PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

Adam Maj
for the PARIS collaboration

Project PARIS

NUSTAR Week 2015

from September 27, 2015 to October 1, 2015
Warsaw
Europe/Warsaw timezone

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

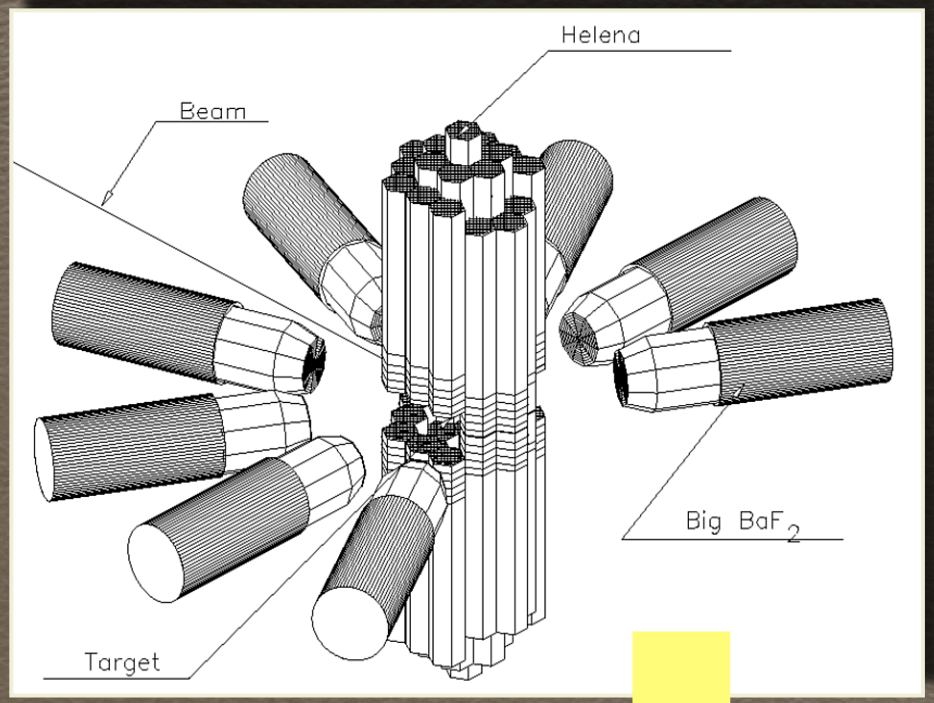
Title: High-energy γ-rays as a probe of hot nuclei and reaction mechanisms

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

Origin of the name PARIS



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

PARIS

PHOTON ARRAY FOR STUDIES WITH RADIOACTIVE ION AND STABLE BEAMS

SPIRAL2

NFS: neutron beam

DESIR: low-energy radioactive beams

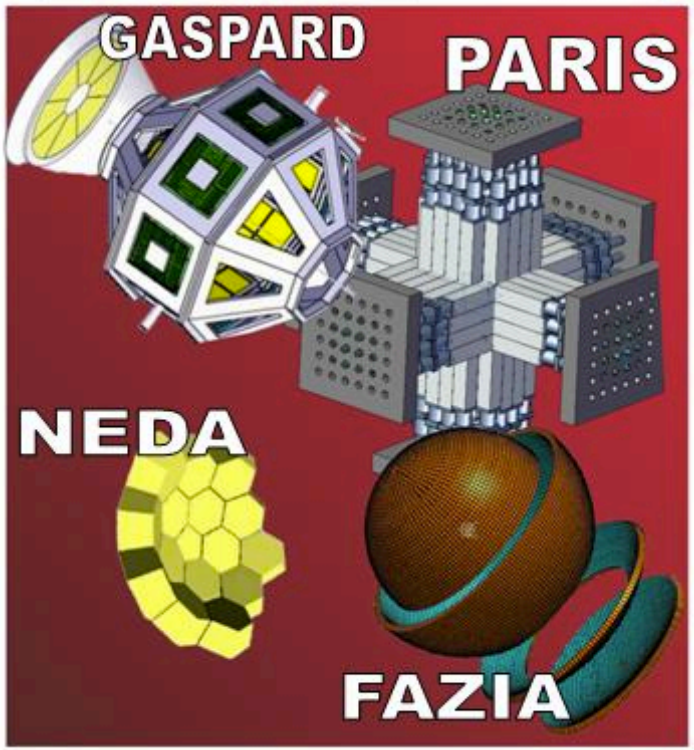
S^3: super separator spectrometer

LINAC driver: p - 33MeV, d - 40 MeV, heavy ions - 14.5 AMeV

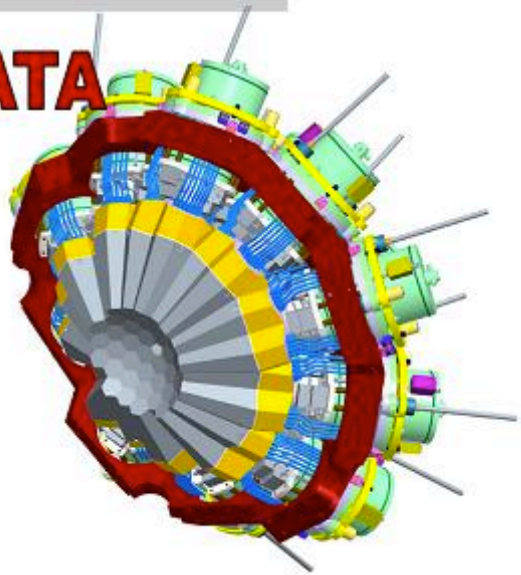
Ion sources: I > 1 mA

GANIL/SPIRAL1: existing infrastructure

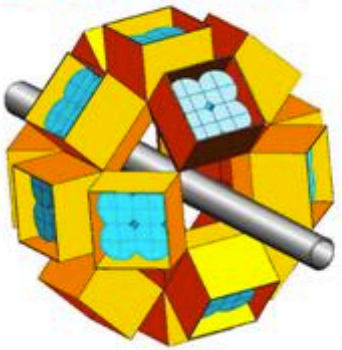
Radioactive beams production cave: 10^{14} fissions/s



AGATA



EXOGAM2



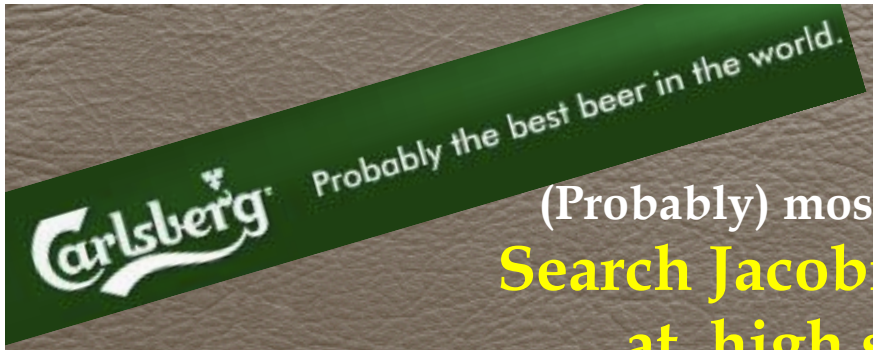
PARIS desing concepts:

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..

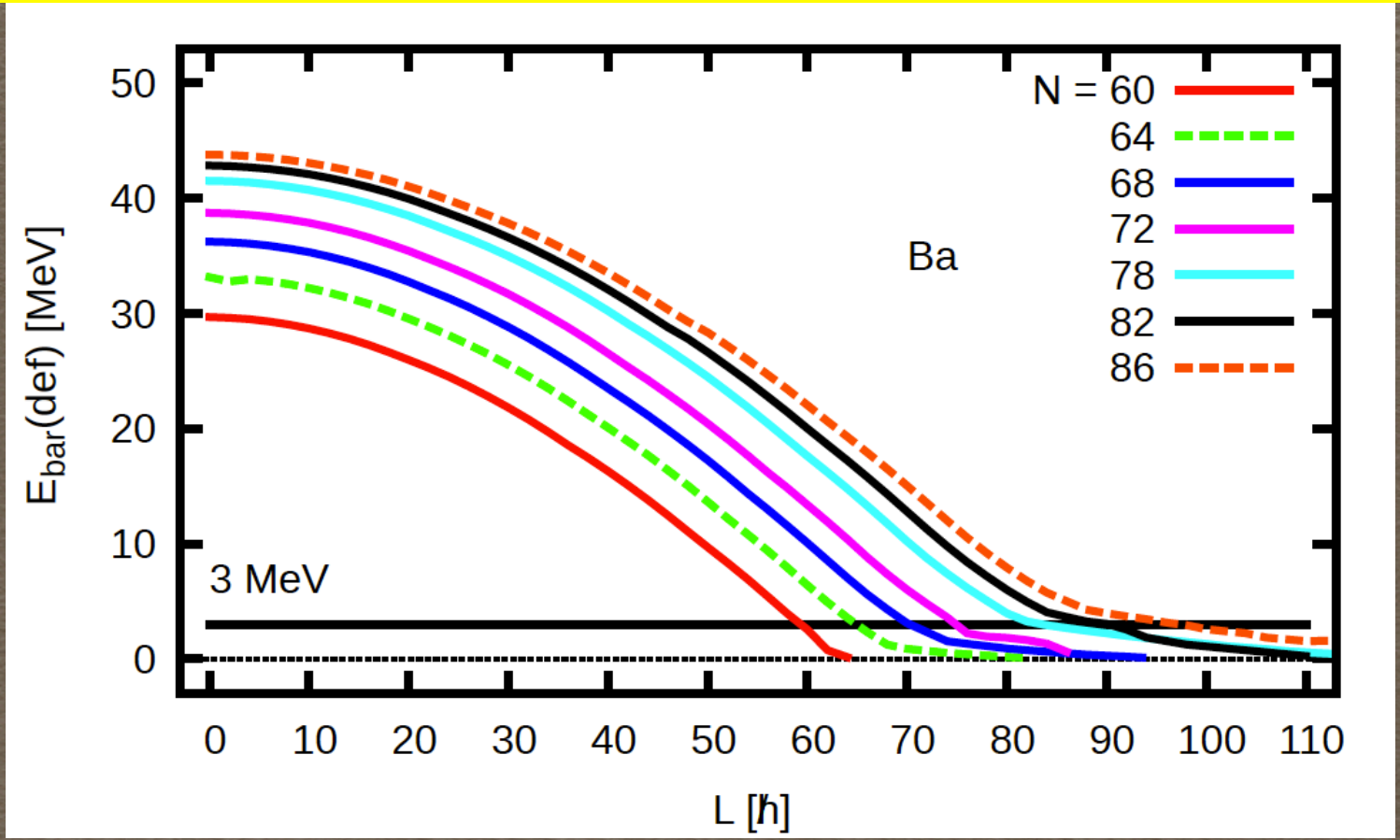
2-shell or phoswich concept, in addition to being more economic, shall help to distinguish a high-energy photon from a cascade of low energy gamma transitions in fusion evaporation reactions



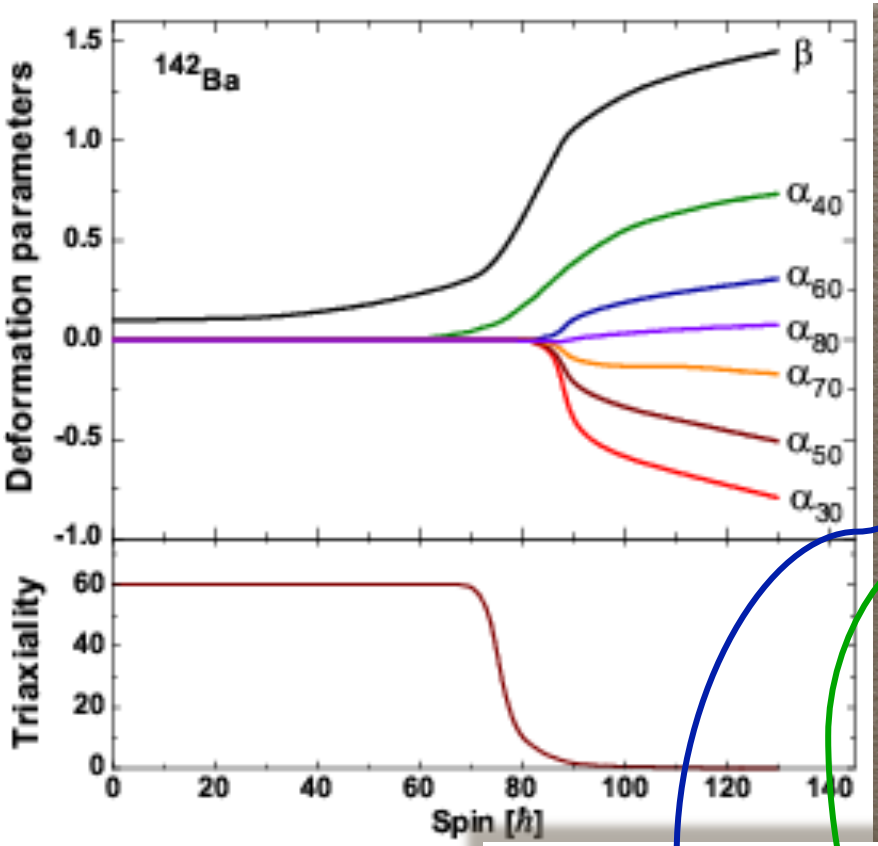
(Probably) most spectacular physics case for SPIRAL2 Phase2:

Search Jacobi and Poincare shape transitions at high spins in neutron-rich nuclei

With RI beams extremely high spins can be reached in fusion-evaporation reactions



Poincare shape transitions (e.g. ^{142}Ba)

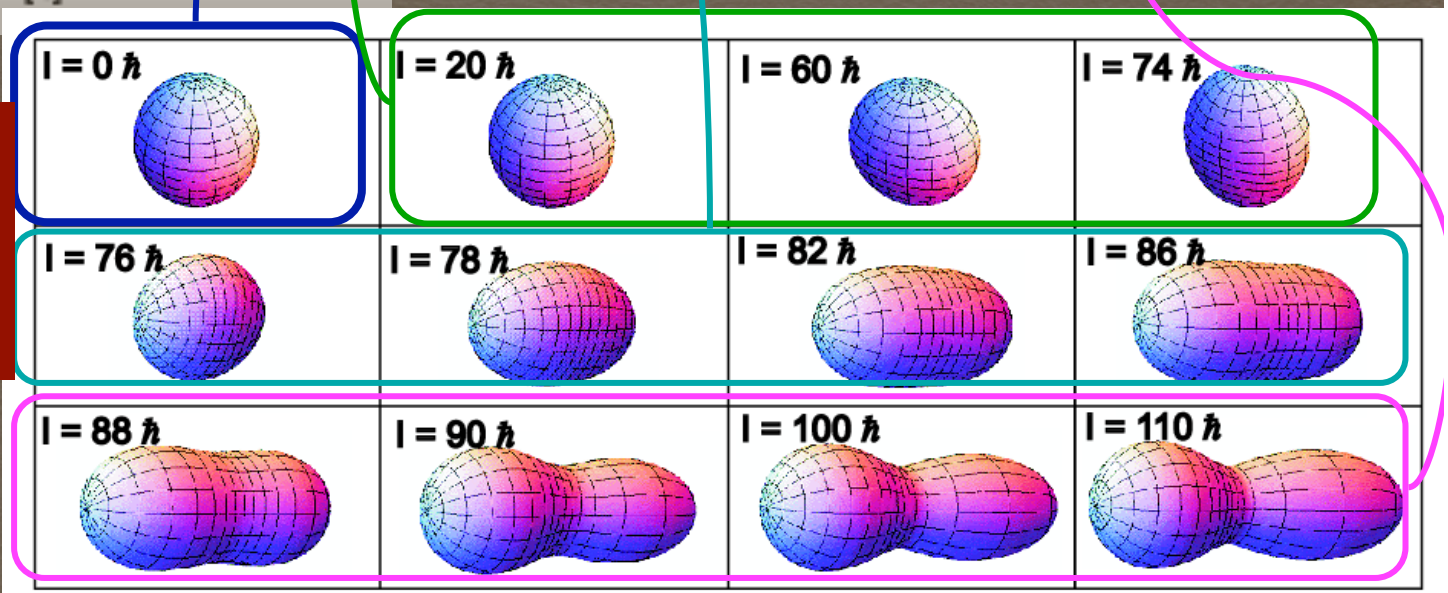


Sphere

Oblate (MacLaurin)

Elongated triaxial (Jacobi)

Octupole, left- right asymmetric (Poincare)

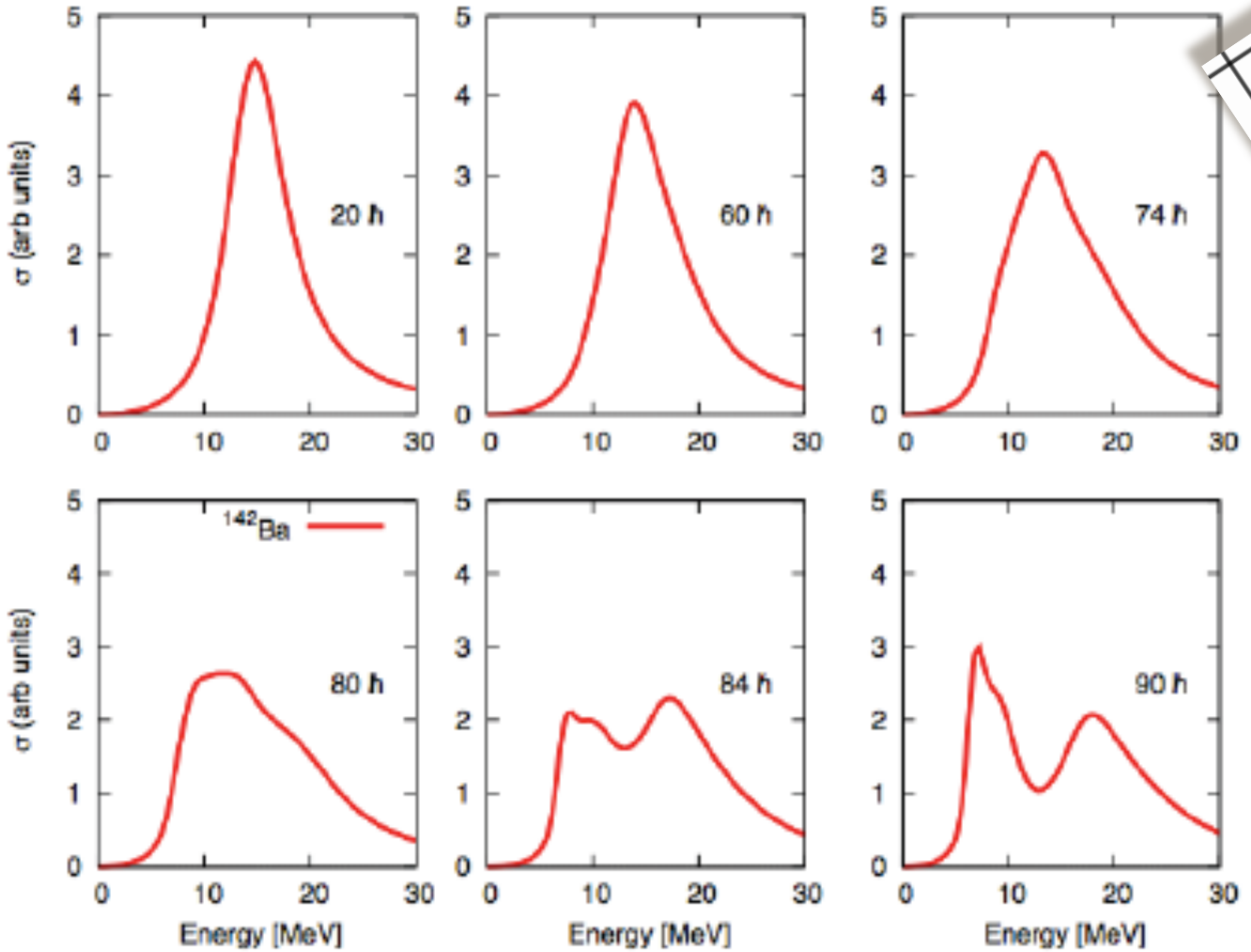


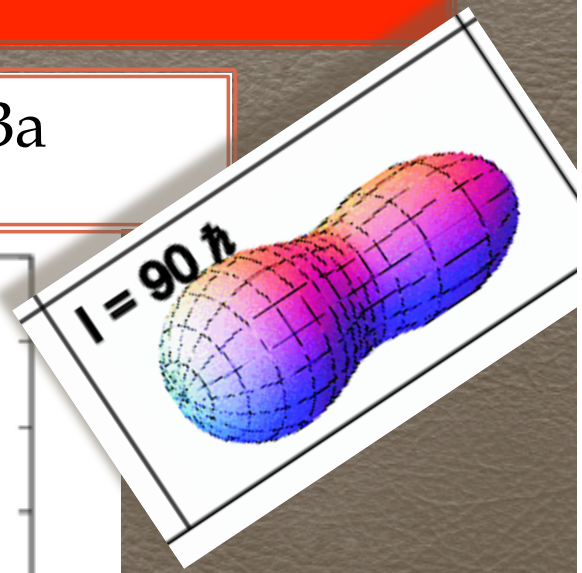
Theoretical prediction *(for the first time)* of the Poincare shape transition in atomic nuclei

GDR wibrations in whole nucleus and in the semifragments: Fragmented GDR strength function

Evolution of GDR strength function for ^{142}Ba

K. Mazurek et al., to be published

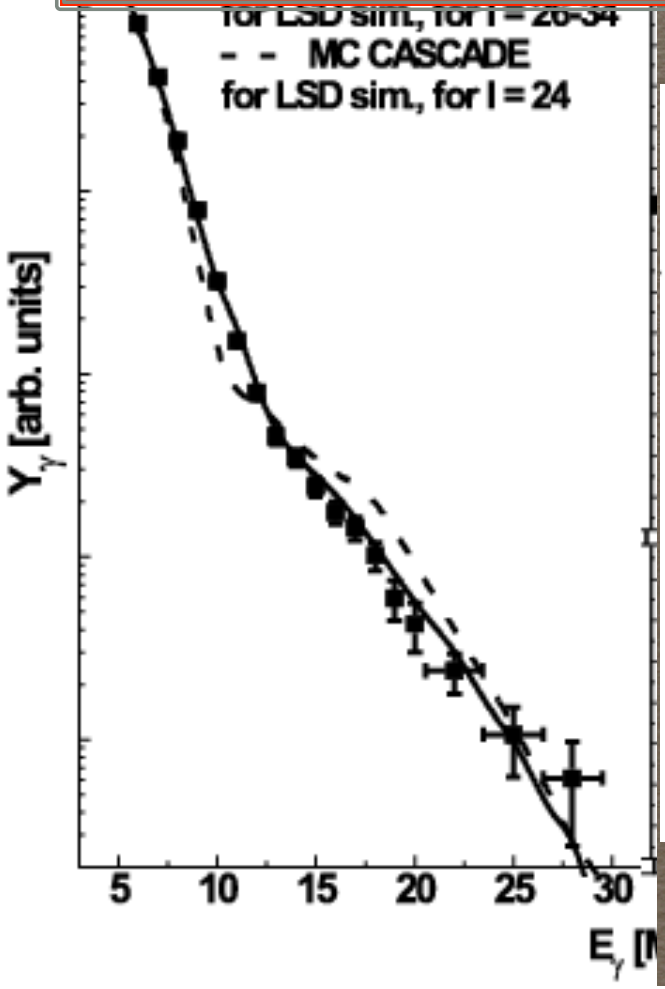


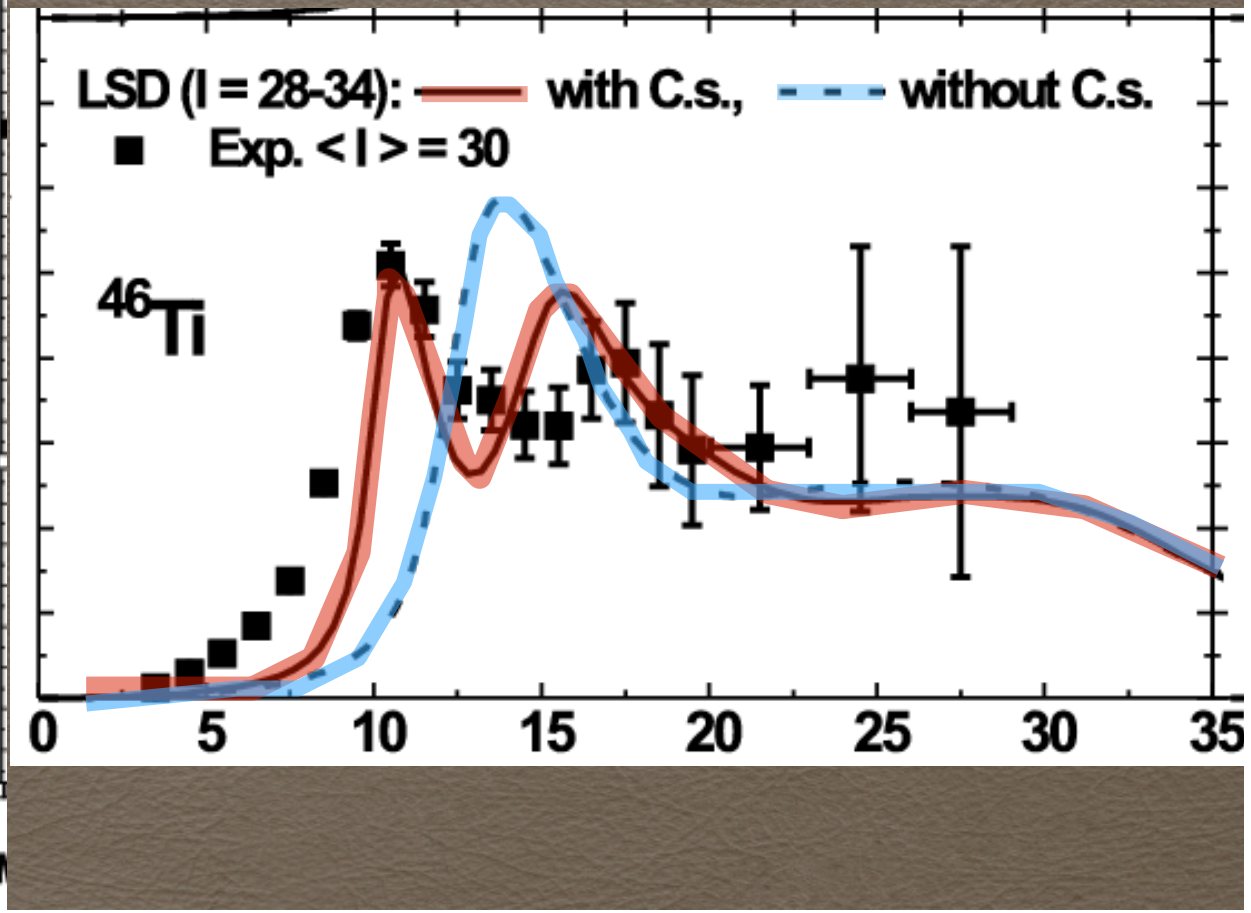


Comparison to the calculated GDR shape based on LSD

A. Maj et al, Nucl. Phys. A731 (2004) 319
M. Kmiecik et al., Acta Phys. Pol. B36, (2005) 1169

Evidence of the „Jacobi shapes" in ^{46}Ti at high spins and *(for the first time)* of the Coriolis splitting





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

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. ^{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: PARIS +AGATA
S. Leoni et al.

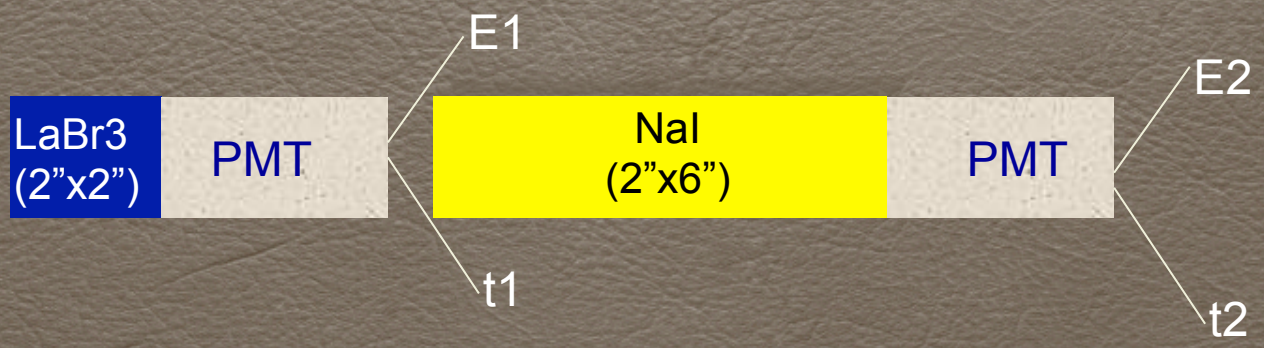
p) **Evolution of nuclear structure of ^{78}Ni and ^{132}Sn with ACTAR+PARIS**
G.F. Grinyer et al..

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**, HIE-ISOLDE, Mumbai, NUSTAR@FAIR?,…)

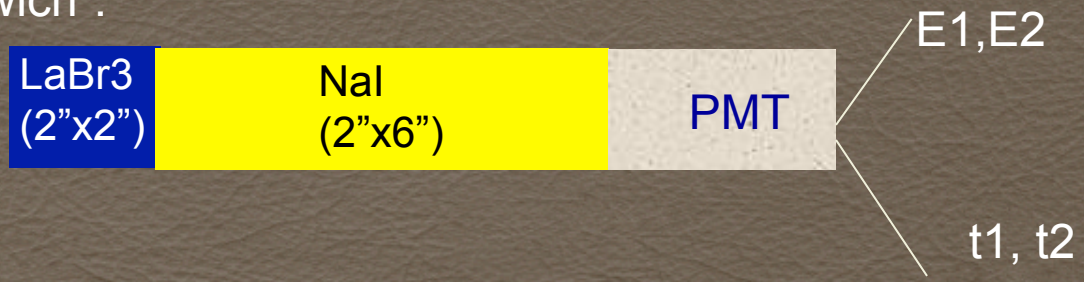
4 POSSIBILITIES FOR A „GAMMA-TELESCOPE" ELEMENT

Possibility 1.

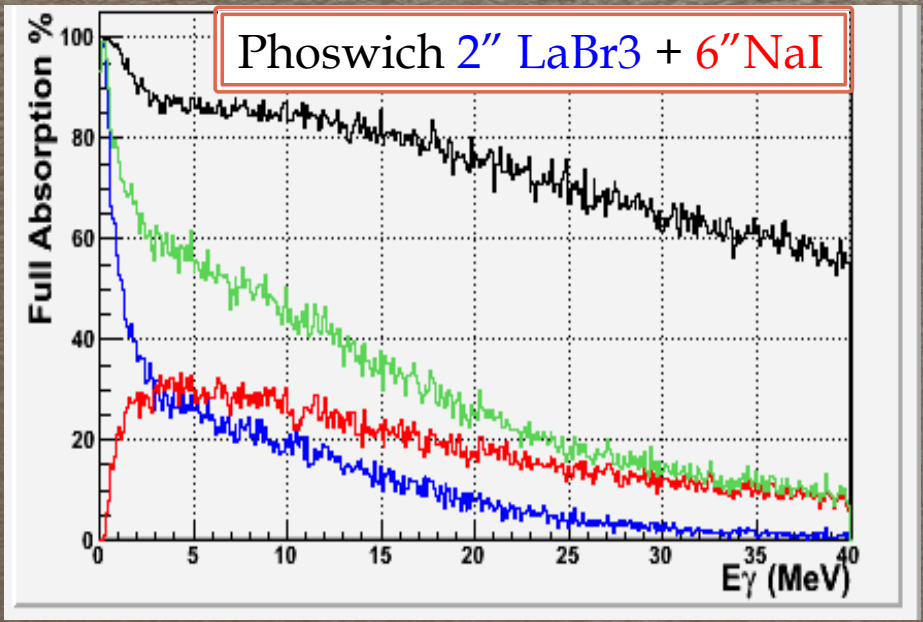


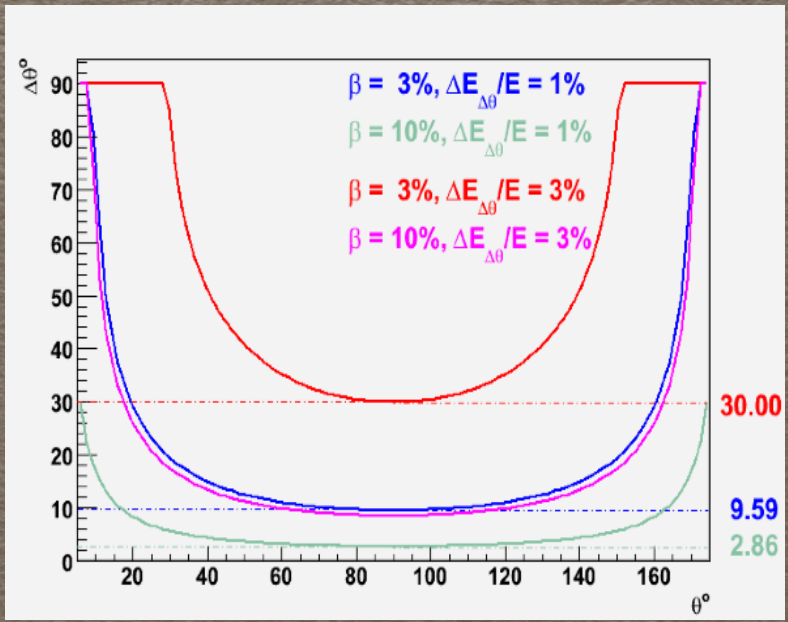
Possibility 2.

Possibility 3 – „phoswich".



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



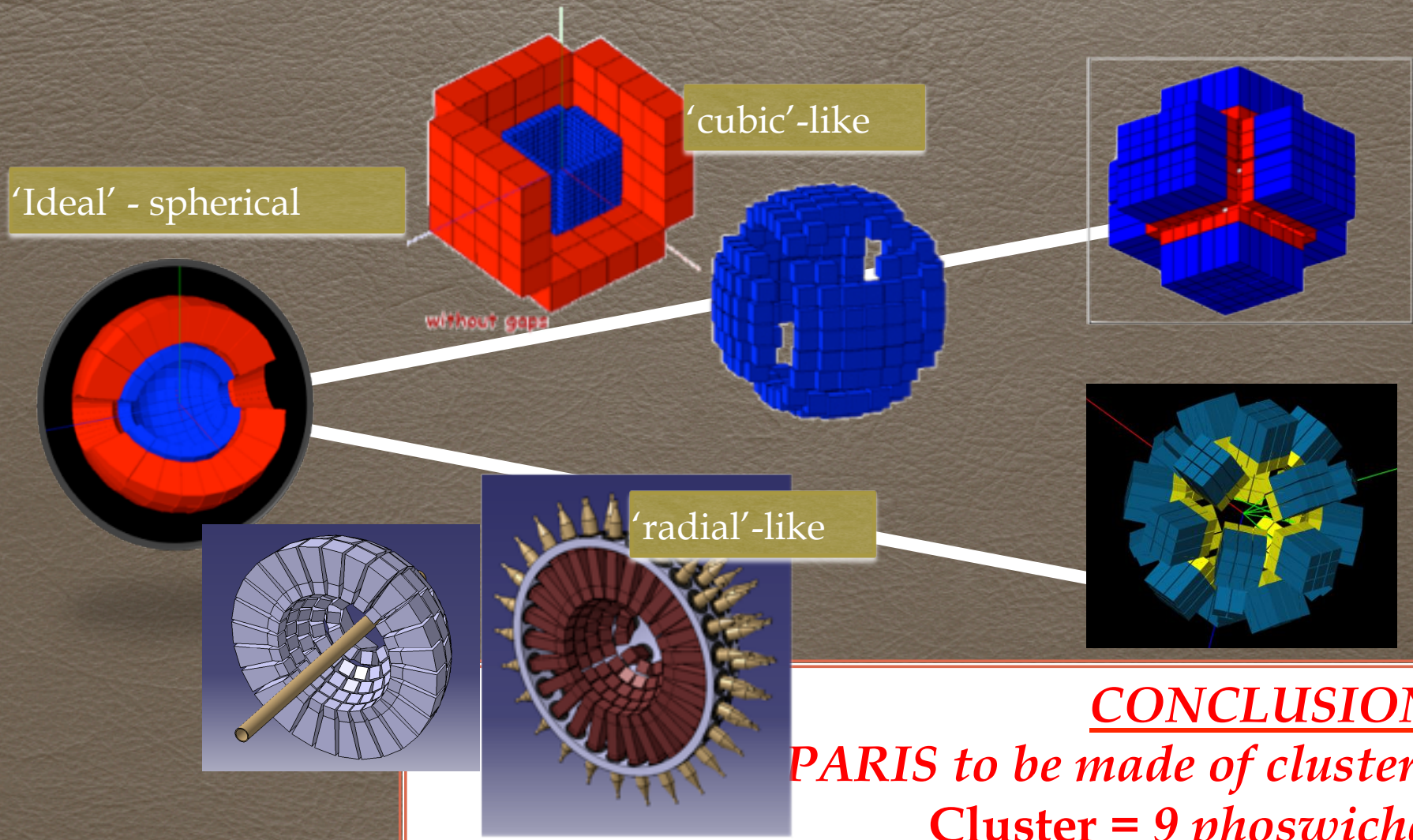


Extensive simulation studies have been performed to understand how γ–rays with energies from few keV up to 50 MeV are absorbed and recovered. Figure above is used for instance to determine the opening angle required to not spoil out the intrinsic LaBr3 resolution. All the considerations drive the ***design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

a phoswich 2″x2″x2″ LaBr3 followed by 2″x2″x6″ NaI.

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

Several geometries studied



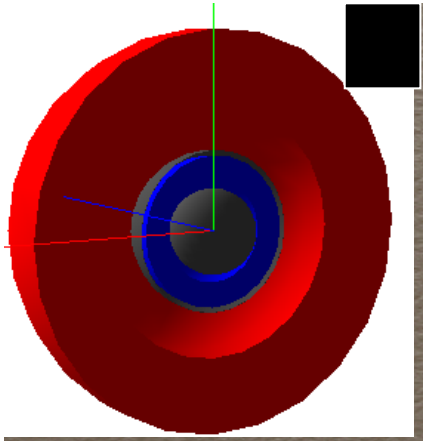
CONCLUSION:

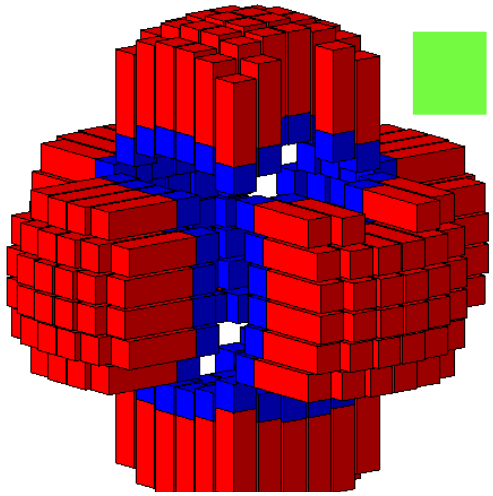
PARIS to be made of clusters:

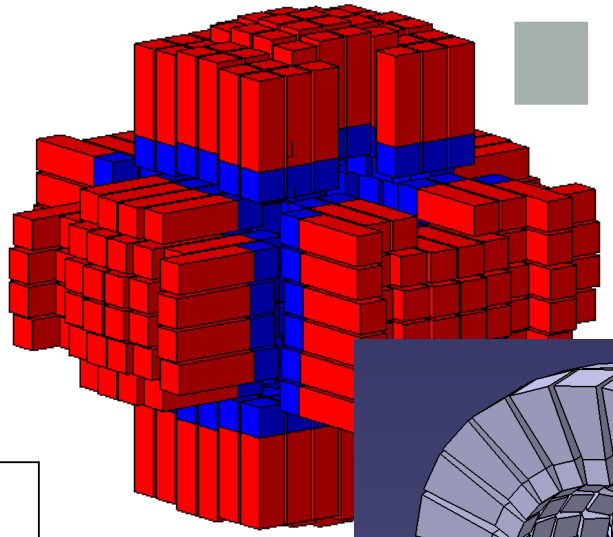
Cluster = 9 *phoswiches*

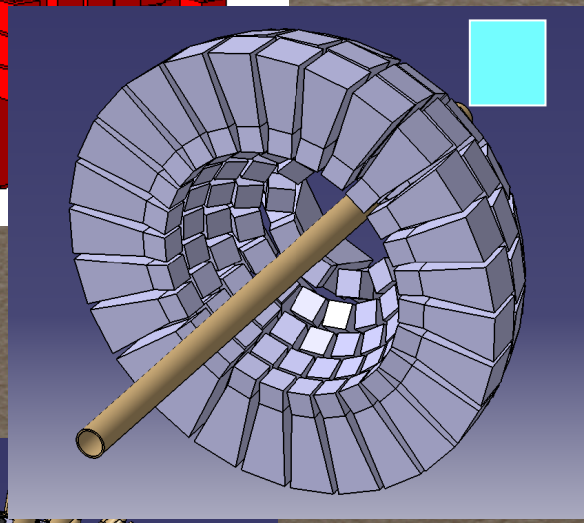
This allows *cubic* or *semi-spherical* geometry with 24 clusters (216 phoswiches)

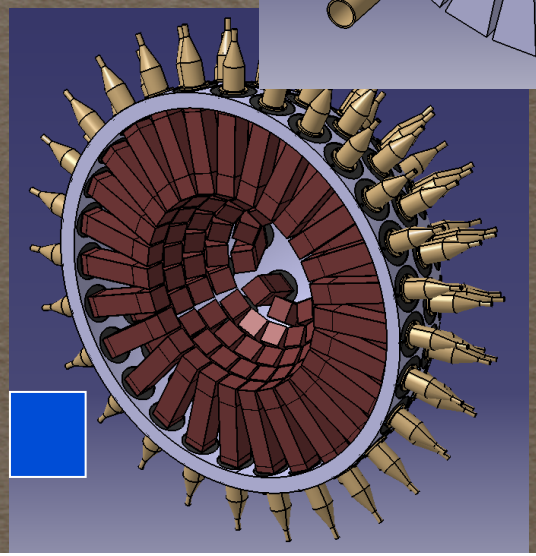
Cubic vs. Radial geometry

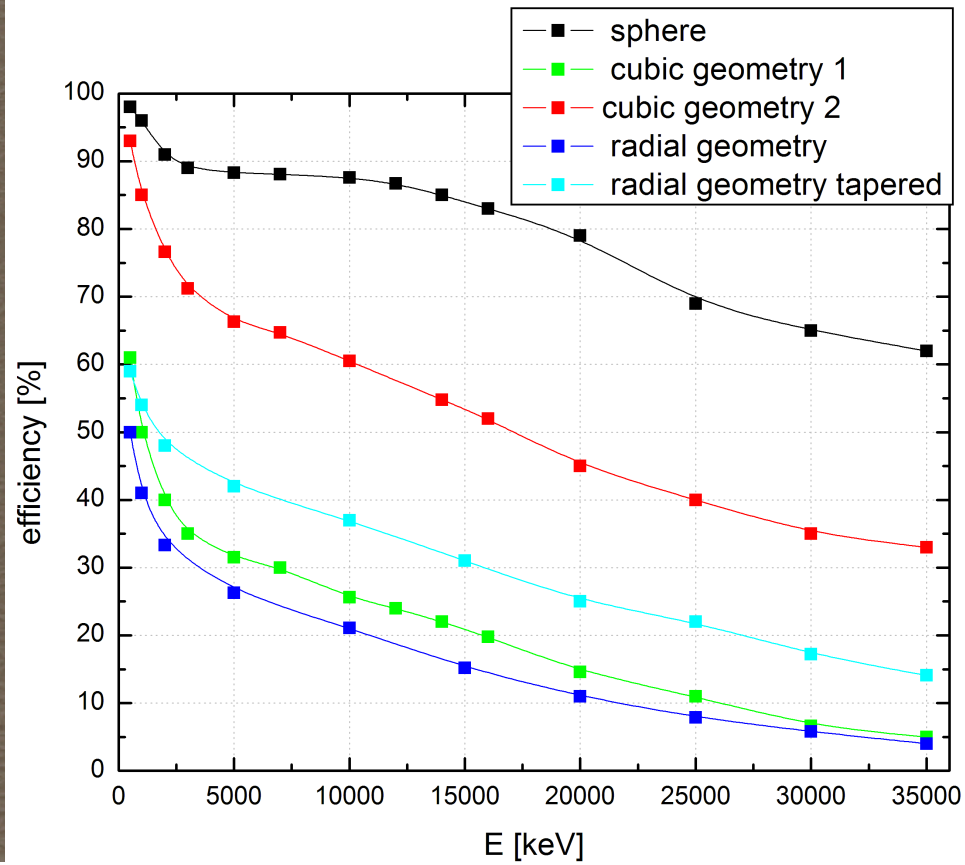












Institutions actively working for PARIS

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

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

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

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

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

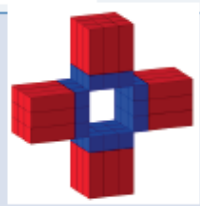
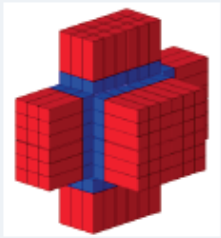
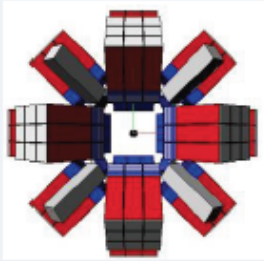
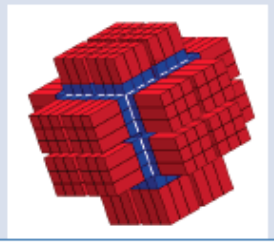
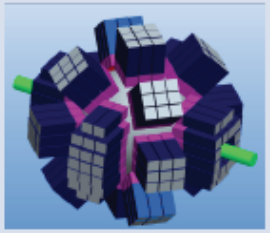
BULGARIA (cord.: D. Balabanski) INRNE Sofia

HUNGARY (coord.: Z. Dombradi) ATOMKI Debrecen

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 **2015** **PARIS Demonstrator**	5 clusters: 45 phoswiches		1100 k€	**Only if Phase1 validated** Funds: MoU Ph1Day1 exp@S3
Phase 3 **2017** **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 **≈2019** **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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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€

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

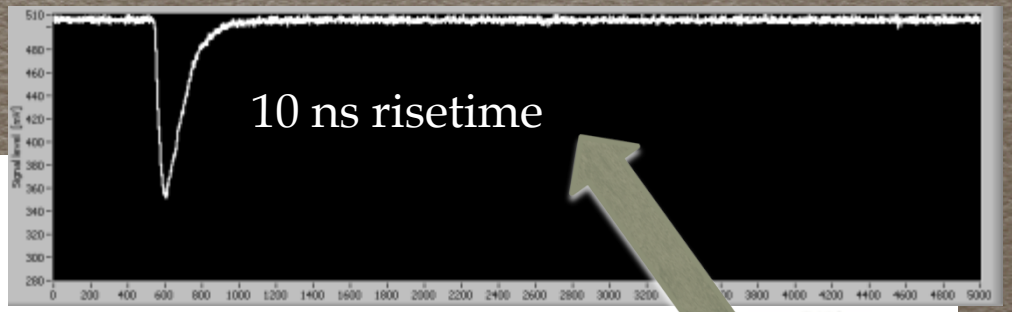
Campaign Spokesperson
(nominated by lab directors):
GANIL: C. Schmitt
IPN Orsay: I. Matea

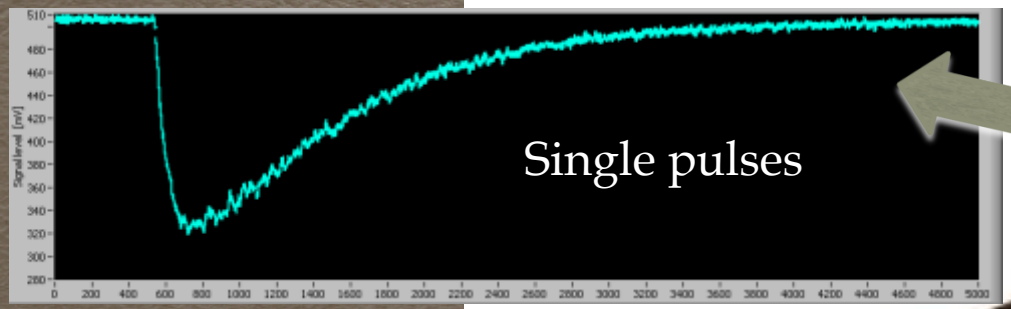
PARIS Collaboration Council – representing each institution interested in PARIS. Chair is elected for 2 years term

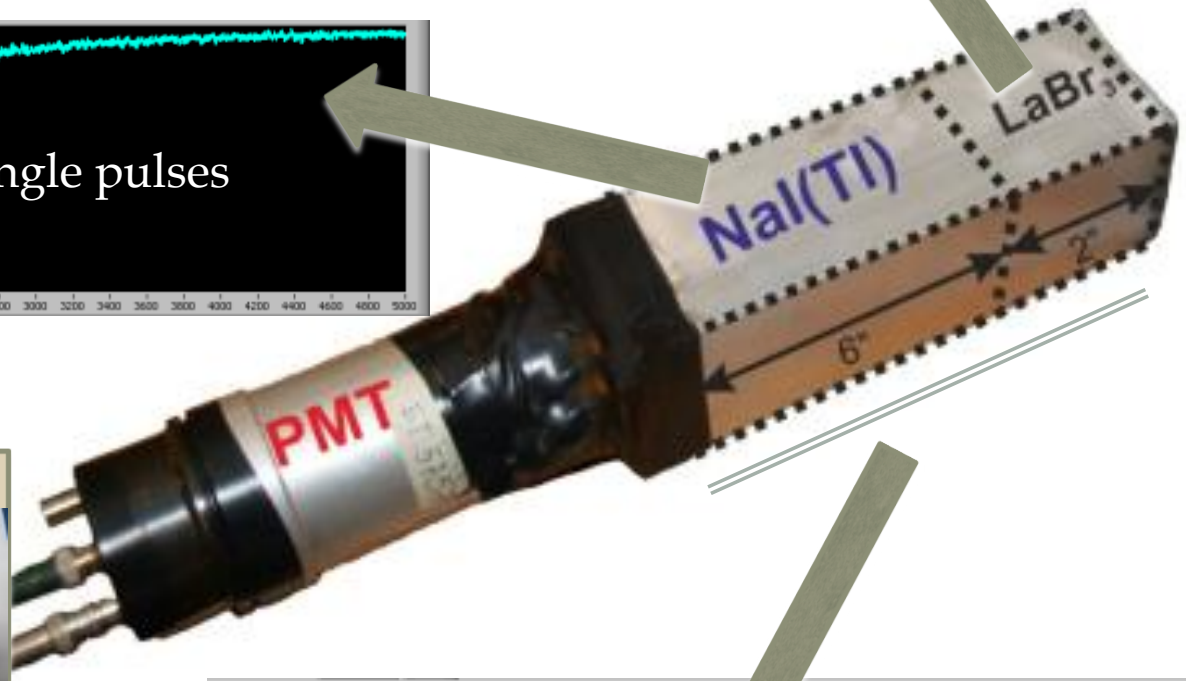
PARIS Collaboration Council:

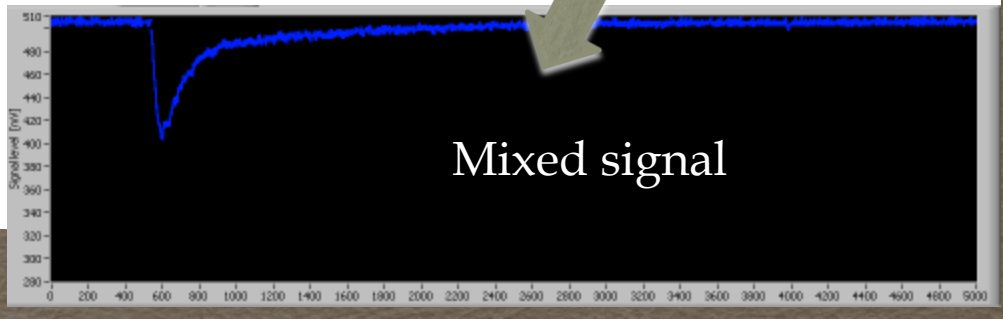
David Jenkins (University of York, UK) - chair and PARIS spokesman
Sudhee R. Banerjee (VECC Kolkata, India)
Franco Camera (INFN and University of Milano, Italy)
Wilton N. Catford (University of Surrey, UK)
Marco Cinausero (LNL Legnaro, Italy)
Sandrine Courtin (IPHC Strasbourg, France)
Zsolt Dombradi (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 Nanal (TIFR Mumbai, India)
Pawel Napiorkowski (HIL Warsaw, Poland)
Marek Ploszajczak (GANIL, France)
Mihai Stanoiu (IFIN-HH Bucharest, Romania)
Jonathan Wilson (IPN Orsay, France)

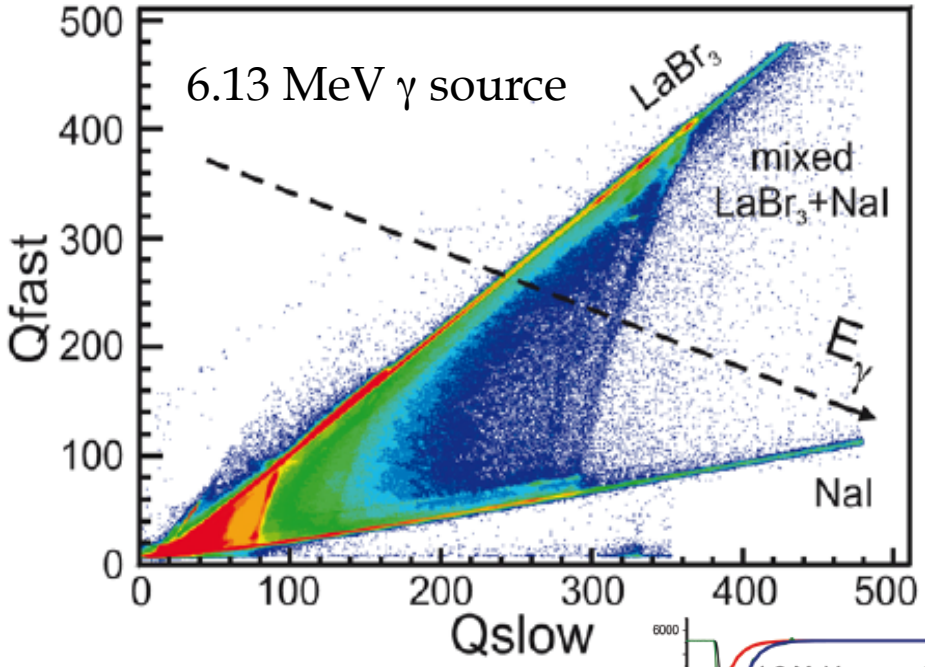
The PARIS PHOSWICH at work

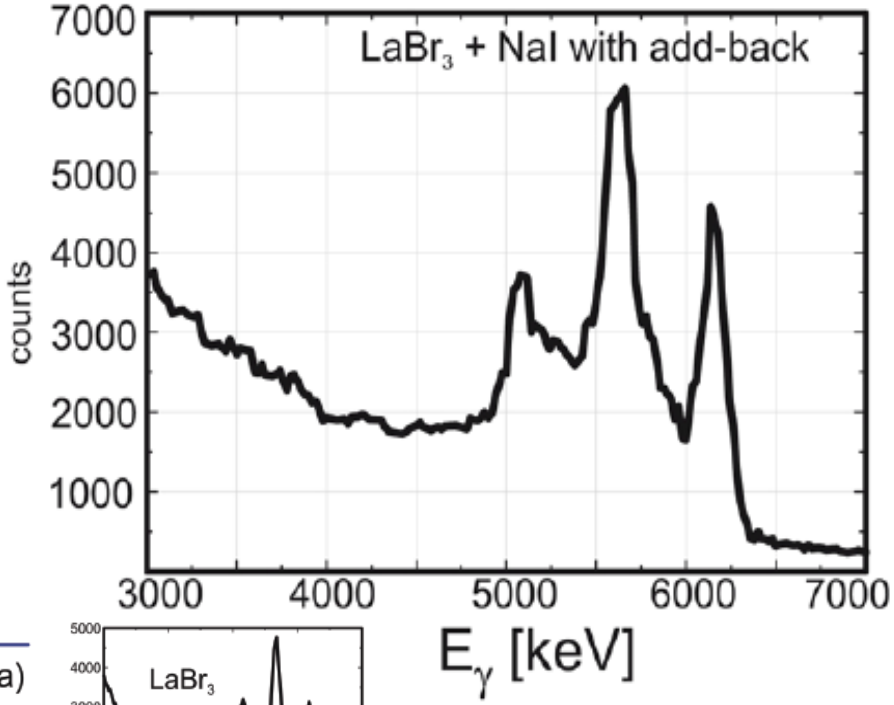


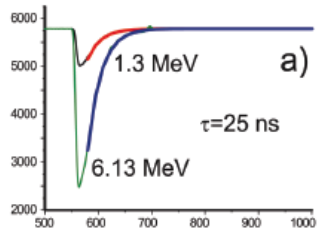


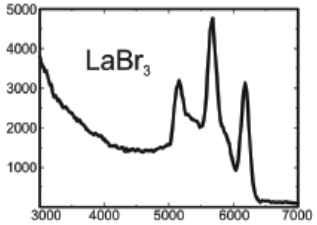


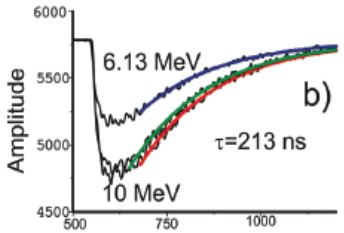


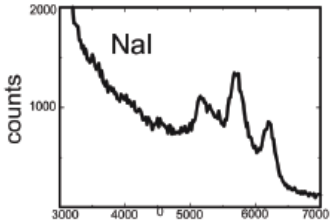


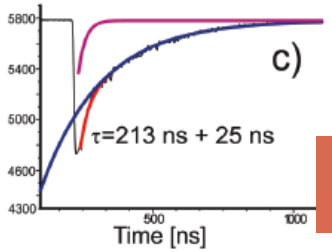


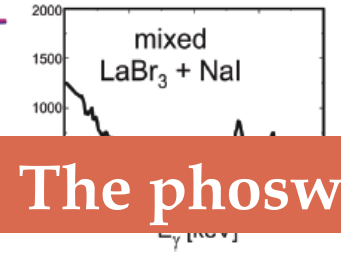












A test measurement at IFJ PAN, Kraków (2011) with BafPro module from Milano

- 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!

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

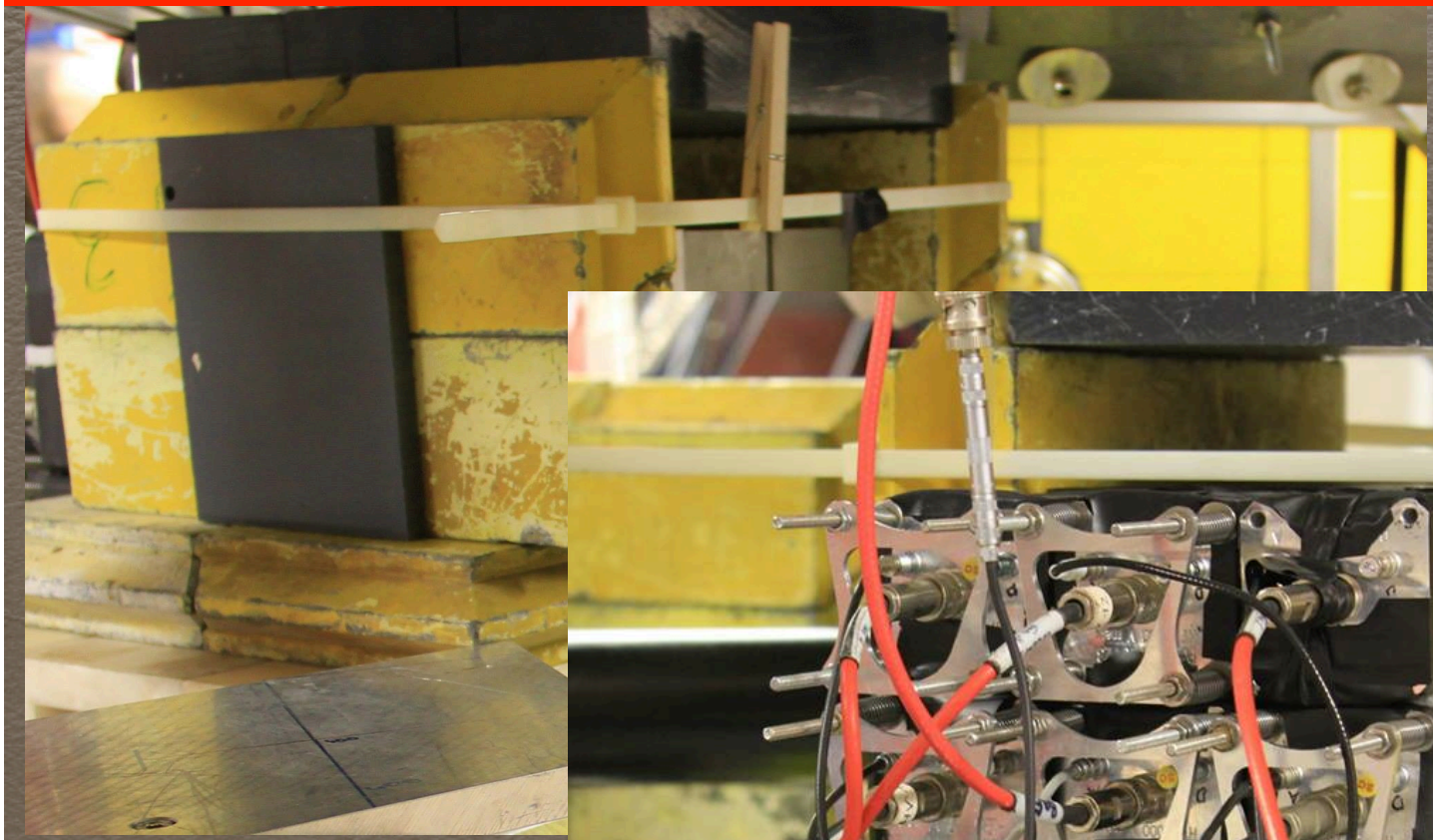
$^{11}B(p, \gamma)^{12}C$ at 7.2 MeV

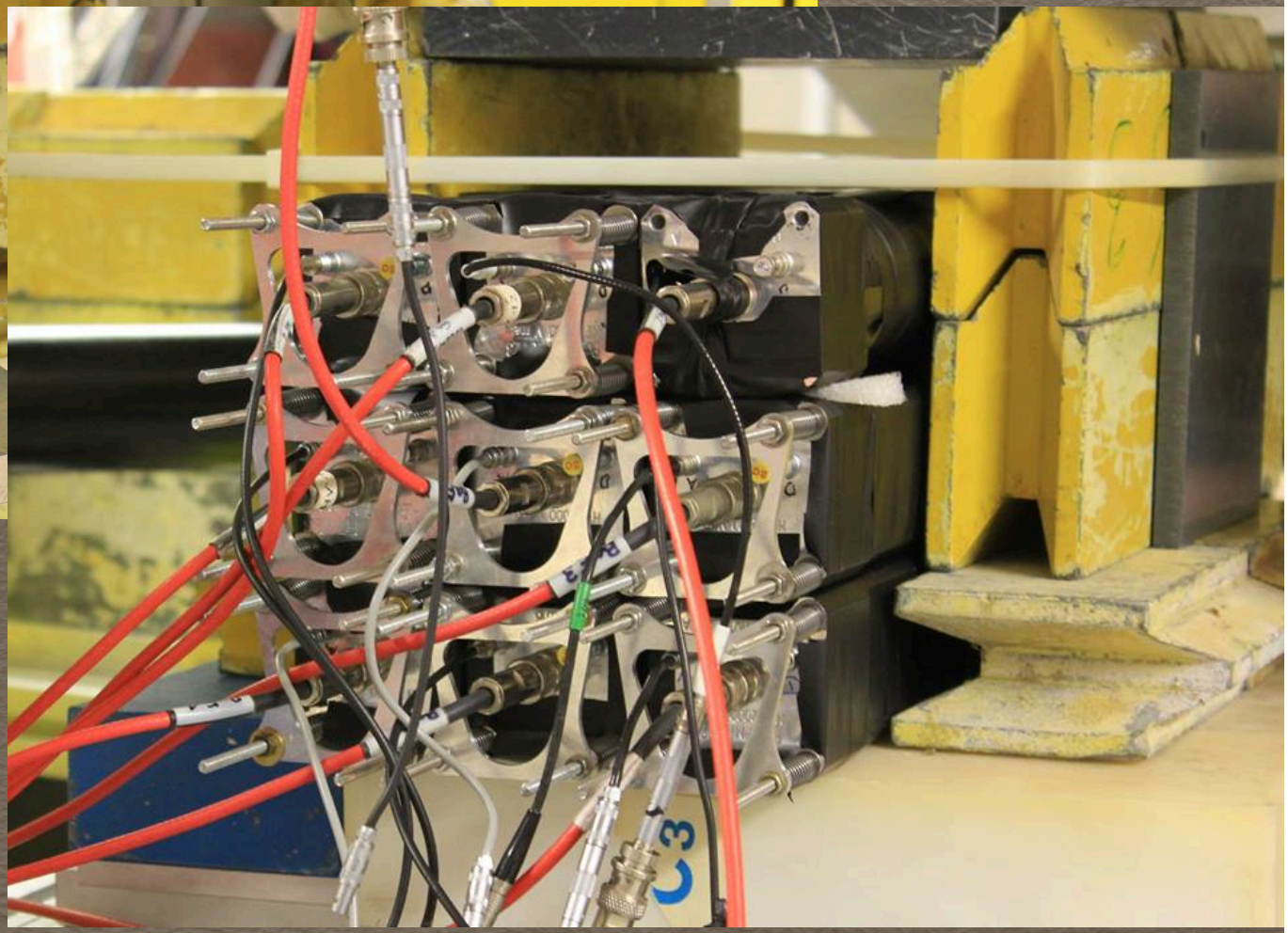
Eγ: …, 18.12 , 22.56 MeV

Goal:
testing addback capabilities at high energies

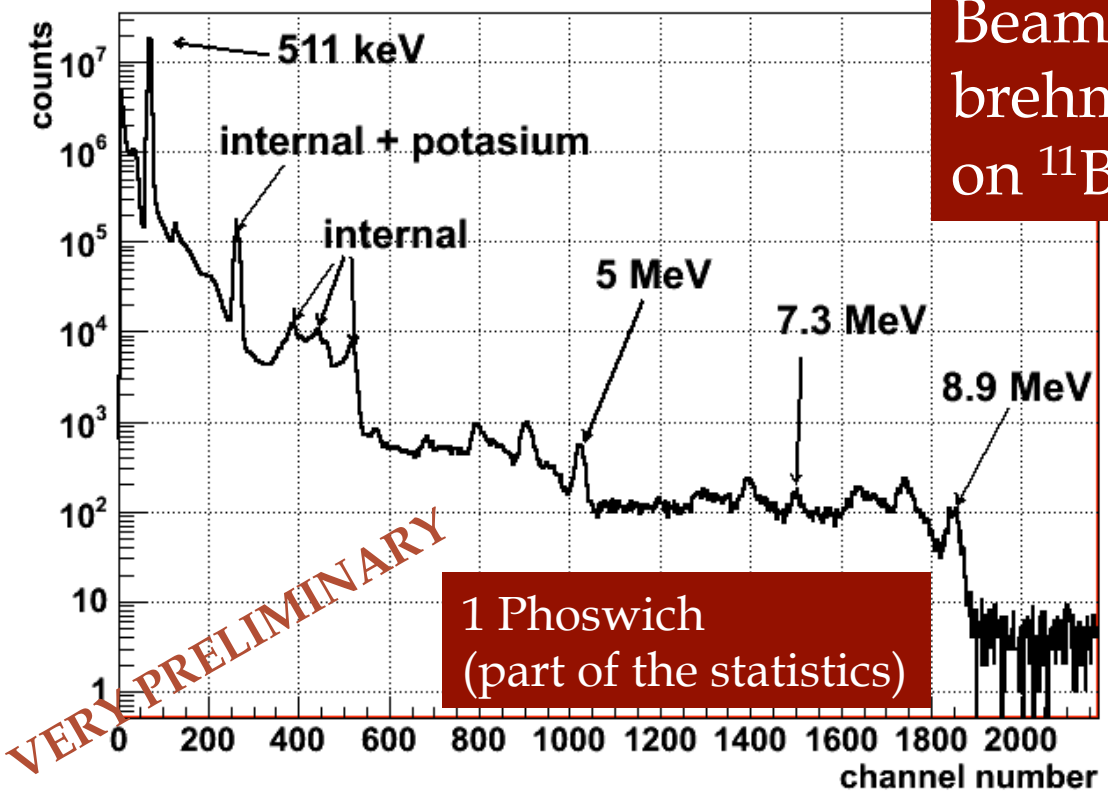
ELBE facility, Dreseden 10-12 December, 2013

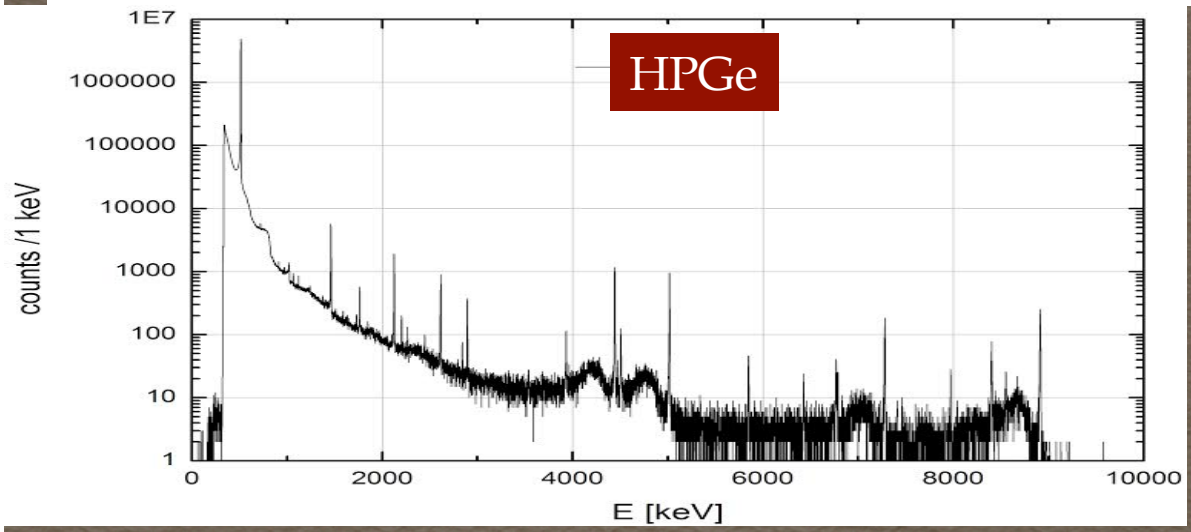
Nuclear Resonance Fluorescence experiment (Mazumdar, Maj, Schwengner)





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





Other PARIS cluster/phoswich tests performed

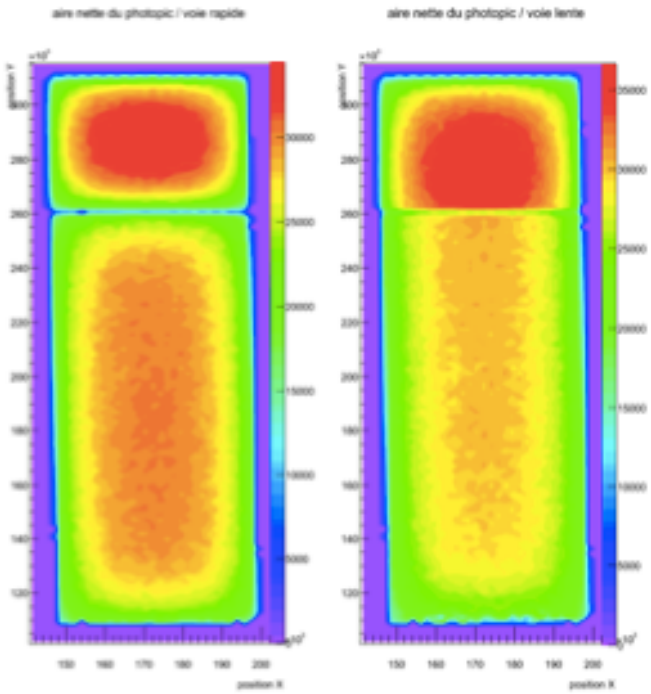
- **Milano, April 2015 – testing PARIS_Pro modules with full cluster, S. Brambilla, F. Camera**
- **IPN Orsay, May 26-29, 2015, „Measurement of the neutron response of PARIS cluster between 0.5 to 12 MeV (LICORNE)", J. Wilson, I. Matea**
- **Coulex experment at HIL Warsaw, June 2015**

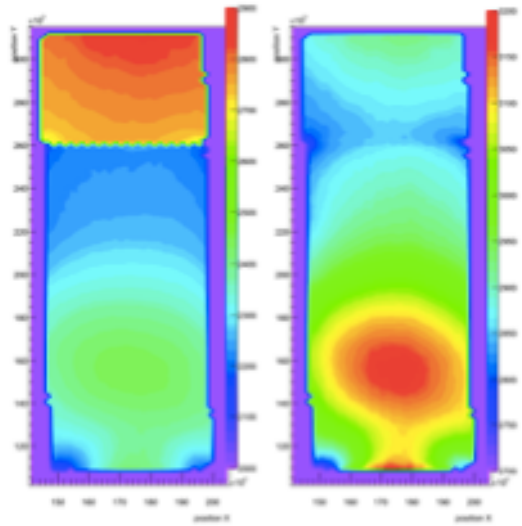
Next tests: depending of availability

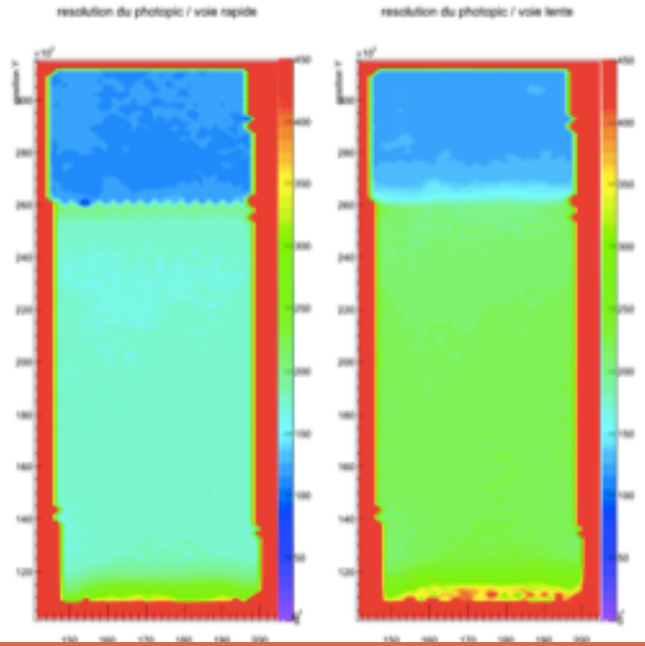
- CCB Krakow, 2016 ?

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

IPHC Strasbourg
O. Dorvaux et al..







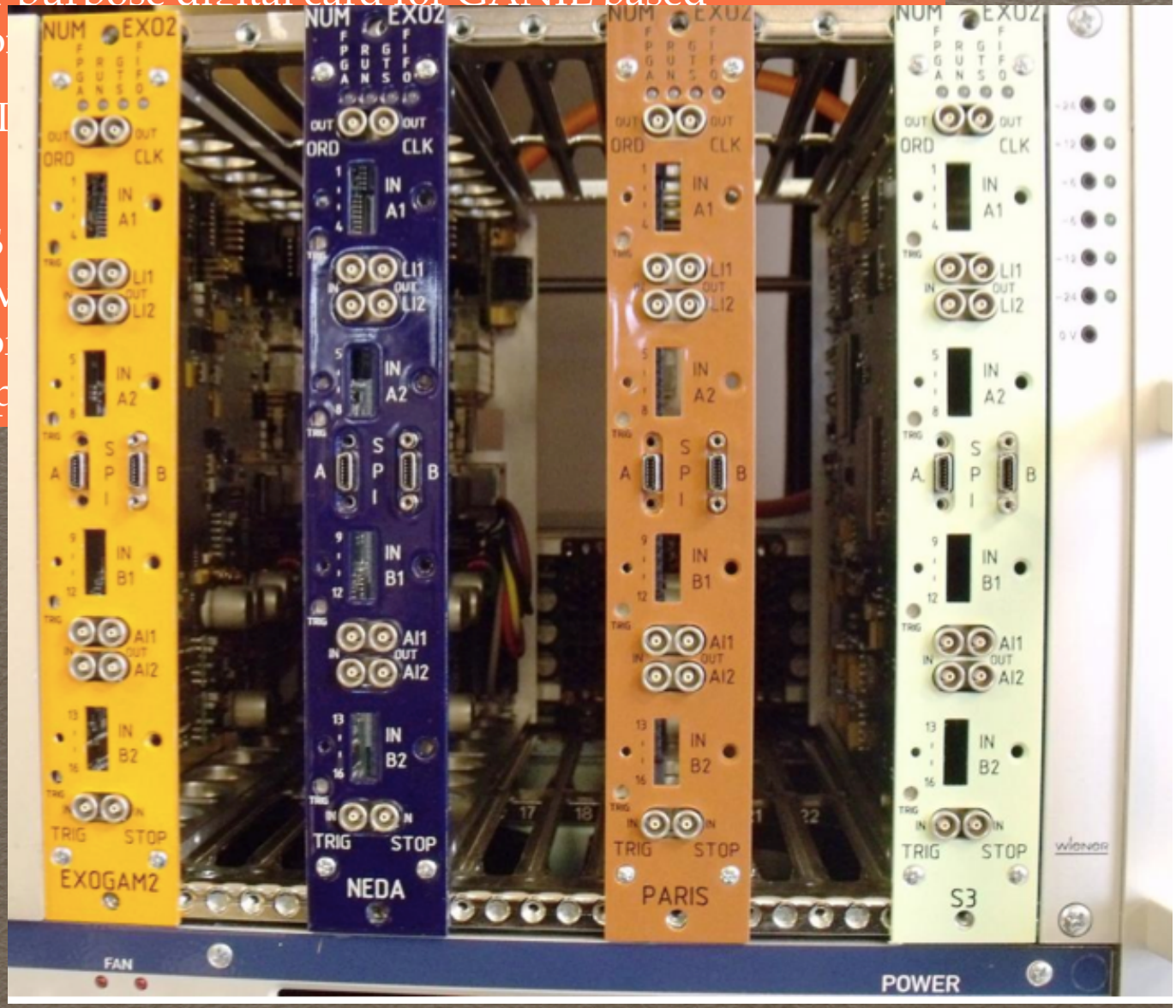
IPHC Strassbourg: Database of all PARIS phoswiches

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.

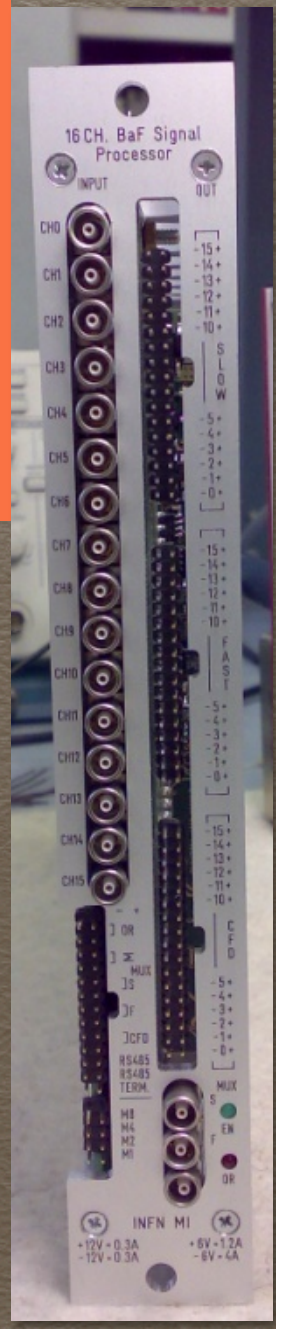
2) **Analogue electronics** based on **Milano "PARIS_Pro"** cards (S. Brambilla et al.) + **AGAVA** interface (A. Czermak et al..):

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



Planned first experiments

AGATA@GANIL (ca. 2017)

PARIS campaigne manager: Ch. Schmitt

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 44Ti via discrete and continuum γ-spectroscopy** with AGATA, PARIS (4 clusters) and DIAMANT

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

PARIS campaigne manager: I. Matea

Proposals accepted by the Orsay PAC

- M. Wiedeking - **Coulomb Excitation of 14C**
- B. Blank - **Measurement of the super-allowed branching ratio of 10C**
- P.J. Napiorkowski - **Coulomb excitation of super-deformed band in 40Ca**
- M. Lebois - **Prompt gamma and neutron emission for 238U fast neutron induced fission as a function of incident neutron energy**
- O. Kirsebom - **A new probe of alpha-cluster structure in 12C**
- A. Kozulin - **Prompt γ-rays as a probe of nucleardynamics**

(all of them require 2-4 clusters)

Next posible PARIS campaigns

CCB Krakow (2016/2017, campaign manager tbc)

- **Studies of resonance states in nuclei using high-energy proton beam** (Crespi, Kmiecik): HECTOR, PARIS, KRATTA, Ge_array
- **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 induced fusion-eveporation reactions** (Camera, Kmiecik) HECTOR, PARIS, KRATTA
- **Investigation of proton induced spallation** (Ch. Schmitt, D. Mancuzi): HECTOR, PARIS, KRATTA

HIL Warsaw

(2016/2017, campaign manager tbc)

- **Coloumb excitations in A=40-50 nuclei** (Napiorkowski, Bednarczyk): EAGLE+PARIS

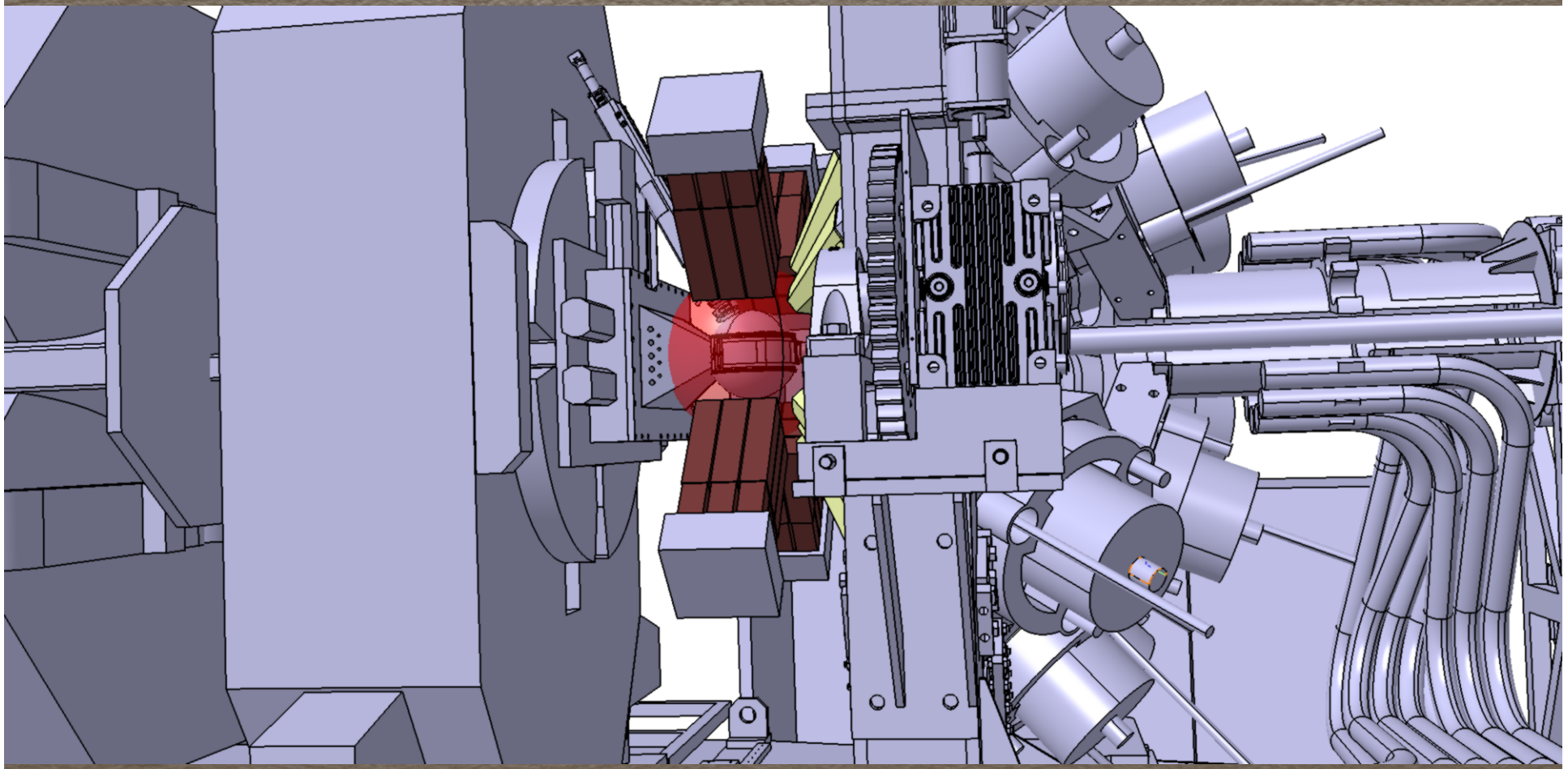
LoIs PARIS4SPES campaign (2018?)

- **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~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)

Mechanical coupling of 4 PARIS clusters to AGATA with VAMOS will be done using EXOGAM frame

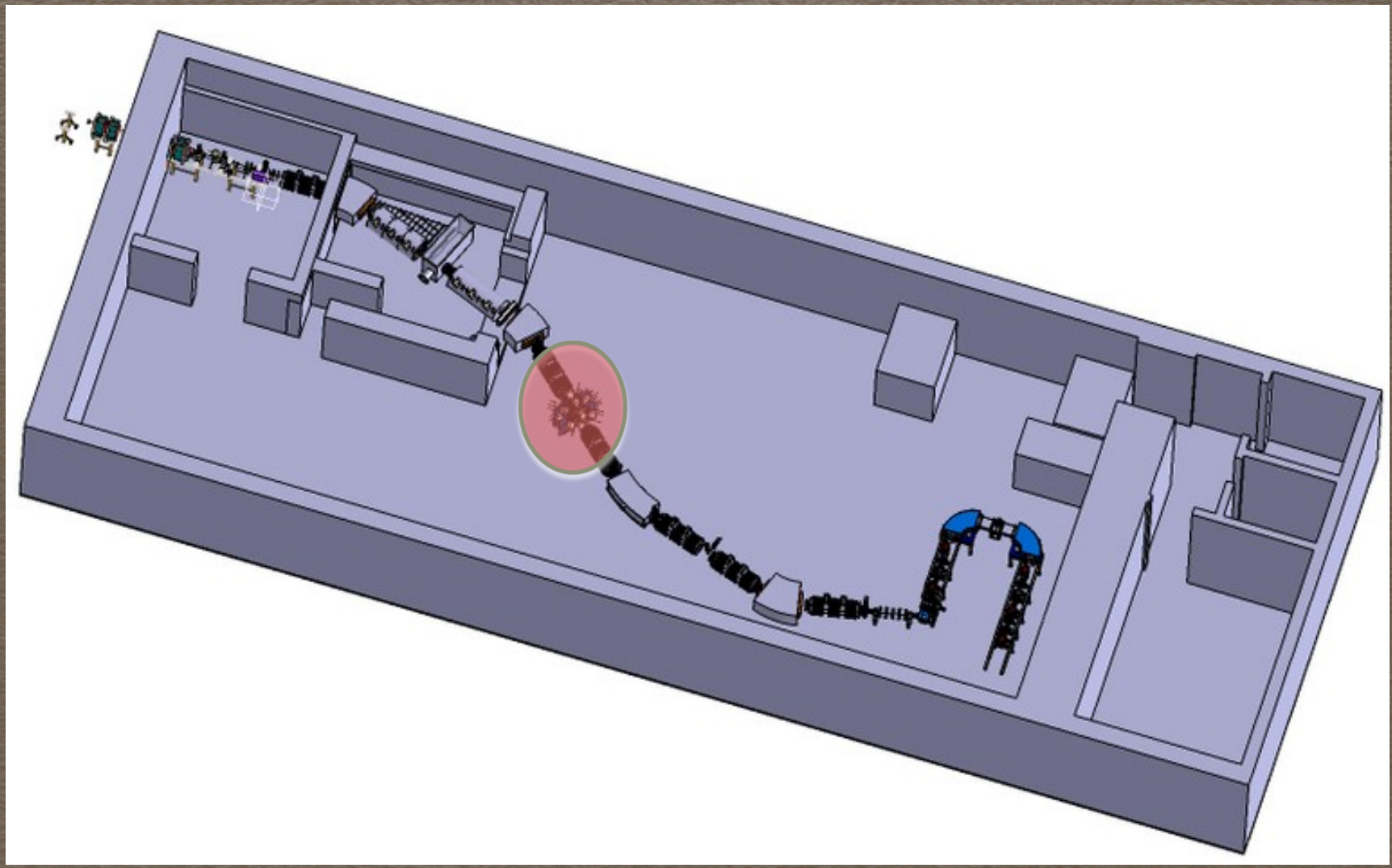
PARIS detectors are at 23 cm distance from target

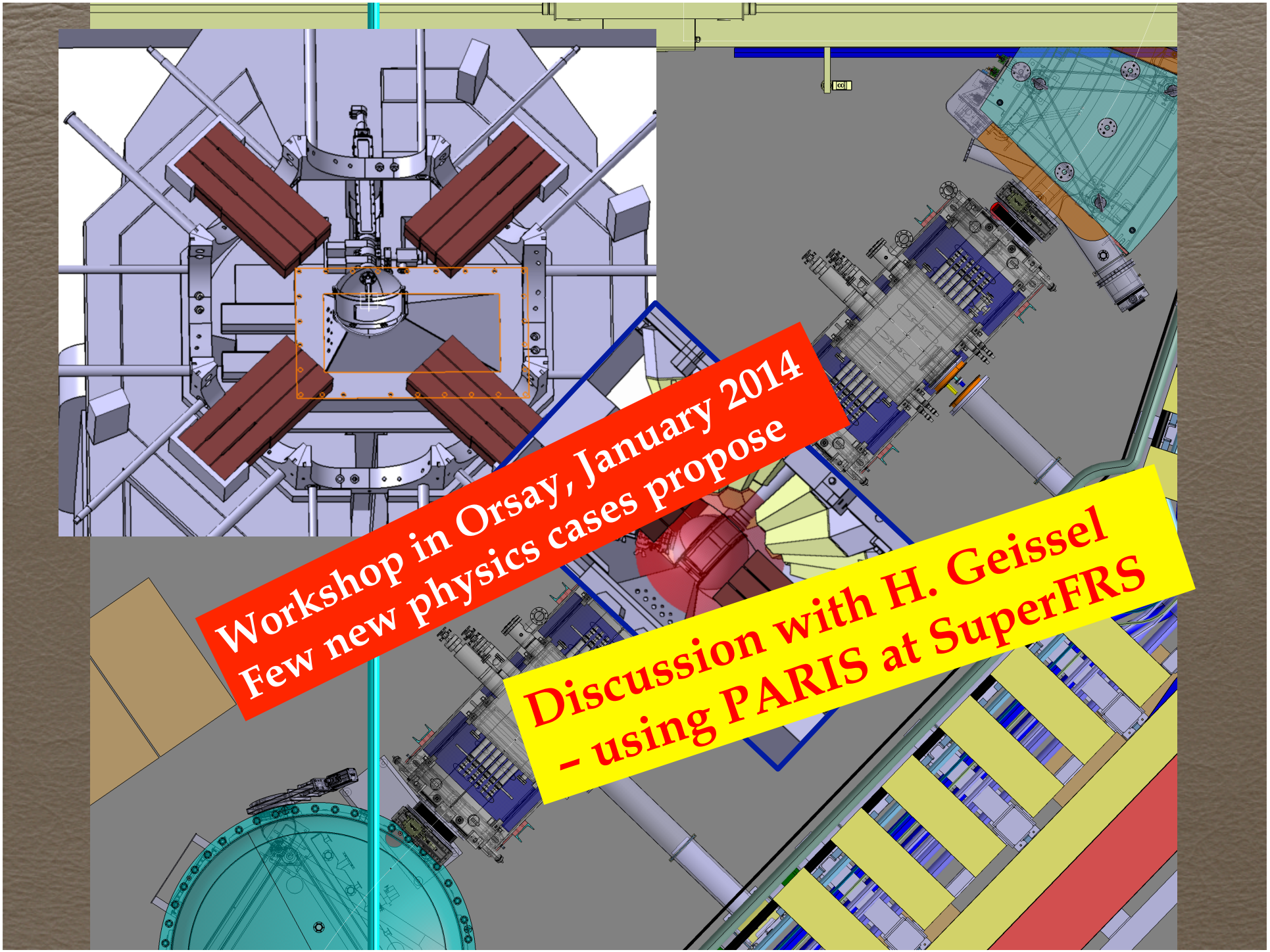
PARIS and VAMOS and AGATA @GANIL



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

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




Workshop in Orsay, January 2014
Few new physics cases propose
Discussion with H. Geissel
- using PARIS at SuperFRS

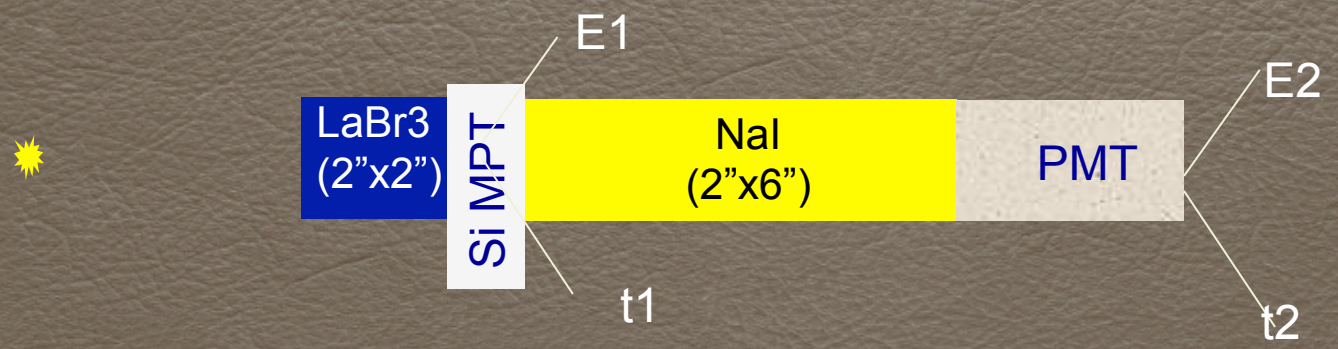
Murphy law: If everything goes smoothly with PARIS…

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 will be delivered until end of this year.

In addition we have resumed work on alternative desings:

A).



B).

Phoswich made of CeBr+NaI

- 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.
- Holding structure with magnetic shield for 1 cluster done and being tested
- Electronics for AGATA experiments based on analoque PARIS-Pro + AGAVA, data stream via VAMOS branch
- The next phase will be to complete the PARIS Phase2 (Demonstrator) of 4 clusters, each of 9 phoswich detectors. *(Some delays possible, due to the delays in delivery time of phoswiches)*
- First physics experiments are coming (AGATA@GANIL, IPNO, Krakow/Warsaw, LNL)

Summary on PARIS@AGATA

1. Two experiments accepted:

a) Leoni, Fornal, Ciemala et al, PARIS+AGATA+VAMOS+PLUNGER (at least 2 PARIS clusters needed)

b) Bednarczyk, Maj et al., PARIS+AGATA+DIAMANT (4 clusters needed)

2. PARIS electronics will be based on the analogue PARIS_Pro modules (2 of them are purchased and tested) and AGAVA, inserted into the VAMOS Branch. This solution was verrified that is working.

3. PARIS Cluster Holding structure with magnetic shielding was designed and 1 is manufactured (in IPN Orsay). It was, together with phoswich detectors, tested positively with the magnetic field of VAMOS. The remainig 3 holding structures have to be still manufactured (probably in IFJ PAN Krakow).

4. The connections of the holding structures to the VAMOS frame are not yet done - there are plans that they will be designed by Daresbury.

5. The simulations of the influence of PARIS setup on the AGATA tracking are being simulated (Ciemala, Stezowski,..)

6. The main problem is the delay in delivery of the phsowiches by Saint Gobain. Therefore we would like to have the experiments not before 2017

Thanks to: P. Bednarczyk, M. Kmiecik, B. Fornal, K. Mazurek, B. Wasilewska, M.Krzysiek, M.Zieblinski, M.Jastrzab, A. Czermak – IFJ PAN Krakow; F.Azaiez, I.Matea – IPN Orsay; O.Dorvaux, S. Kihel – IPHC Strasbourg; M.Ciemała. Ch. Schmitt – GANIL; D. Jenkins – York; A.Bracco, S.Leoni, F.Camera, S.Brambilla, B.Million, O.Wieland, A. Giaz – Milano; P.Napiorkowski, K.Hadynska-Klęk – HIL Warsaw; V.Nanal, I.Mazumdar – TIFR Mumbai; and many others

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