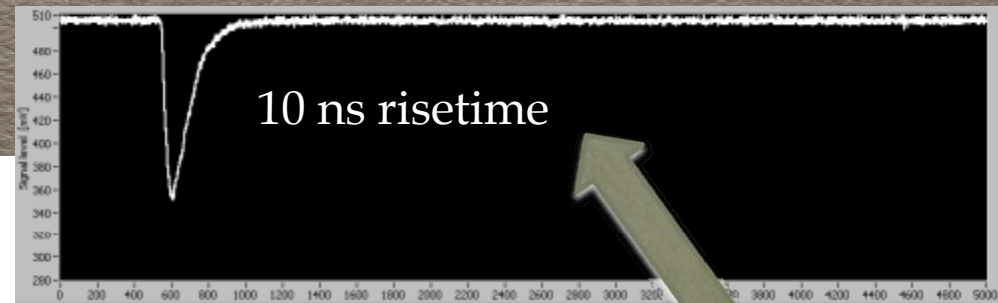
Marek Płoski (IFJ PAN Krakow, Poland)

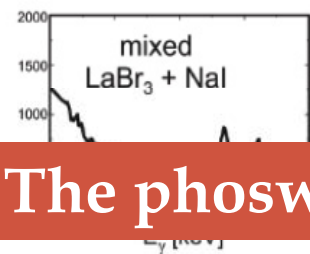
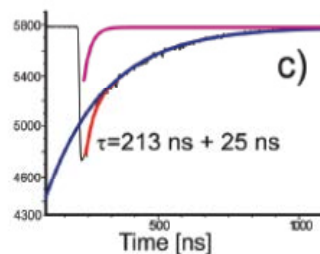
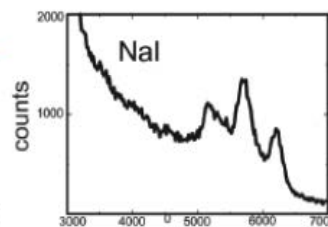
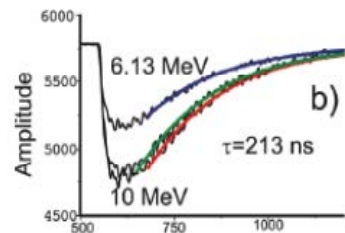
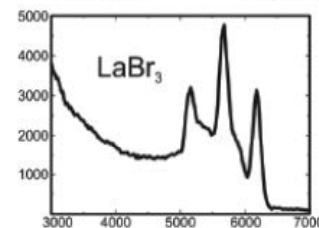
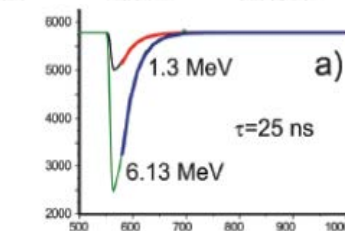
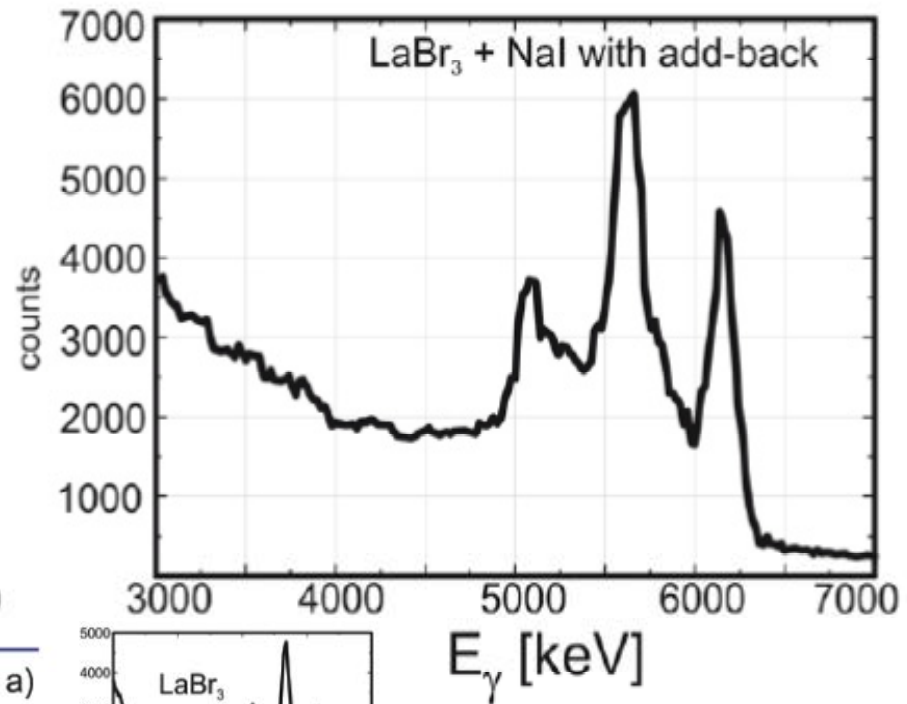
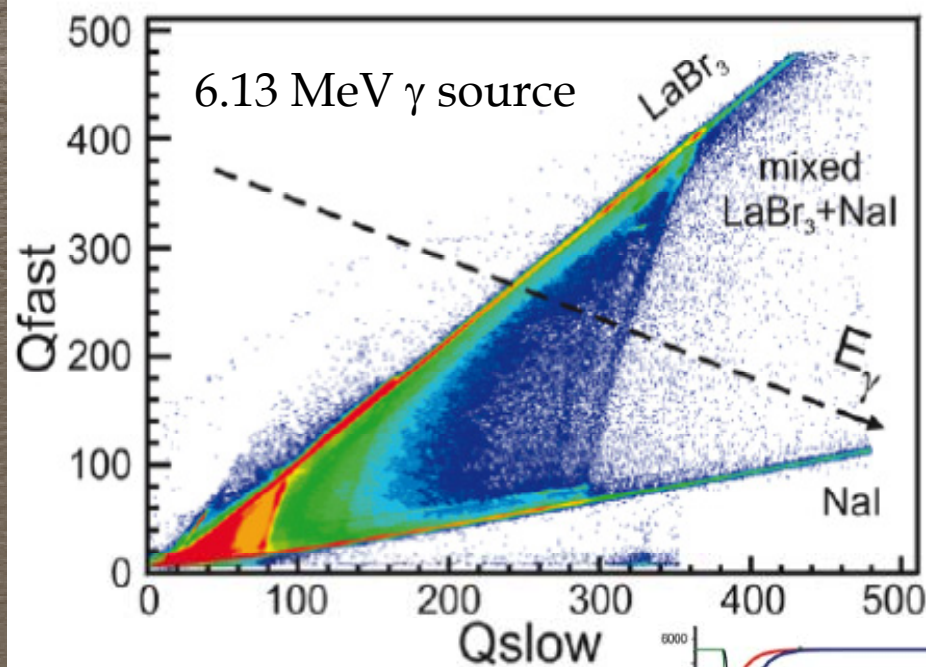
Mihai Stanescu (Horia-Nicolai Timbulescu Institute, Bucharest, Romania)

Jonathan Wilson (IPN Orsay, France)

**Next PARIS Collaboration meeting:
September 5-6, 2016, Krakow**

The PARIS PHOSWICH at work





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

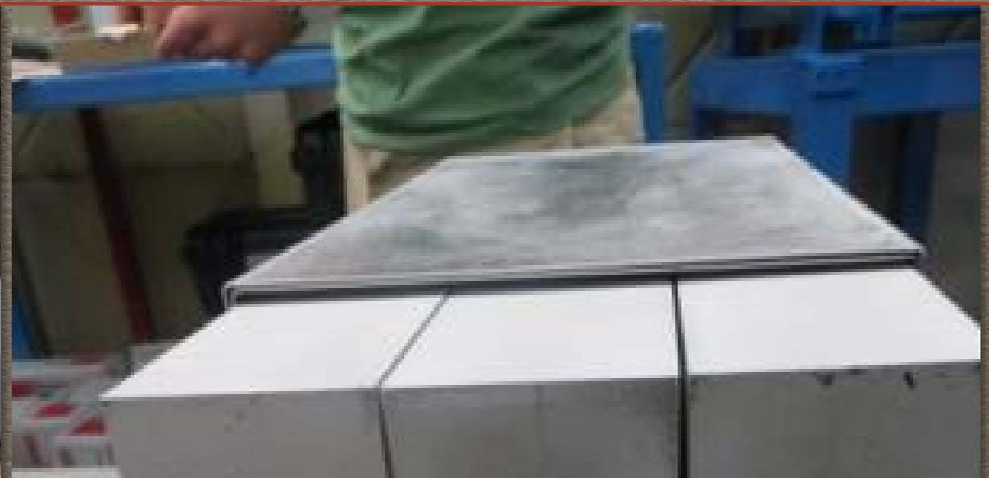
- Sources
- proton beam

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

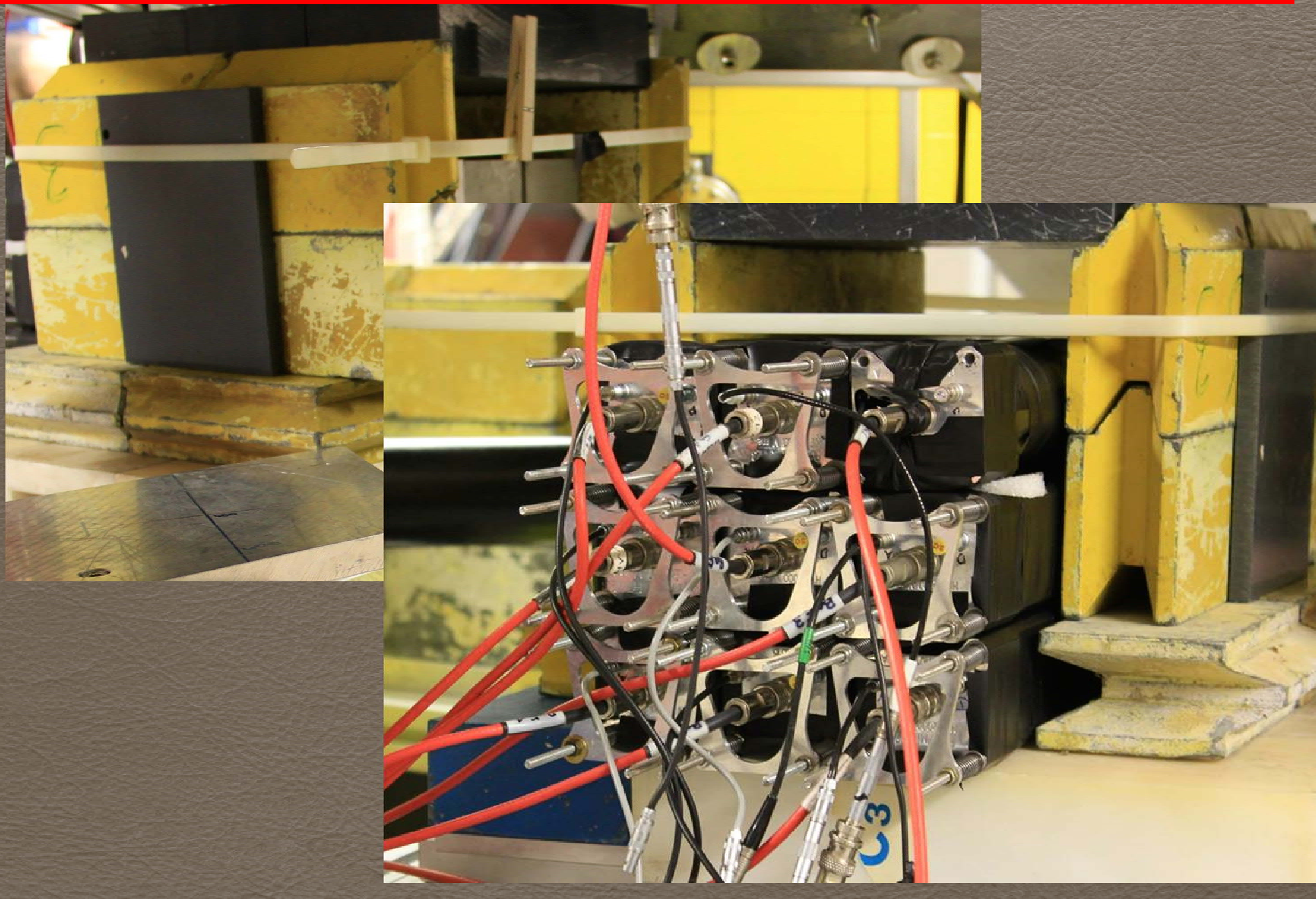
E_γ : ..., 18.12 , 22.56 MeV

Goal:
testing addback
capabilities at high
energies

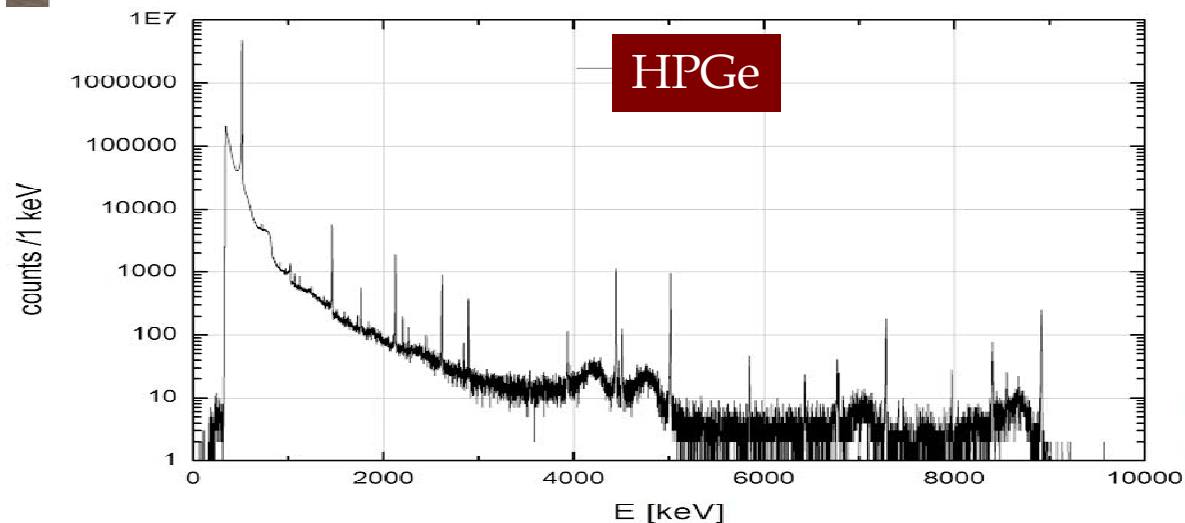
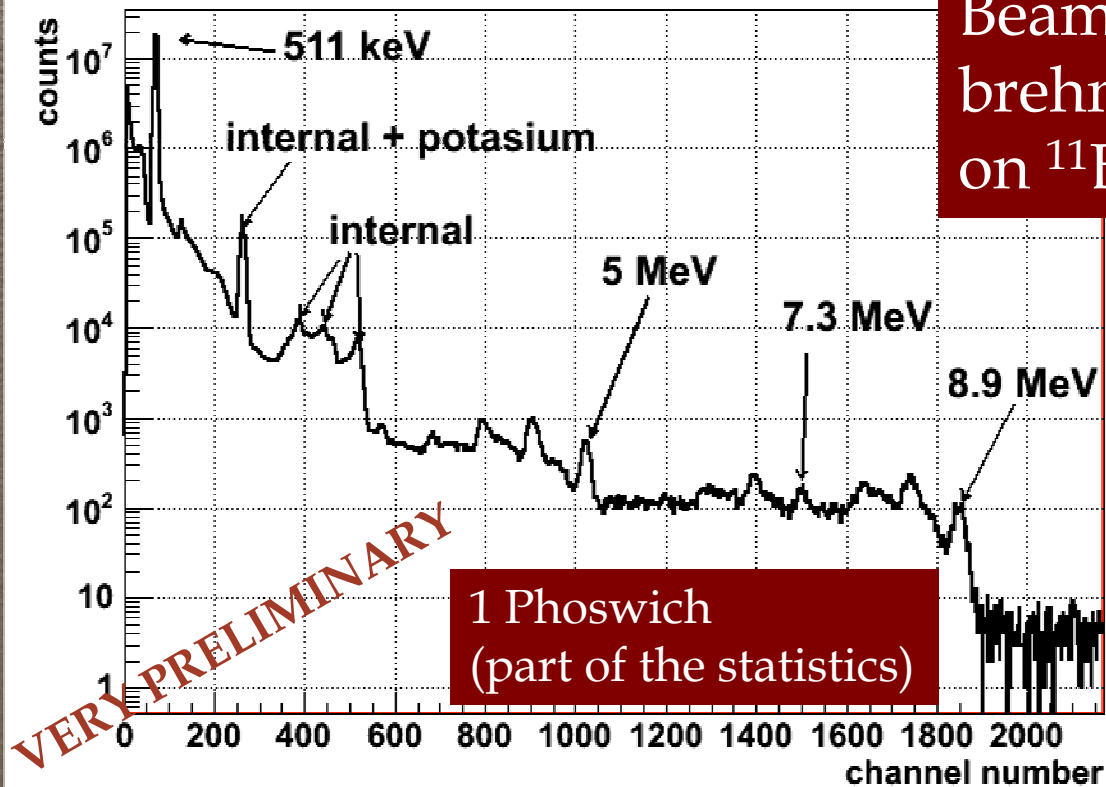


ELBE facility, Dresden 10-12 December, 2013

Nuclear Resonance Fluorescence experiment (Mazumdar, Maj, Schwengner)



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



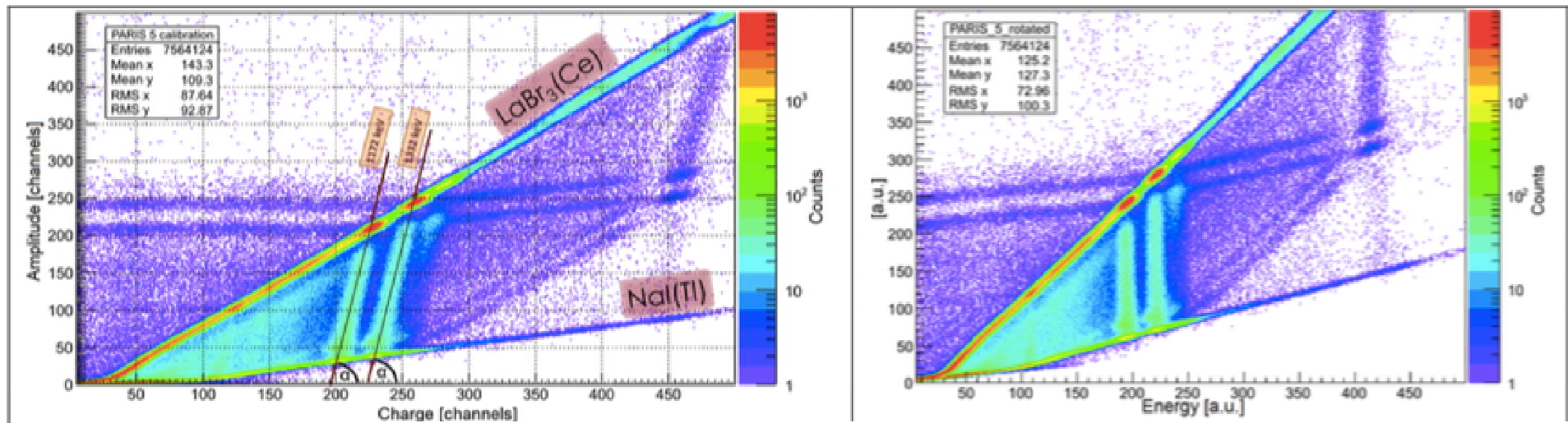


Fig. 4) Example of charge vs calibration run. Lines of evi energy was deposited in on same energy deposited and

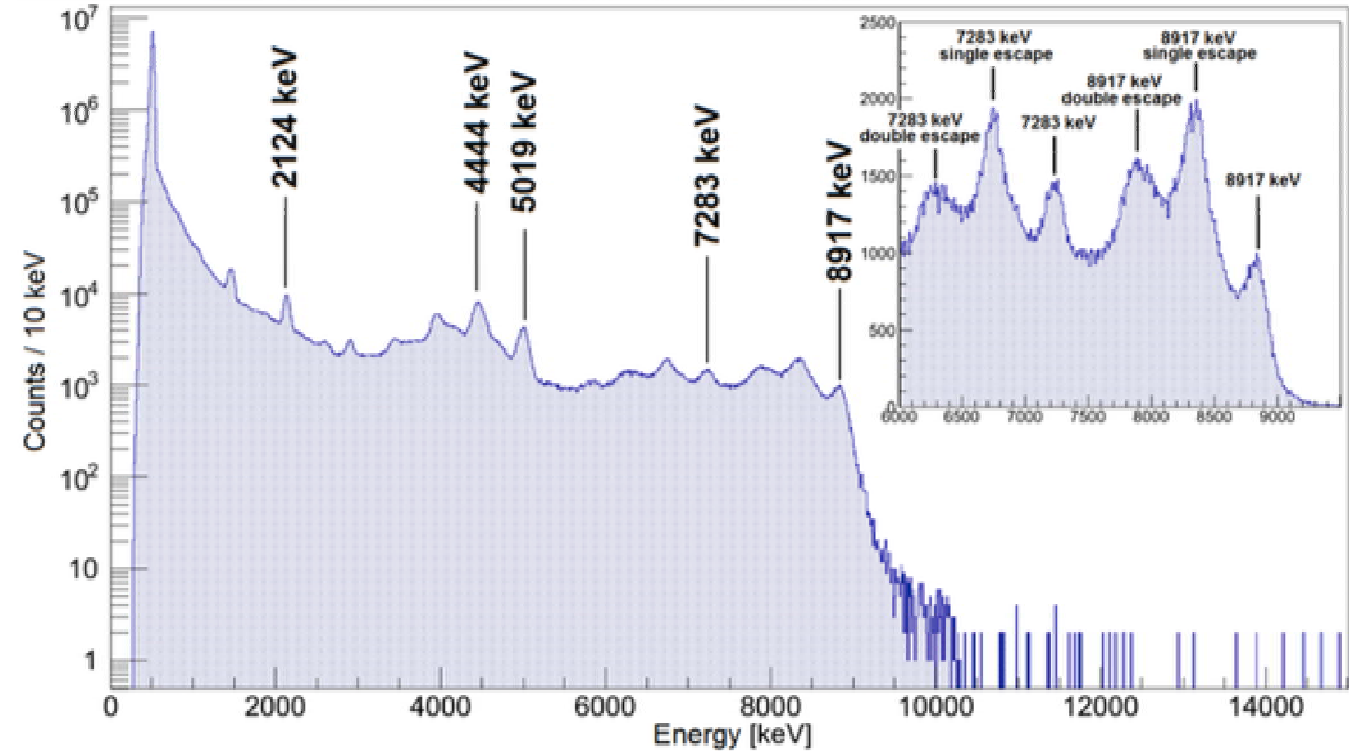


Fig. 6) Energy add-back spectrum of the PARIS cluster.

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

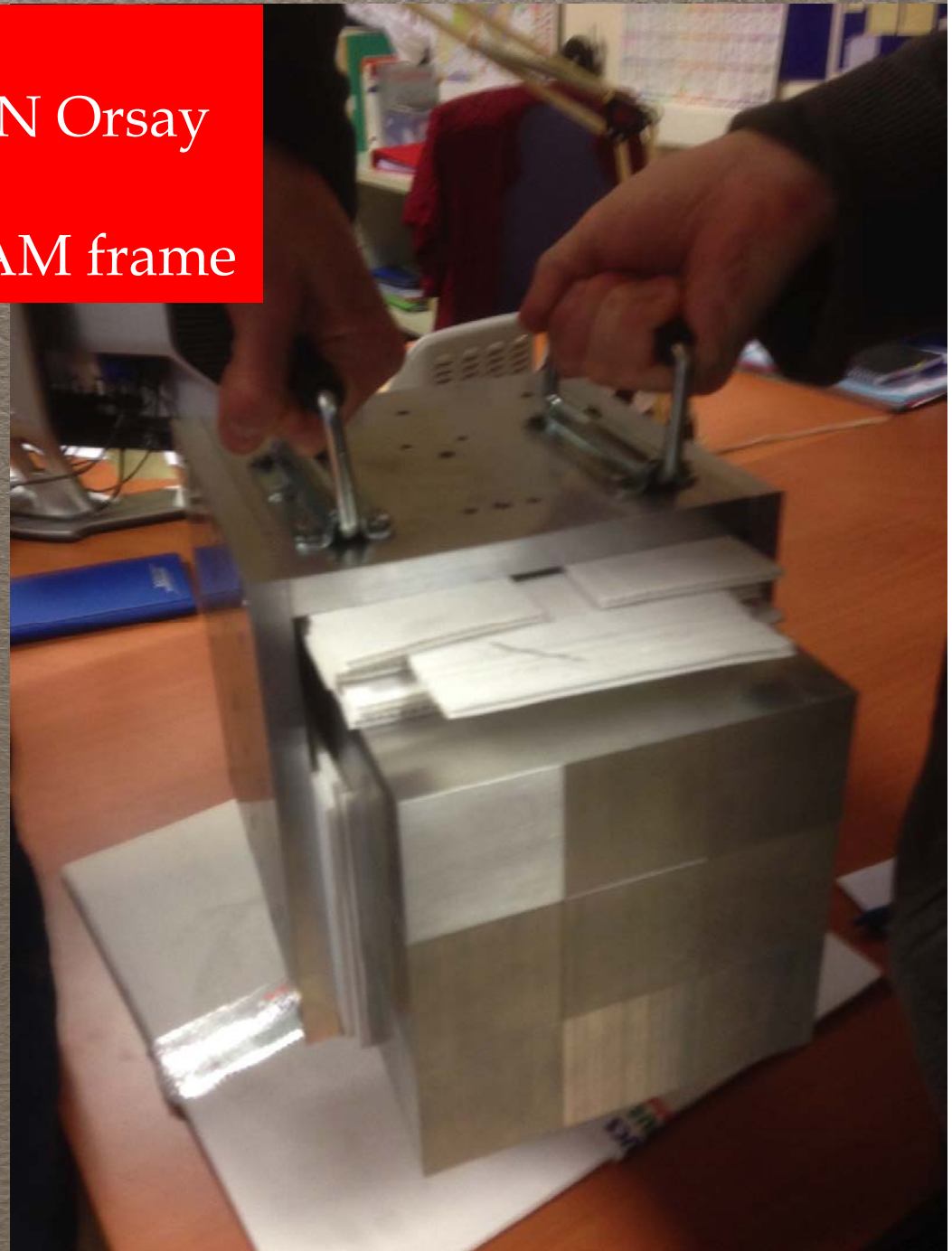
Next tests: depending of availability

- ❑ CCB Krakow, 2016 ?

Cluster holding structure

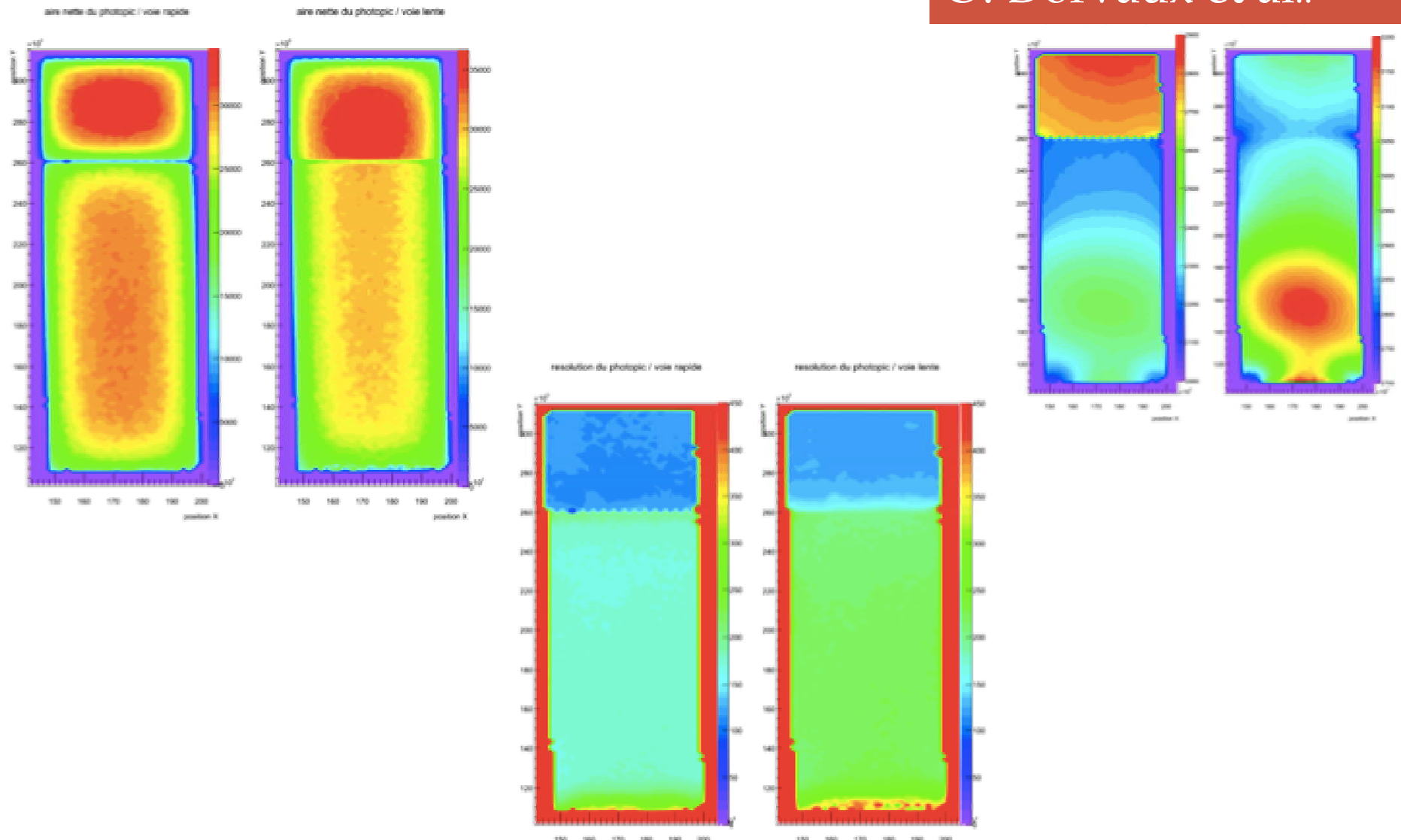
Designed and produced by IPN Orsay

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..



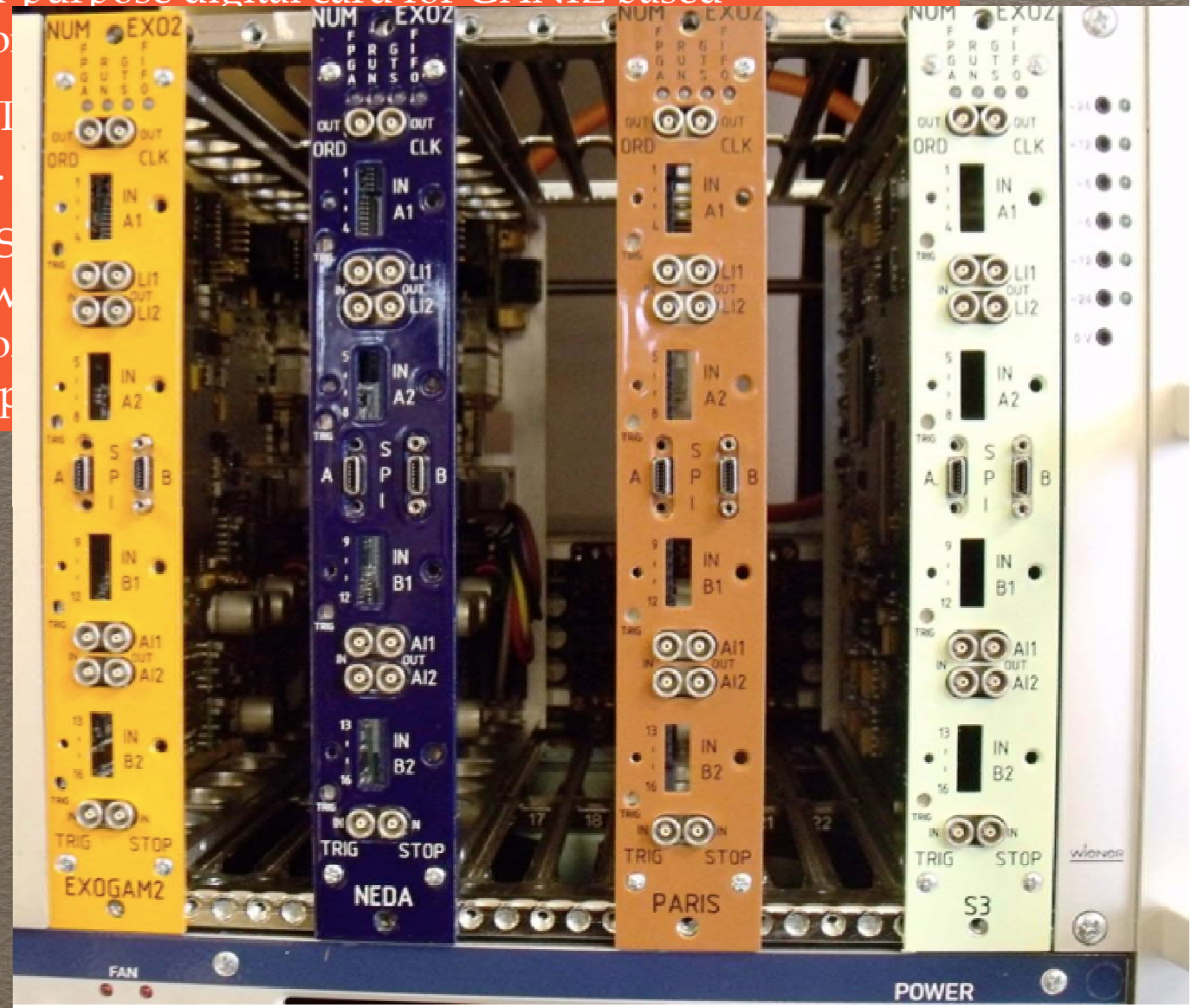
IPHC Strassbourg: Database of all PARIS phoswiches

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.

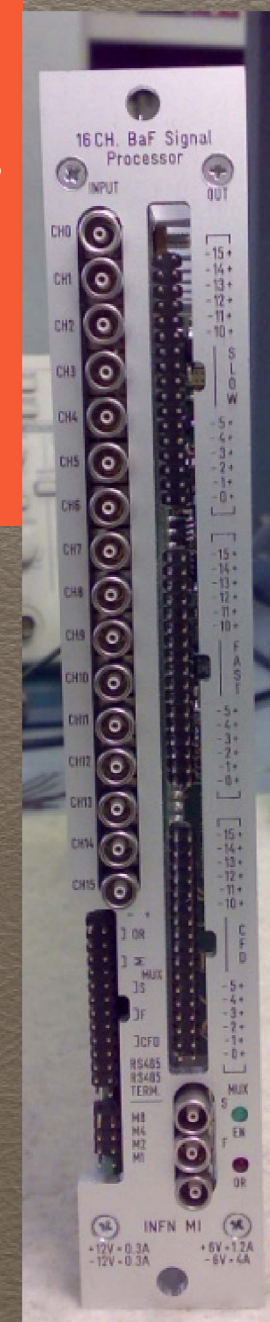
2) **Analogue electronics** based on **Milano "PARIS_Pro"** cards (S. Brambilla et al.) + **AGAVA** interface (A. Czermak et al.):

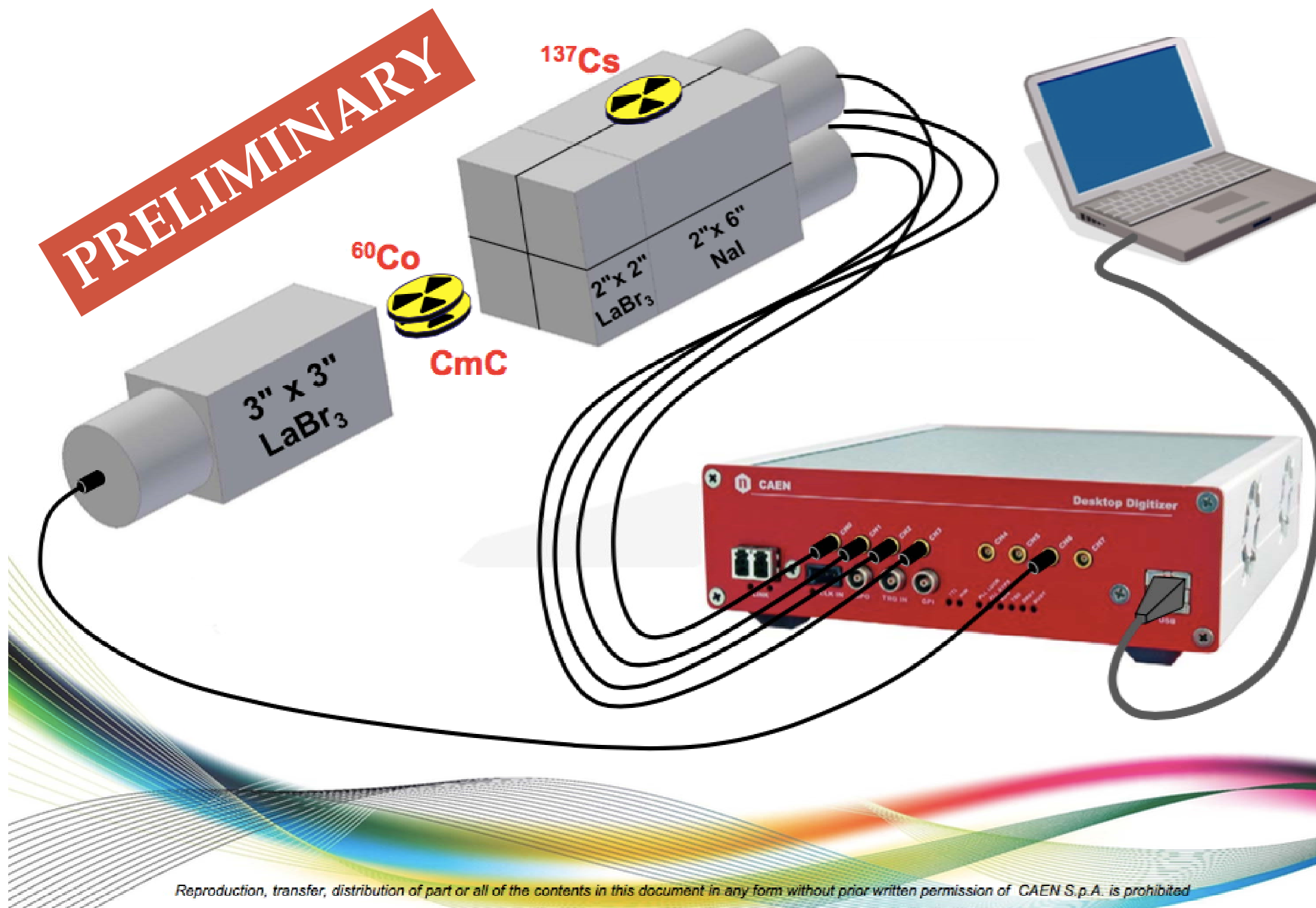
Already tested in AGATA LNL and GSU camapigns!

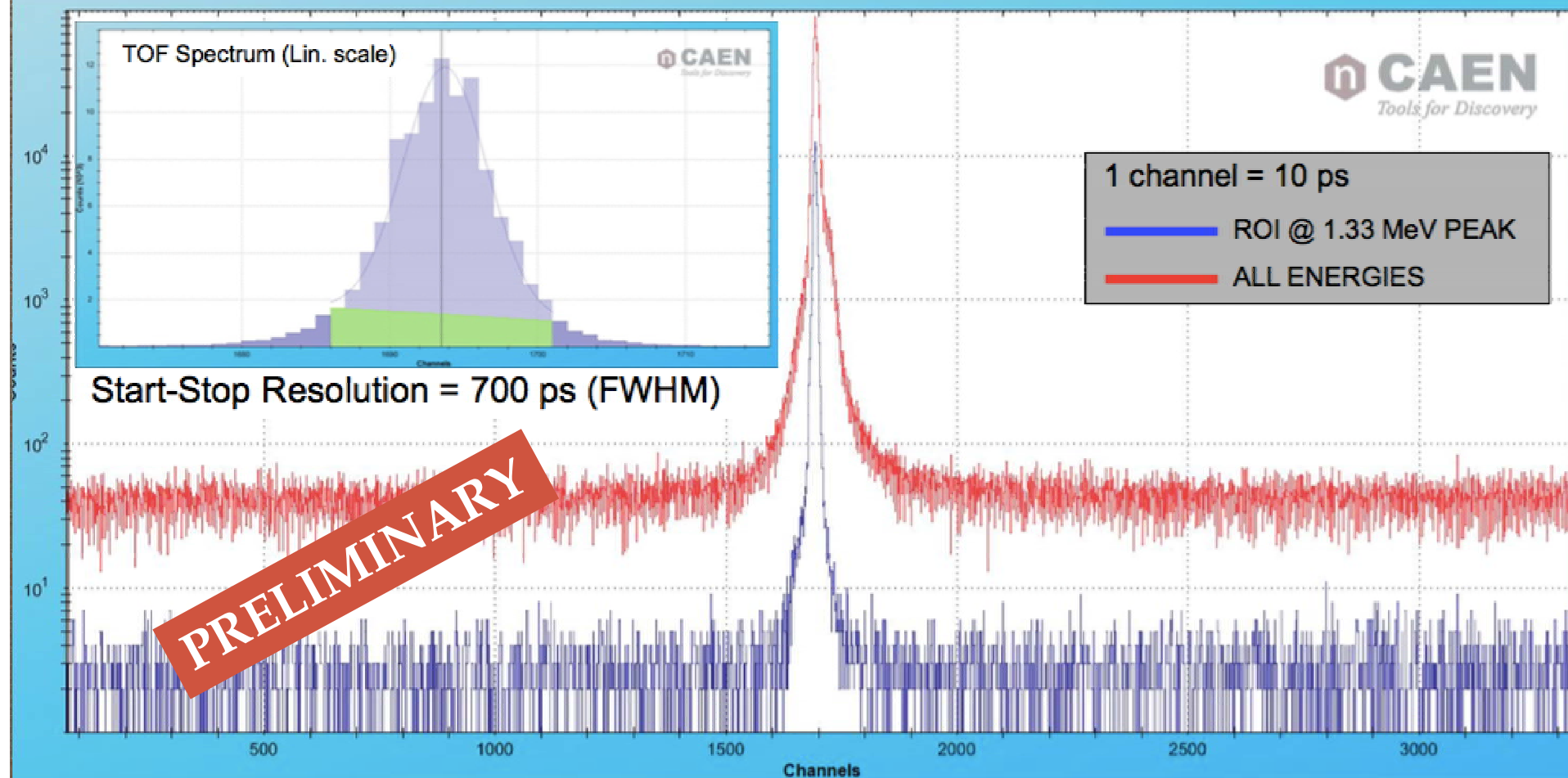
**Will be used fir first experiments with AGATA.
(integrated to the VAMOS branch)**

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 resolution - 0.7ns, low deadtme)







TOF from pure 3"x3" LaBr₃ to Phoswich-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**:

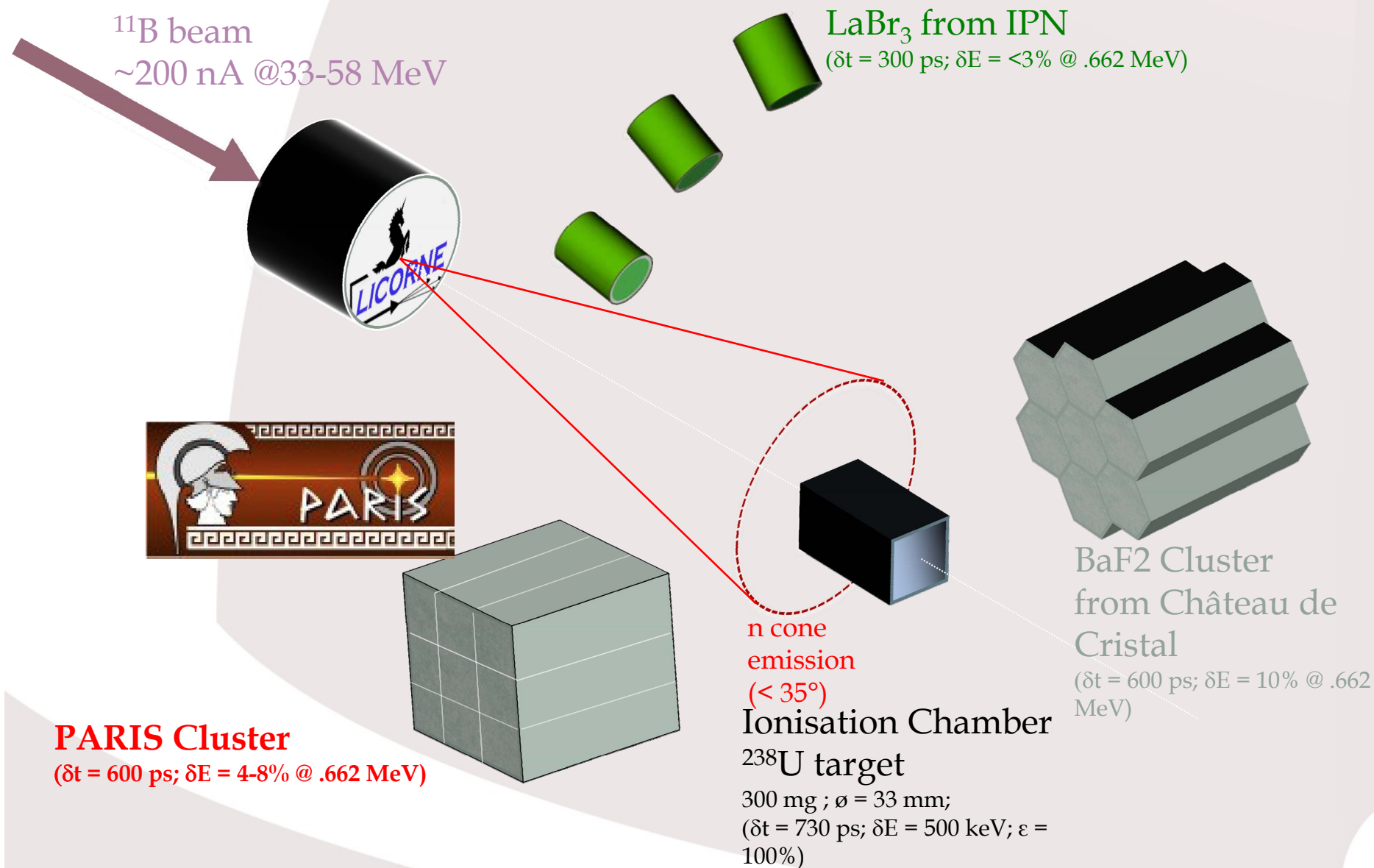
- M. Lebois - Prompt gamma and neutron emission for ^{238}U fast neutron induced fission as a function of incident neutron energy - **Done in April 2016!**
- A. Kozulin - Prompt γ -rays as a probe of nucleardynamics -**running now (end of June 2016)**

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

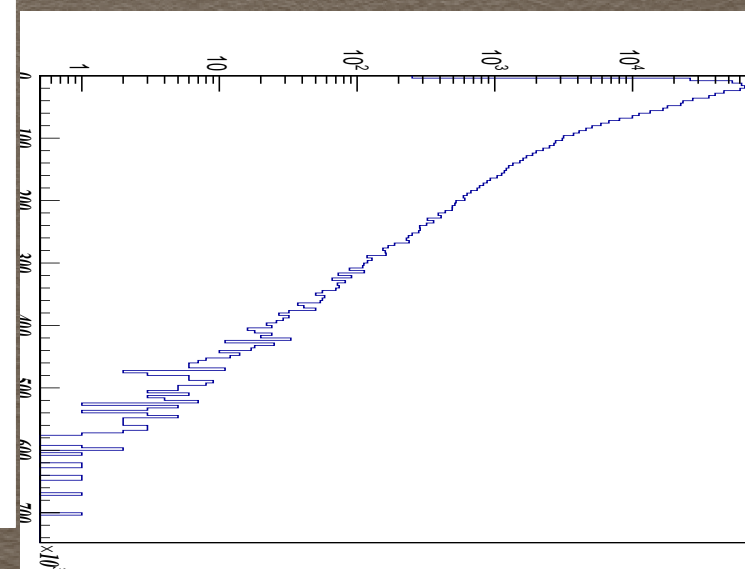
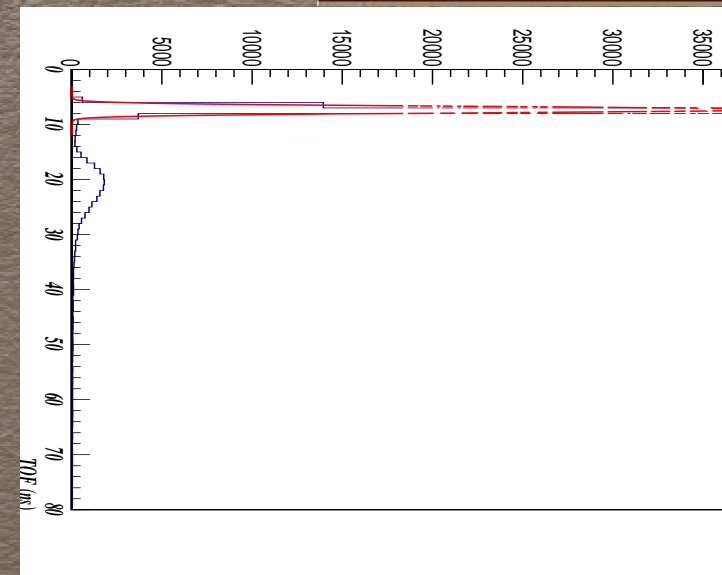
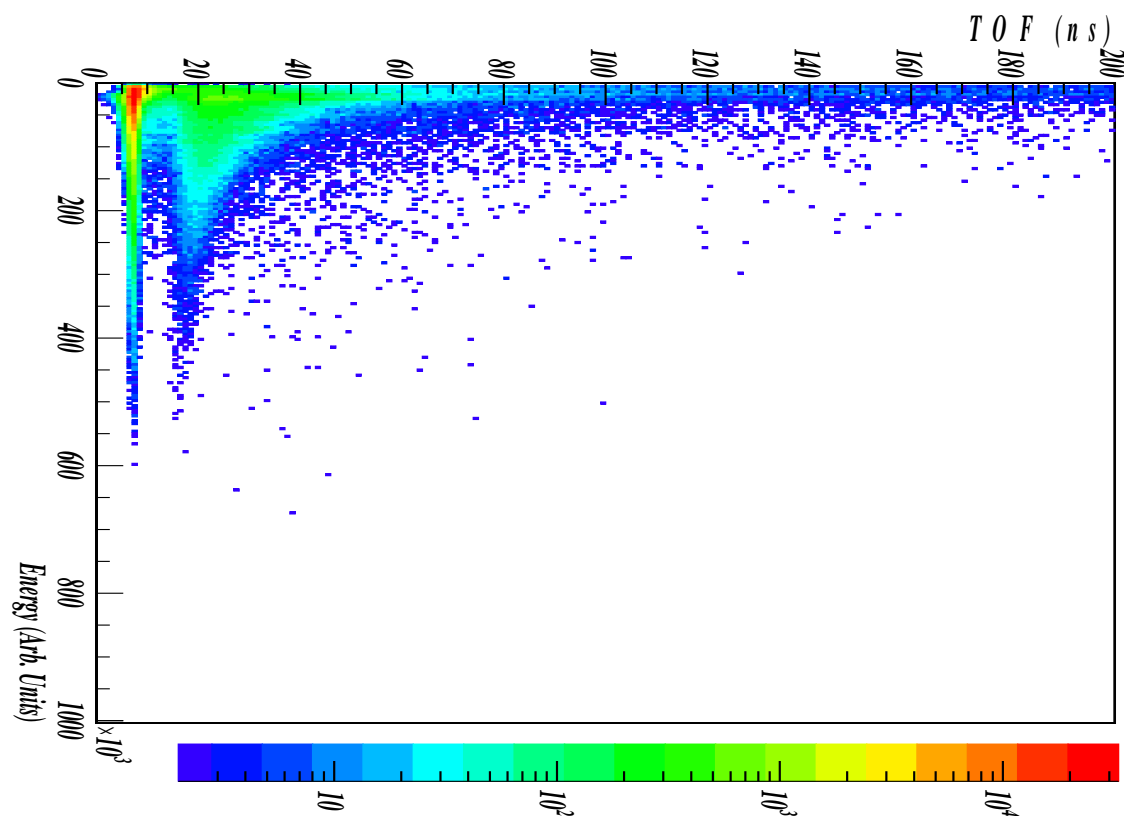




Preliminary Results for N-SI-86 Experiment With PARIS



^{252}Cf γ and neutrons from
spontaneous fission



Courtesy of Q. Liqiang & M. Lebois

CORSET, ORGAM i PARIS

A.Kozulin et al.. - Prompt γ -rays as a probe of nucleardynamics -running now
(Photo taken today)



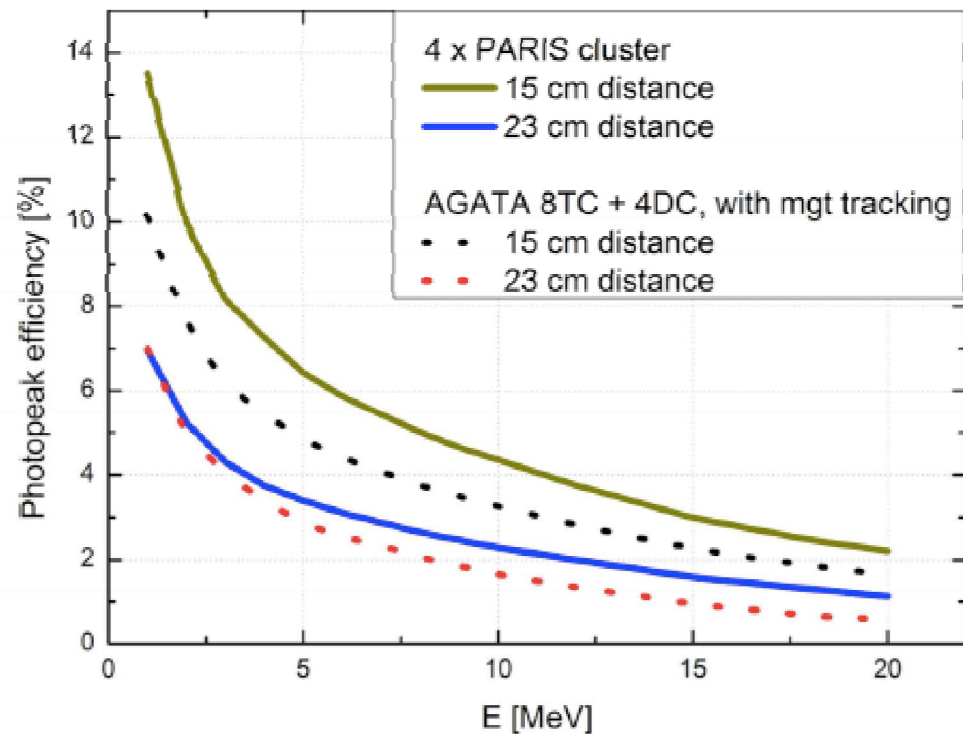
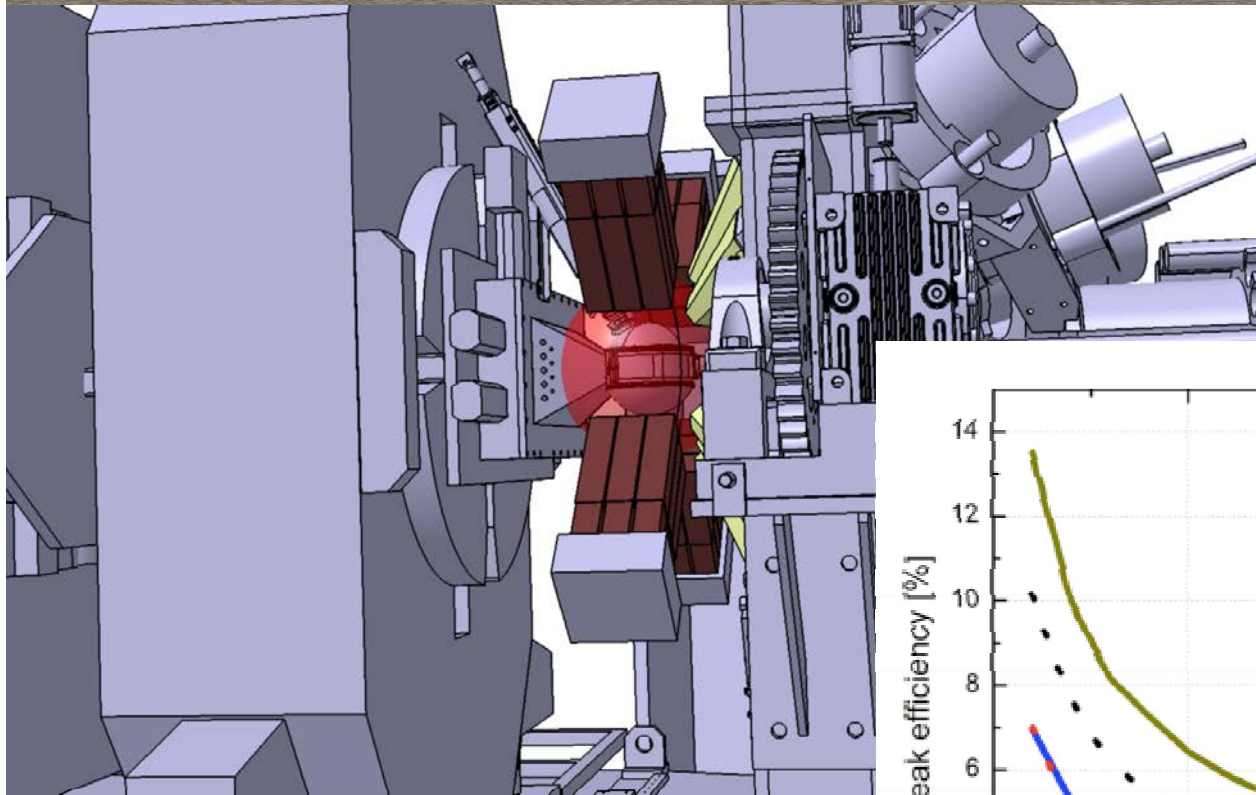
AGATA@GANIL (from mid 2017)

PARIS campagne 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*
- 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*
- 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* (4 clusters) , *PARIS, NEDA, DIAMAND, DSSD*

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

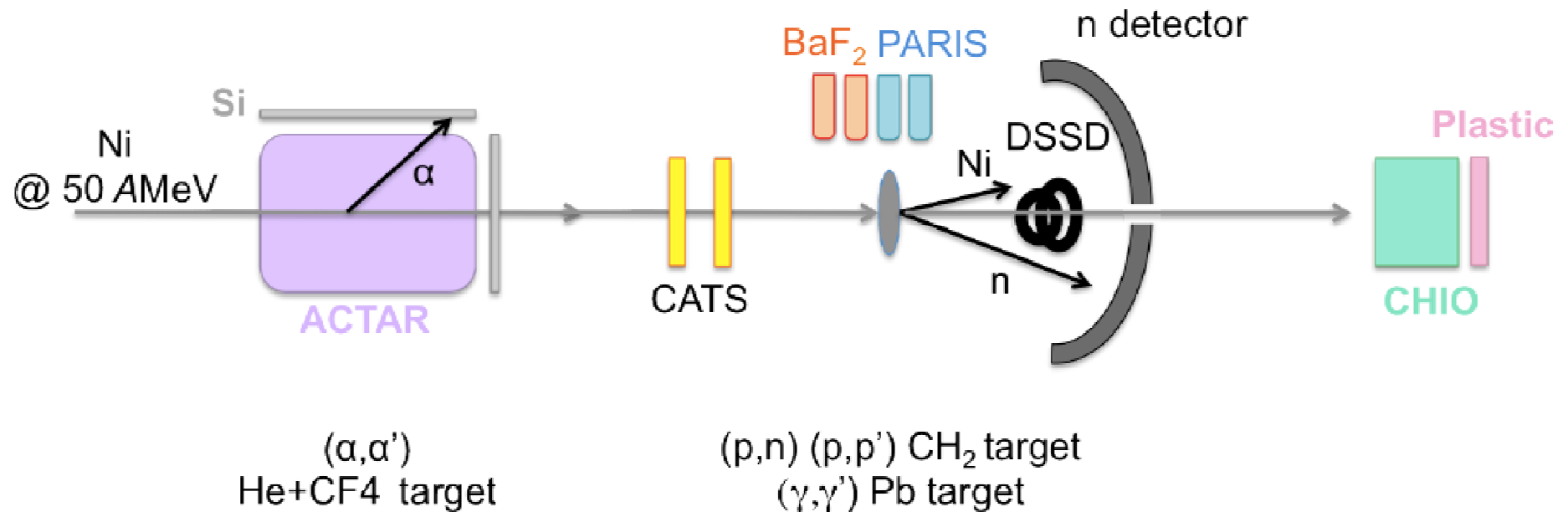


Figure 4: Proposed experimental setup.

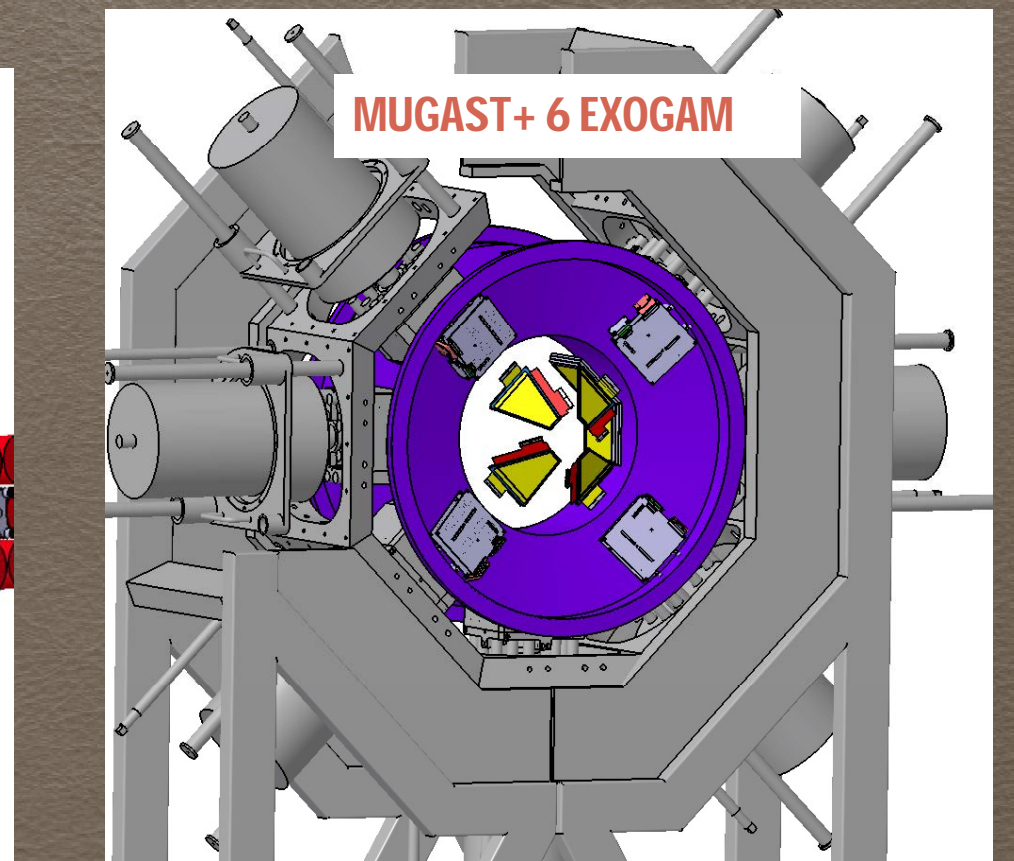
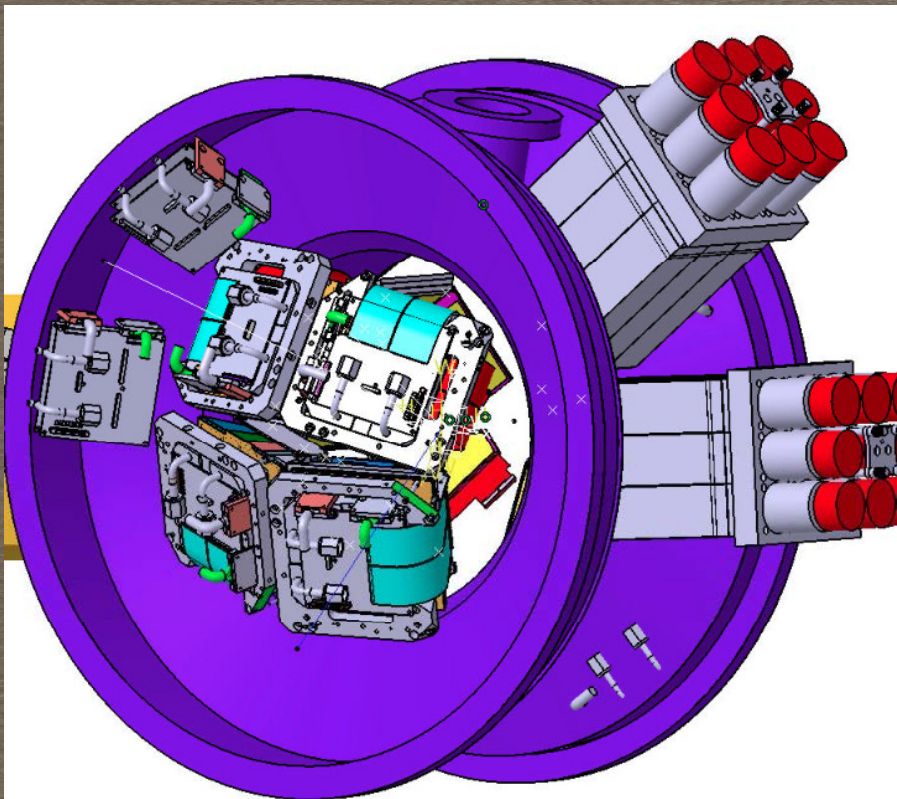
- 1 LoI for MUGAST@GANIL
- G. De Angelis, C. Domingo Pardo, „The $^{79}\text{Se}(n,\gamma)$ capture cross section via the surrogate $^{79}\text{Se}(d,p)^{80}\text{Se}$ reaction”, MUGAST, PARIS

« 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



**Next PARIS campagnes 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

Presnet SETUP

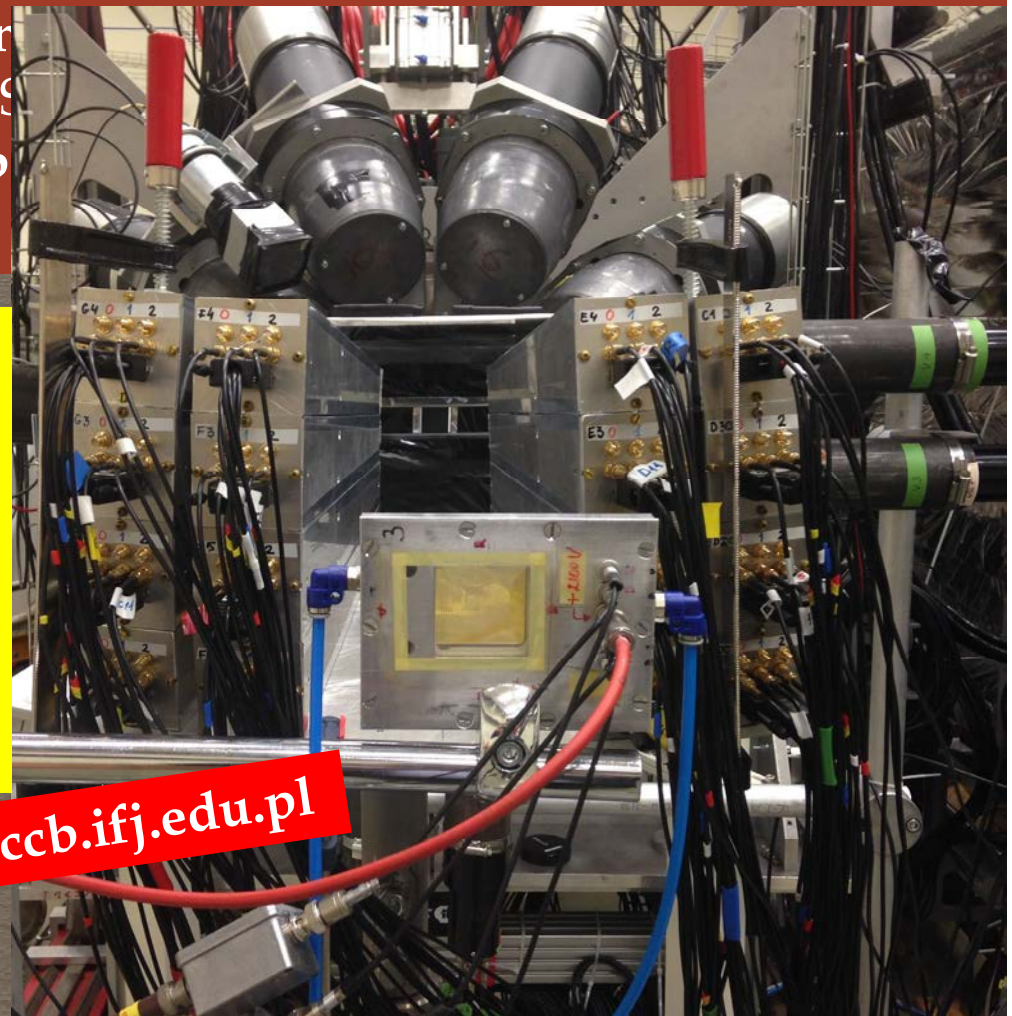
HECTOR: 8 large BaF2's (from Milano)

1 large LaBr3

1 small LaBr3

1 PARIS phoswich

KRATTA tripple telescope array

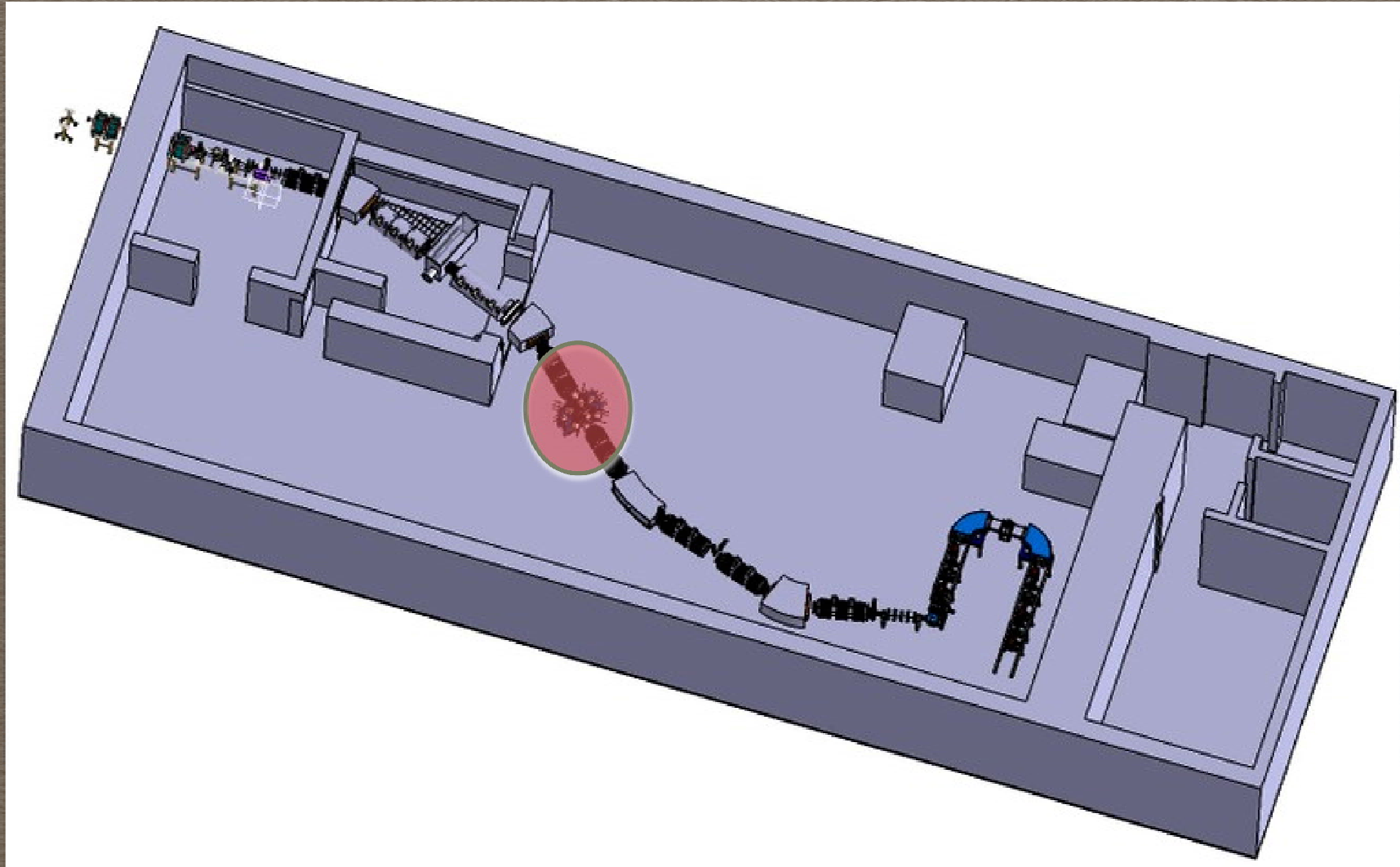


New call for proposals: experimentsccb.ifj.edu.pl

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



New Murphy law:

If everything goes smoothly with PARIS...

**Saint Gobain has again problems in
production of the phoswich detectors**

Newest delay in delivery PARIS phoswich detectors !!!

- 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)

Detector design review

- To potentially use separate hermetic seals, work on definition of :

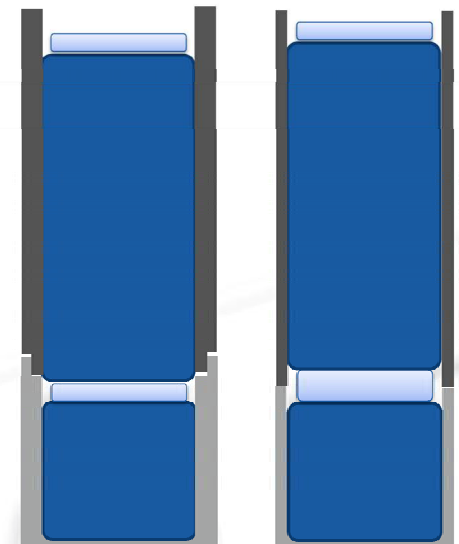
- Housing thickness / Interlocking housings ?

2 main possible designs:
interlocking or dual seal.

- Window Dimensions ?
(Minimum seal size)

- Overall length of detector(s) ?
(Crystal/window axial size limits)

- Nuclear Performance :
Absolute limits on performance?

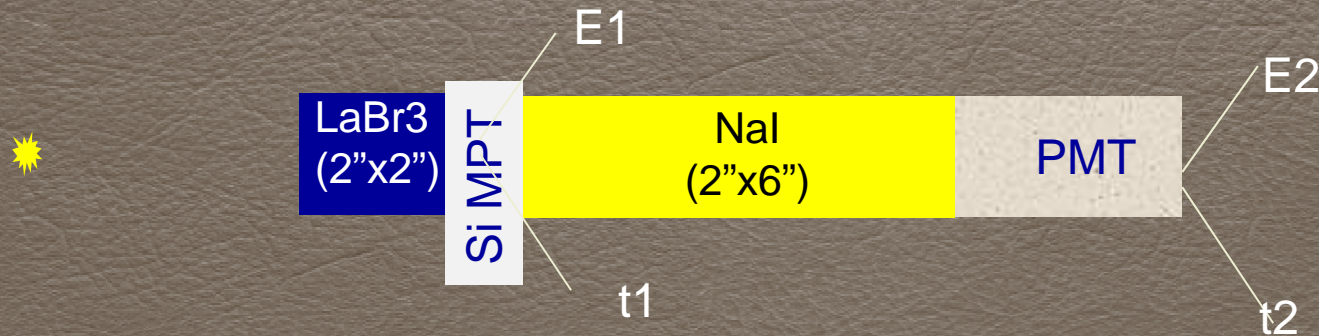


Interlocking

Dual seal around light
hermetic seal window

As a plan B, we have resumed work on alternative designs:

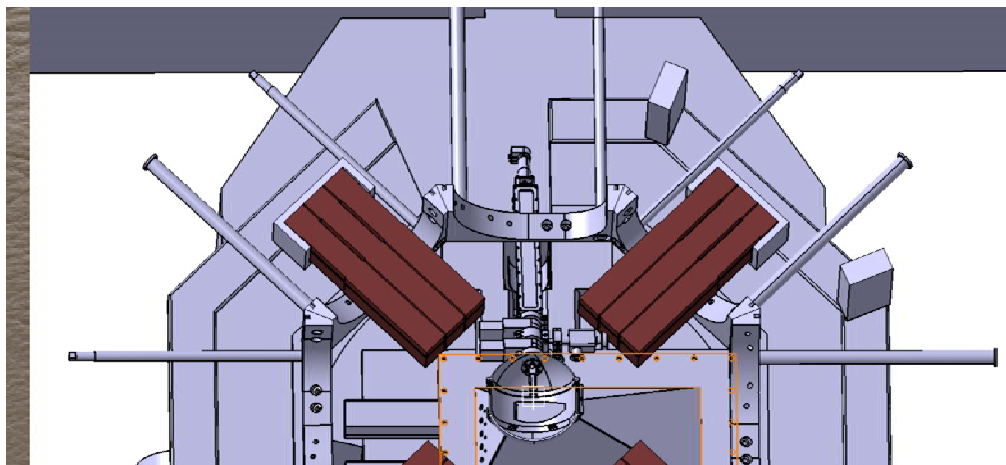
1) Coming back to 2 separate layers idea



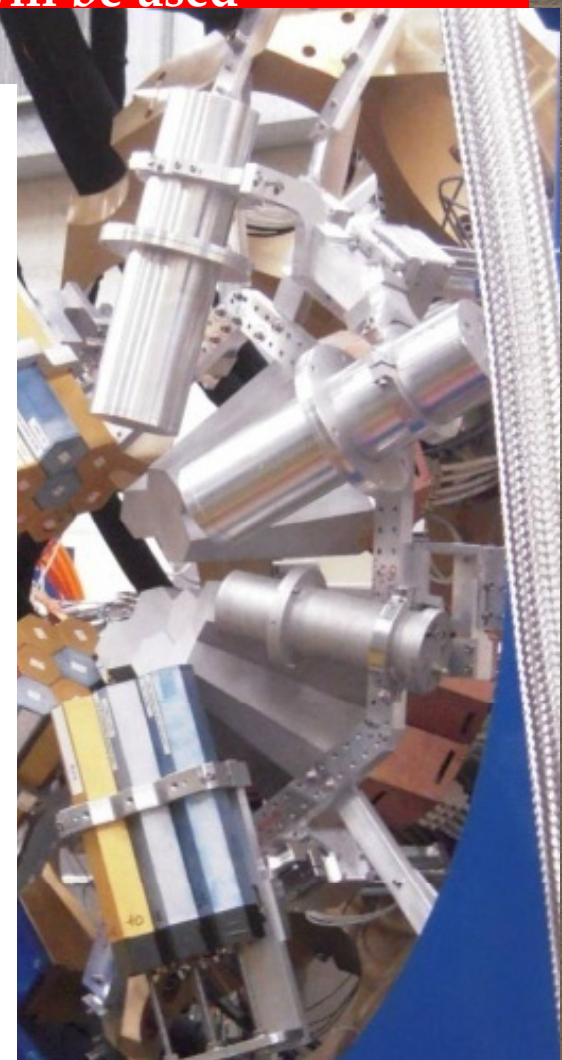
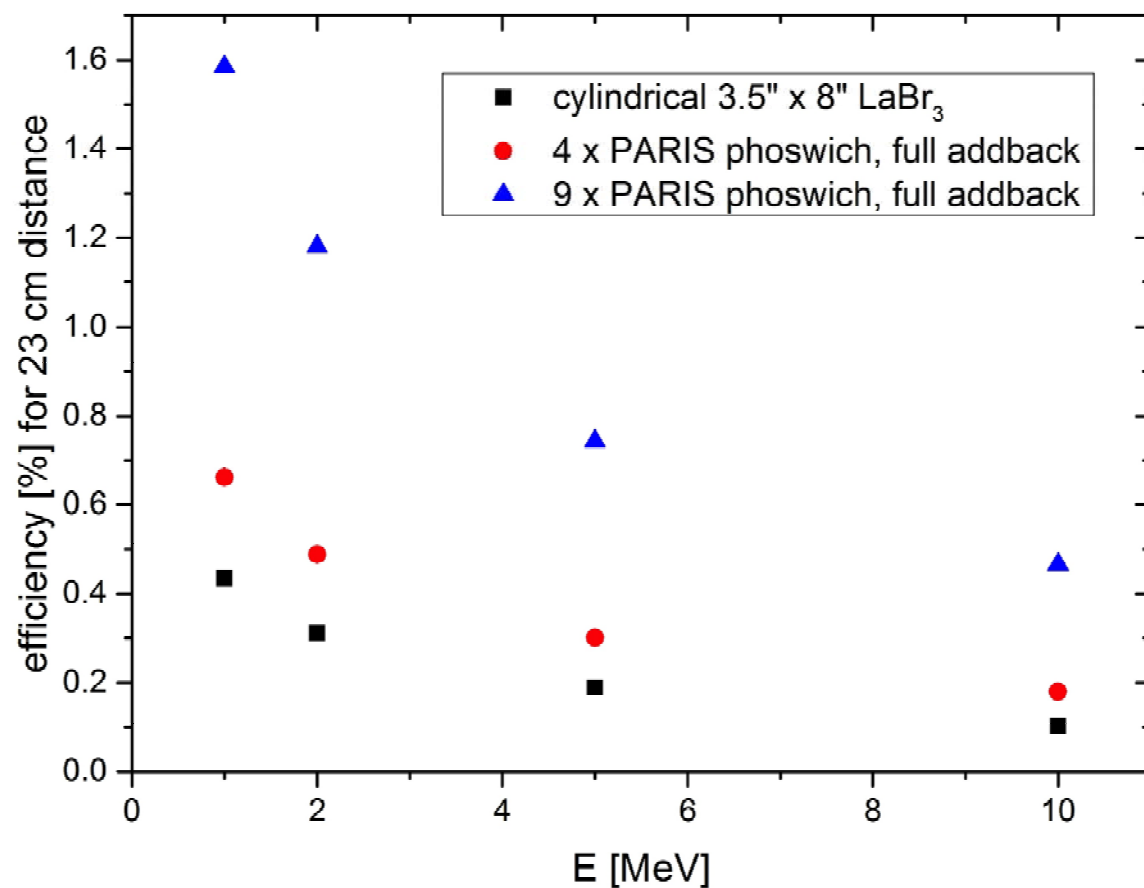
First tests done in York and Krakow. Results look promising but still long way to the prototype

2). Changing LaBr3 to another scintillator, but keeping the phoswich concept

Phoswich made of CeBr3+NaI (discussion with Scionix undertaken, a prototype to be delivered end of July 2016)



Possible measures to mitigate the influence of the delay of delivery of the phoswiches:
For the AGATA experiments large volume LaBr₃ (3.5"x8") from Milano and Krakow will be used



PARIS construction time line

Within PARIS Demonstrator MoU

- **Presently PARIS has 14 operational phoswiches**, and additional 5 are sent to SaintGobain for replacements/repair
- **>9 additional phoswiches were ordered and are on hold**
- **If the production with new design (LaBr₃-NaI or CeBr₃-NaI) starts at the end of this next, until mid of 2017 we might have 3 cluster, and 4 clusters until end of 2017**
- **Beginning 2016: Analogue electronics PARIS-Pro implemented, mechanical integration to AGATA ready**
- **In 2016: NUMEXO2 or CAEN V1730 electronics verified**

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

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

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

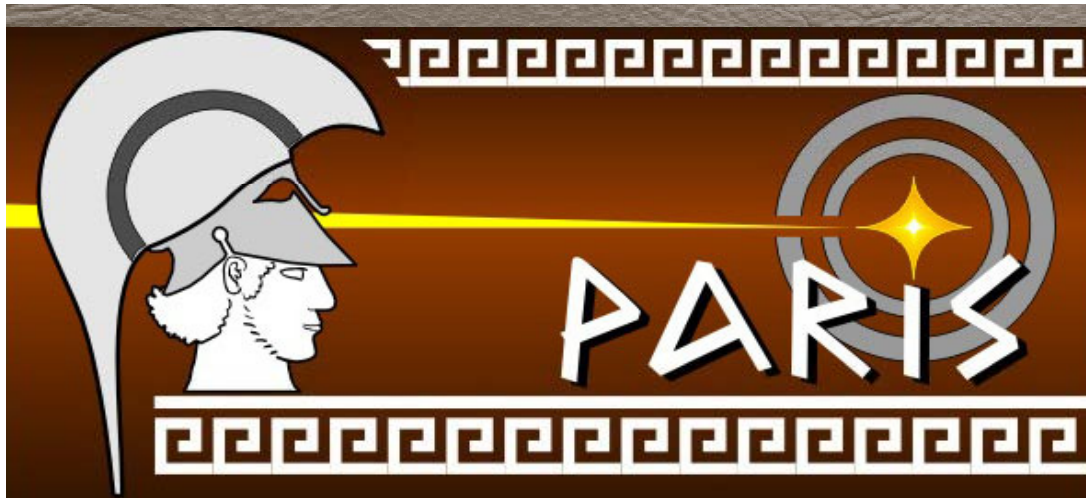
Summary



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).



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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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Partners of the PARIS Demonstrator MoU and their capital investment (2012-2015)

IN2P3 (France): 300 k€

GANIL (France): 180 k€

COPIN (Poland): 300 k€

TIFR/BARC/VECC (India): 180 k€

NIPNE Bucharest (Romania): 70 k€

INFN (Italy): 50 k€

York/Surrey (UK): ca. 40 k€

4 Universities in Turkey: 20 k€

INRNE Sofia (Bulgaria): 15 k€

Together: ca. 1.2 M€

**Preliminary cost of the
PARIS Demonstrator (5 clusters):
ca. 1.1 M€**