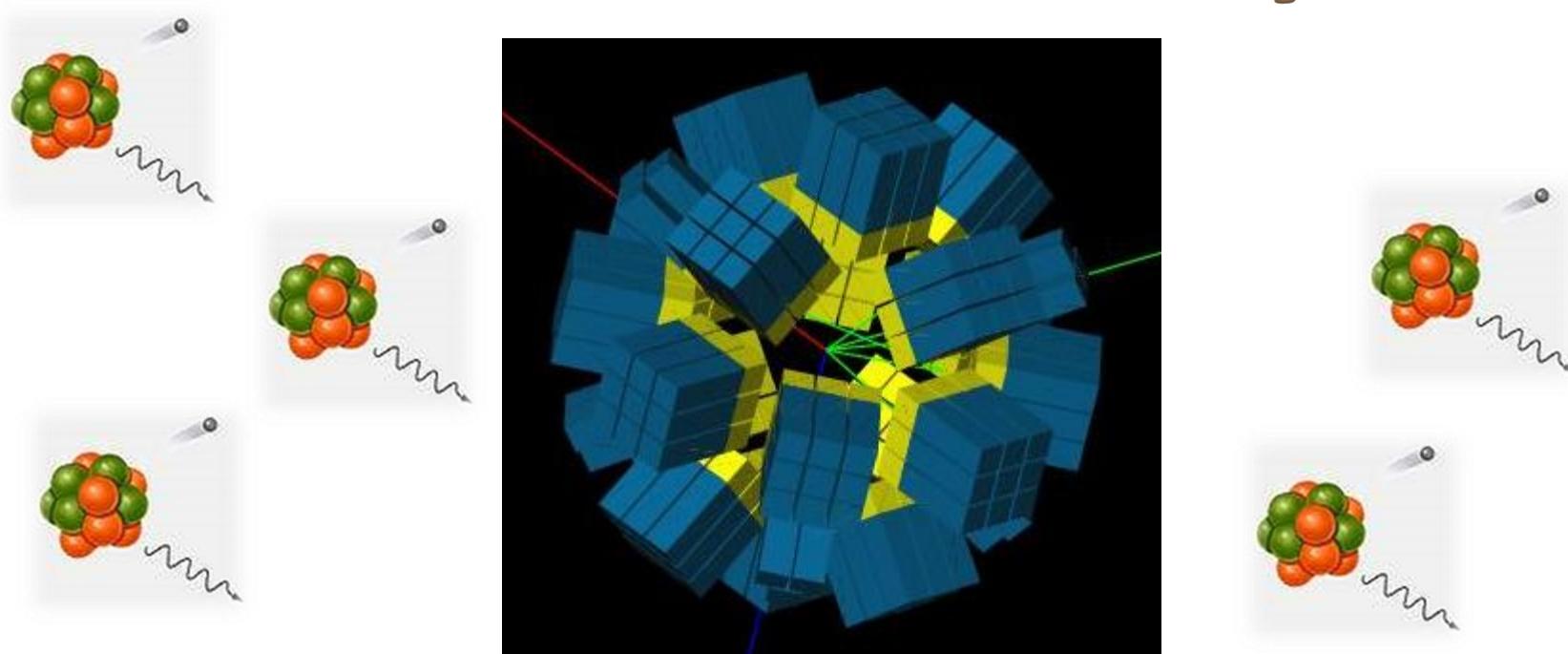


The PARIS array



The PARIS project is an initiative to develop and build a high-efficiency gamma-calorimeter making use of the state of the art scintillators (LaBr₃:Ce) and principally for use at SPIRAL2.



PARIS physics 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 et al.)
- e) Onset of the multifragmentation and the GDR (+FAZIA)**
 $120 < A < 140$, $180 < A < 200$
(J.P. Wileczko, D. Santonocito et al.)
- f) Reaction dynamics by means of γ -ray measurements**
 $^{214-222}\text{Ra}$, $^{118-226}\text{Th}$, $^{229-234}\text{U}$
(Ch. Schmitt, O. Dorvaux et al.)
- g) Heavy ion radiative capture ***
 ^{24}Mg , ^{28}Si
(S. Courtin, D.G. Jenkins et al.)

- h) Multiple Coulex of SD bands**
 $36 < A < 50$
(P. Napiorkowski, F. Azaiez, A. Maj et al.)
- i) Relativistic Coulex (after postacceleration)**
 $40 < A < 90$
(P. Bednarczyk et al.)
- j) Nuclear astrophysics (p,γ)**
e.g. ^{90}Zr
(S. Harissopoulos 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 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..

Design based on Physics cases and Theory Background WG report

LoI physics cases + Coulex below the barrier + Nuclear astrophysics

- E_γ up to 40MeV with $\Delta E_\gamma/E_\gamma \sim (3-5) \%$
 - $\Delta \Sigma_\gamma^{\text{sum}}/\Sigma_\gamma^{\text{sum}} < 5\%$ and $\Delta M_\gamma \sim 4$
 - $\Delta T_{\text{of}} < 1\text{ns}$
 - high efficiency
 - angular coverage $\sim 2\pi$ up to 4π
 - ancillary detectors : large variety (Ge's, scintillators, HI detector...)
 - modular and flexible (connect with AGATA, GASPARD, NEDA ...)
- $\sim 0 < \beta < 10\%$

fusion-ER,
fusion-fission,
multifragmentation

sym/asym
direct/inverse
kinematics

Shell structure with intermediate beam energies + relativistic Coulex

$20\% < \beta < 60\%$

- $E_\gamma \in [1-4\text{MeV}]$ with $\Delta E_\gamma/E_\gamma \sim 1\%$
 - $\Delta T_{\text{of}} < 1\text{ns}$
 - mandatory recoil analyzer (A, Z, v)
- More constraints - needs special design**

two-step
fragmentation

(Courtesy of C. Schmitt)



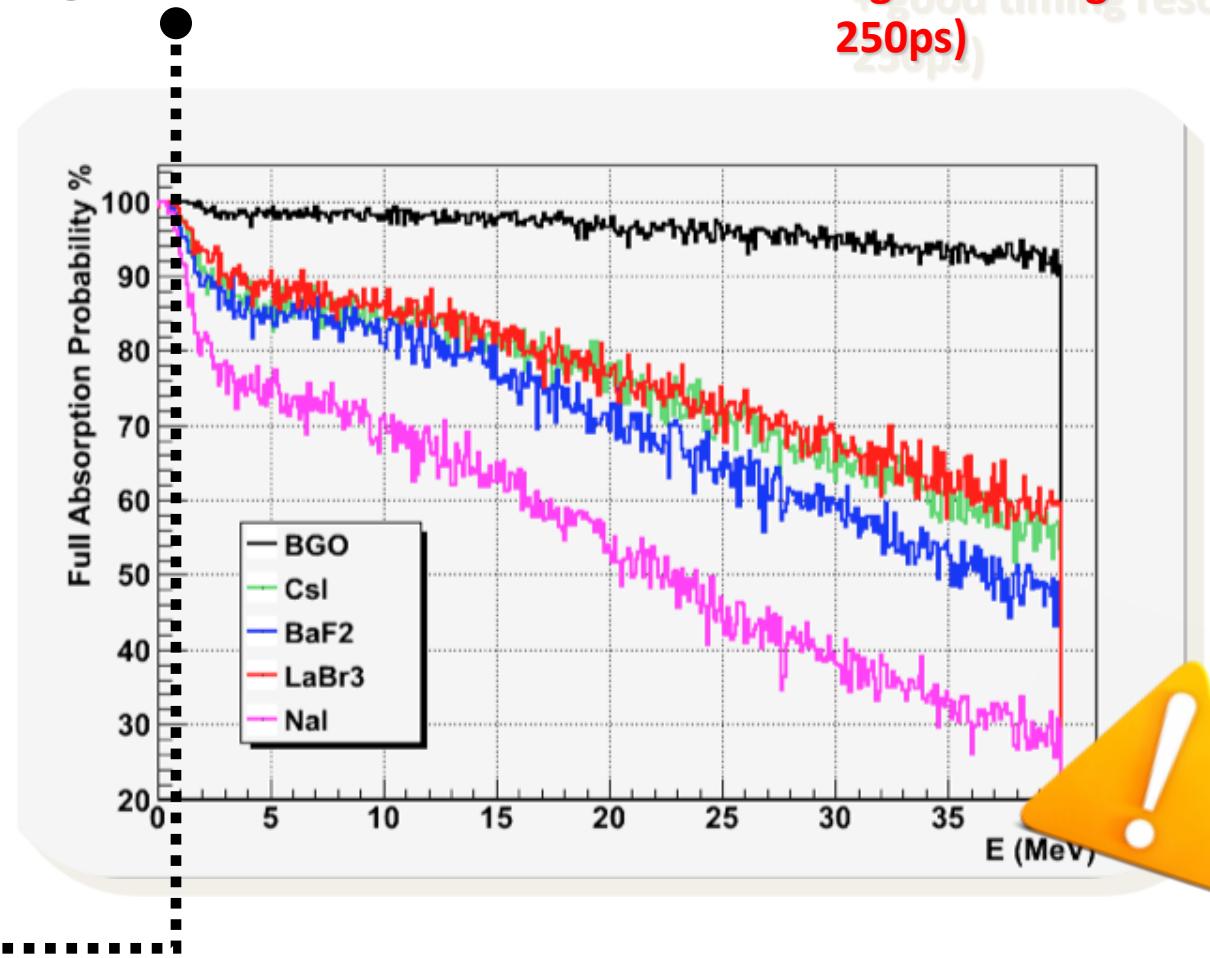
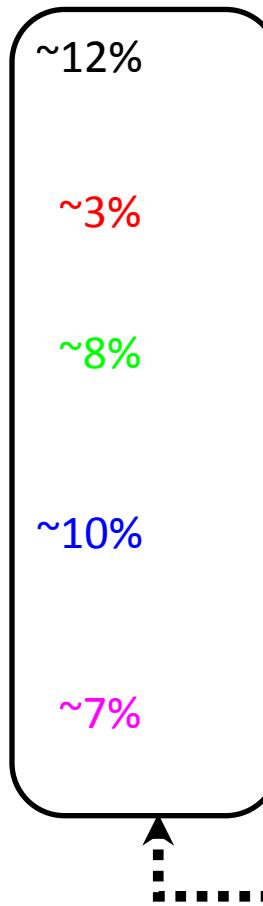
Calorimeter based on LaBr₃

(Geant4 simulations)

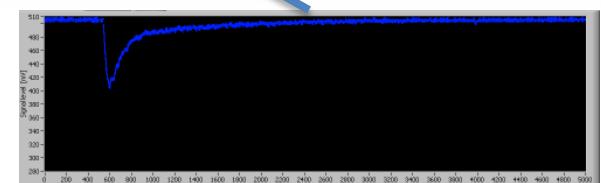
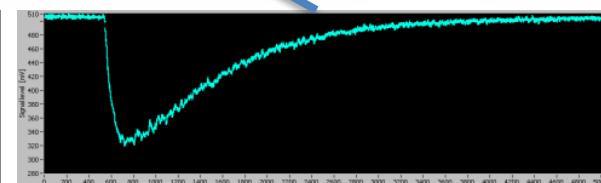
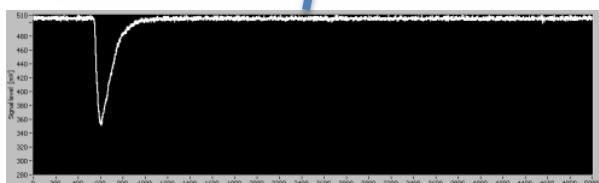
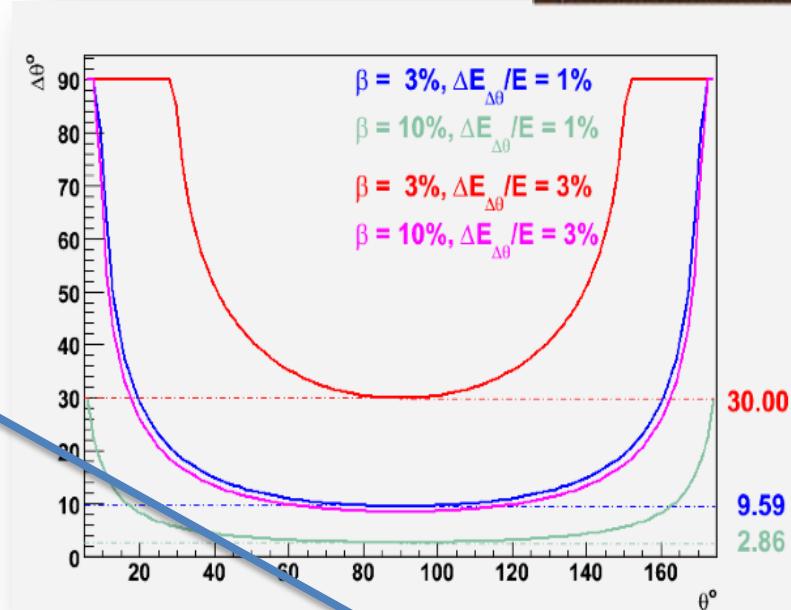
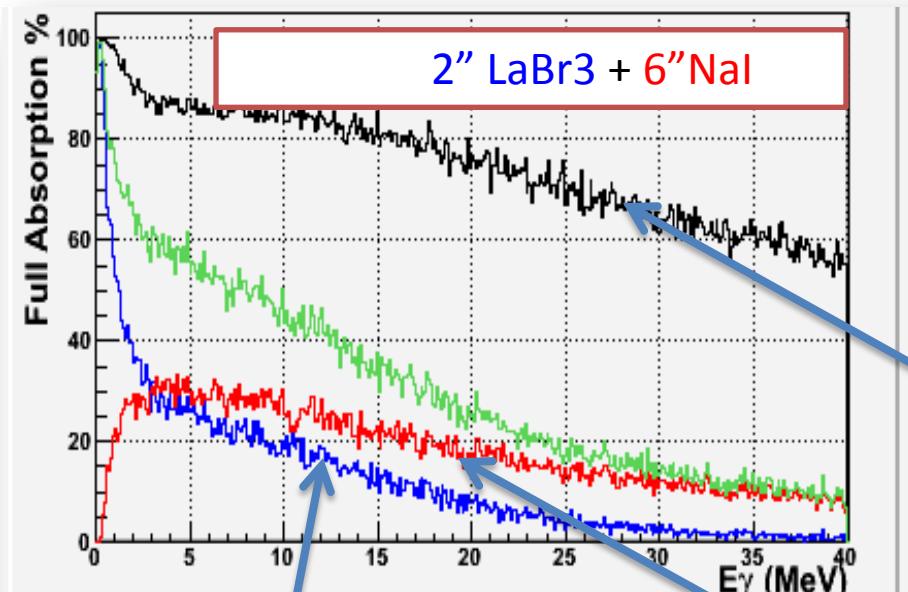


Resolution @ 662 keV

- + fast decay time (~ 16ns)
- + good timing resolution (~ 250ps)



Courtesy of O. Stezowski



The basic element:

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

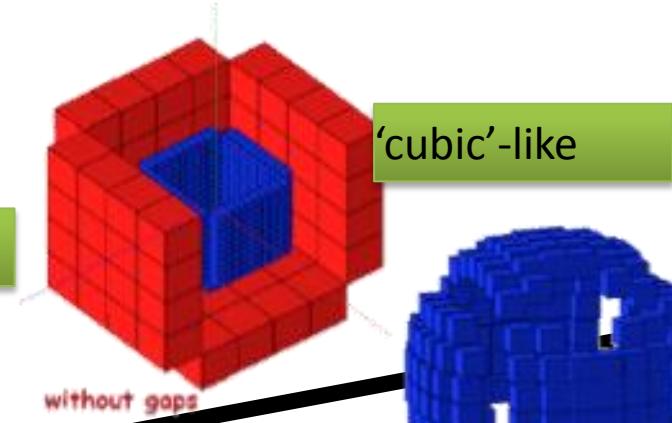
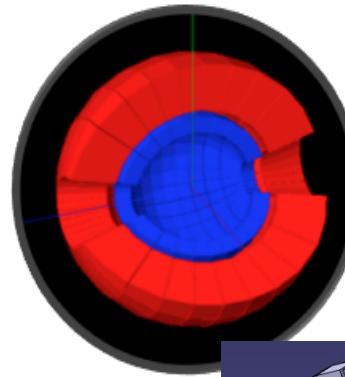
placed at a reasonable distance (ca. 20 cm) from the target position it gives a ***4π array composed of ca. 200 of elements*** for optimal characteristics in ***non-relativistic domain*** ($\beta < 10\%$).



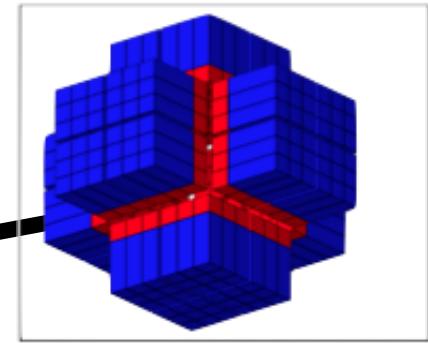
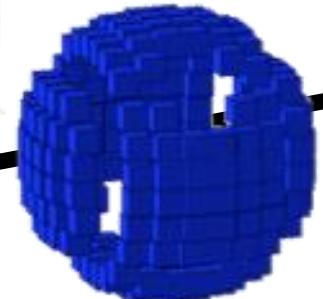
Several geometries studied



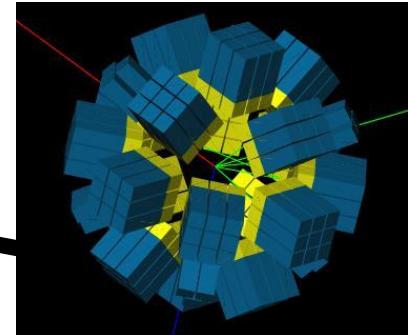
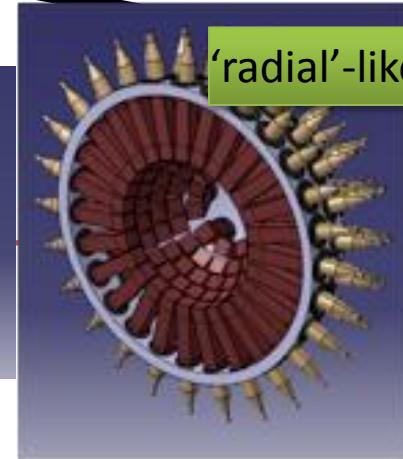
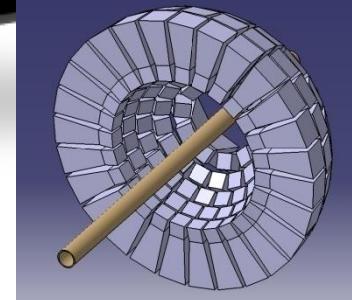
'Ideal' - spherical



'cubic'-like



'radial'-like

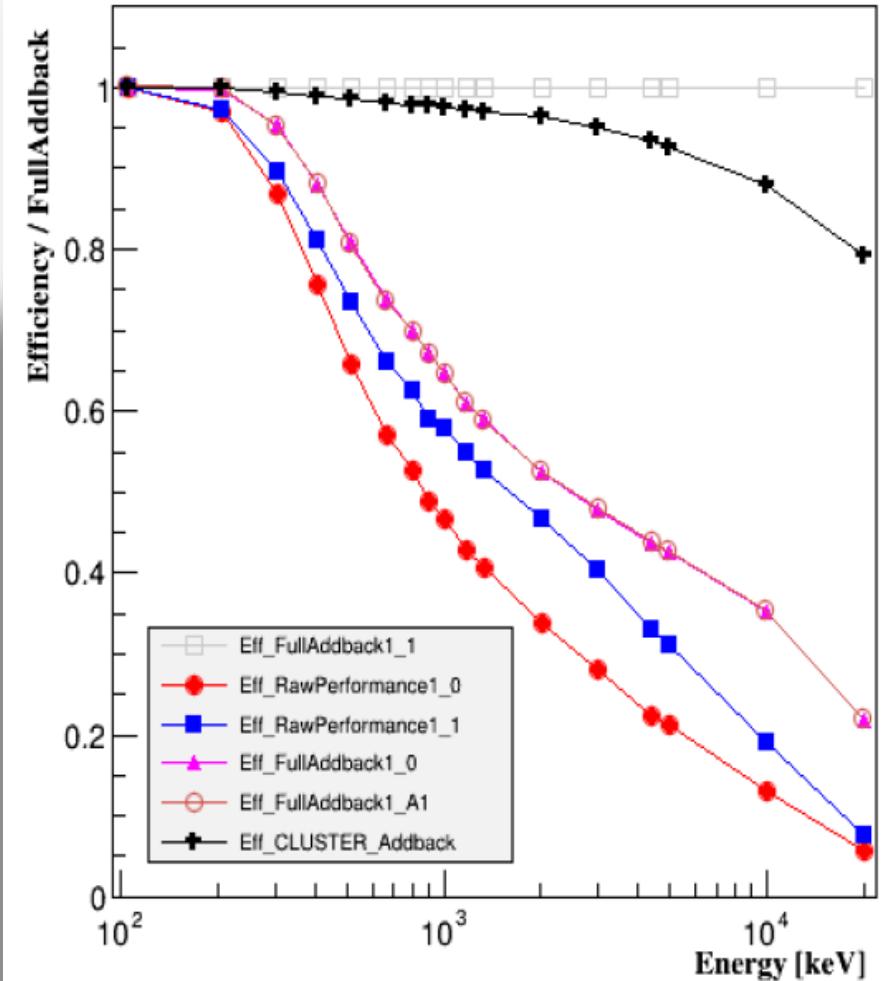
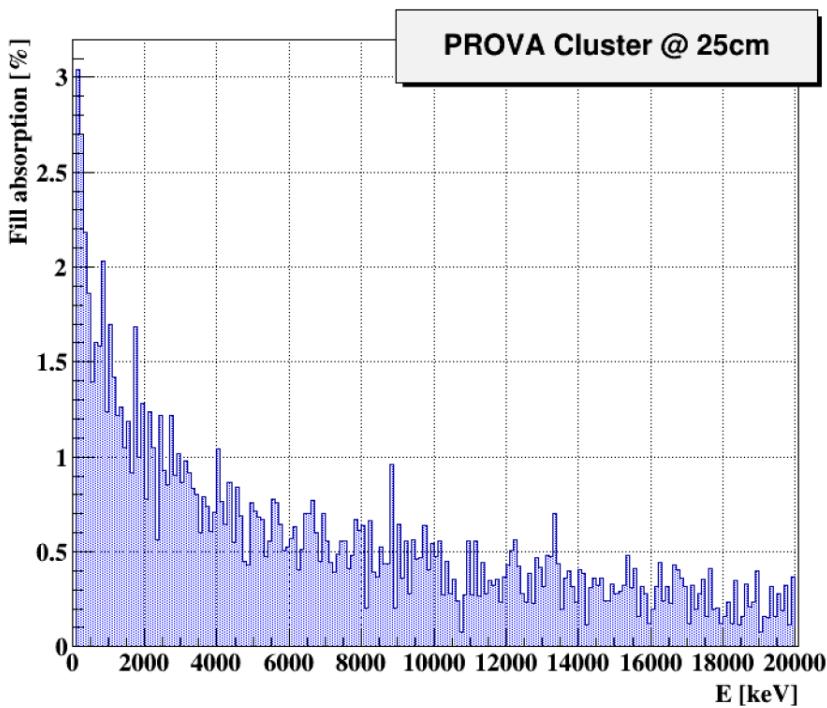


CONCLUSION:

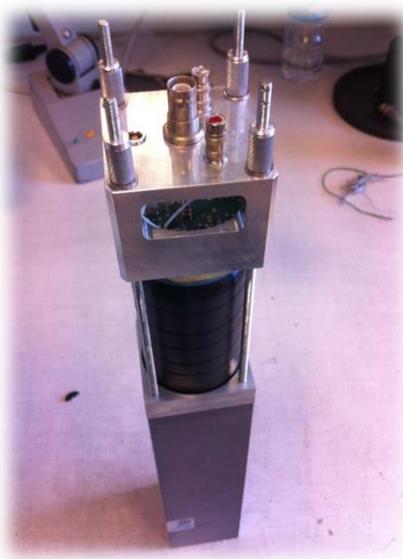
PARIS to be made of clusters:
Cluster = 9 phoswiches

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

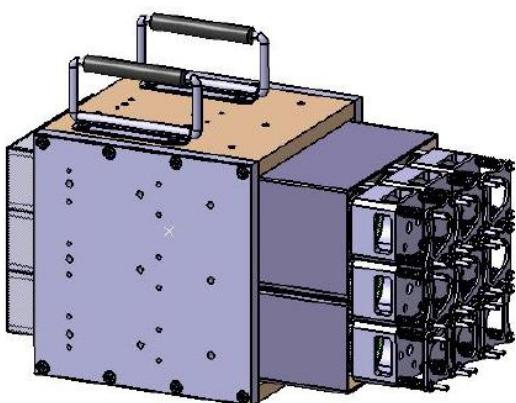
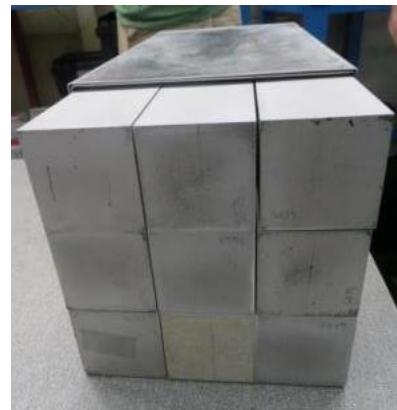
Simulation : One cluster efficiency @ 25 cm



Final Design



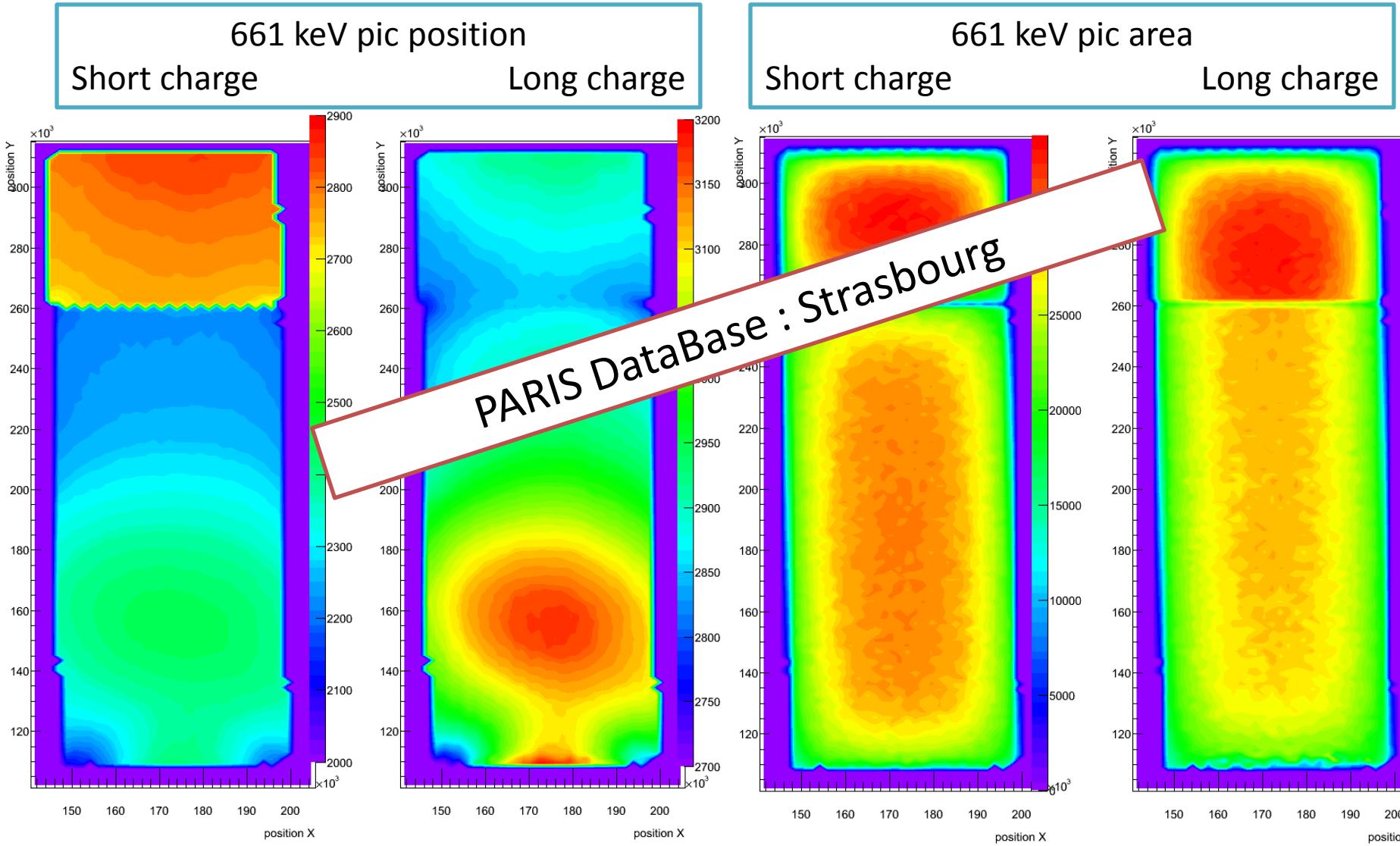
- The detector “phoswich” : 2”x2”x2” LaBr₃:Ce
2”x2”x6” NaI(Tl)
(in vacuum encapsulation into a thin 1 mm Al cup)
- connected to a 2” Hamamatsu PMT R7723-100
- with a voltage divider insuring good linearity for high gain
- Put in a cluster configuration (modularity)



- Energy resolution (measured) :
LaBr₃:Ce < 4.5 % @ 661 keV
NaI(Tl) < 8.0 % @ 661 keV
- Time resolution (measured) :
< 1 ns (only for LaBr₃:Ce events)

Phoswich properties : scanning

- using AGATA scanning table : 1 mm step in (x,y)
- every phoswich is scanned for the PARIS data base



May 2013 – availability of 1 PARIS cluster

→ first in-beam tests with 1 full PARIS cluster (**IPN Tandem ALTO facility**)

- ➔ high energy γ -rays reconstruction algorithms (with low multiplicity events)
- ➔ study of the detector (cluster/phoswich) response function up to 22 MeV
- ➔ (neutron- γ discrimination performances (detector + electronics) by TOF techniques)

γ -rays/neutrons production:

- ➔ standard sources up to 3.5 MeV (off-beam measurements in situ)
- ➔ resonant radiative capture reactions or inelastic scattering with proton beams

$^{nat}B(p,\gamma)^{12}C$: (22 MeV, 18 MeV, 4.4 MeV) gammas

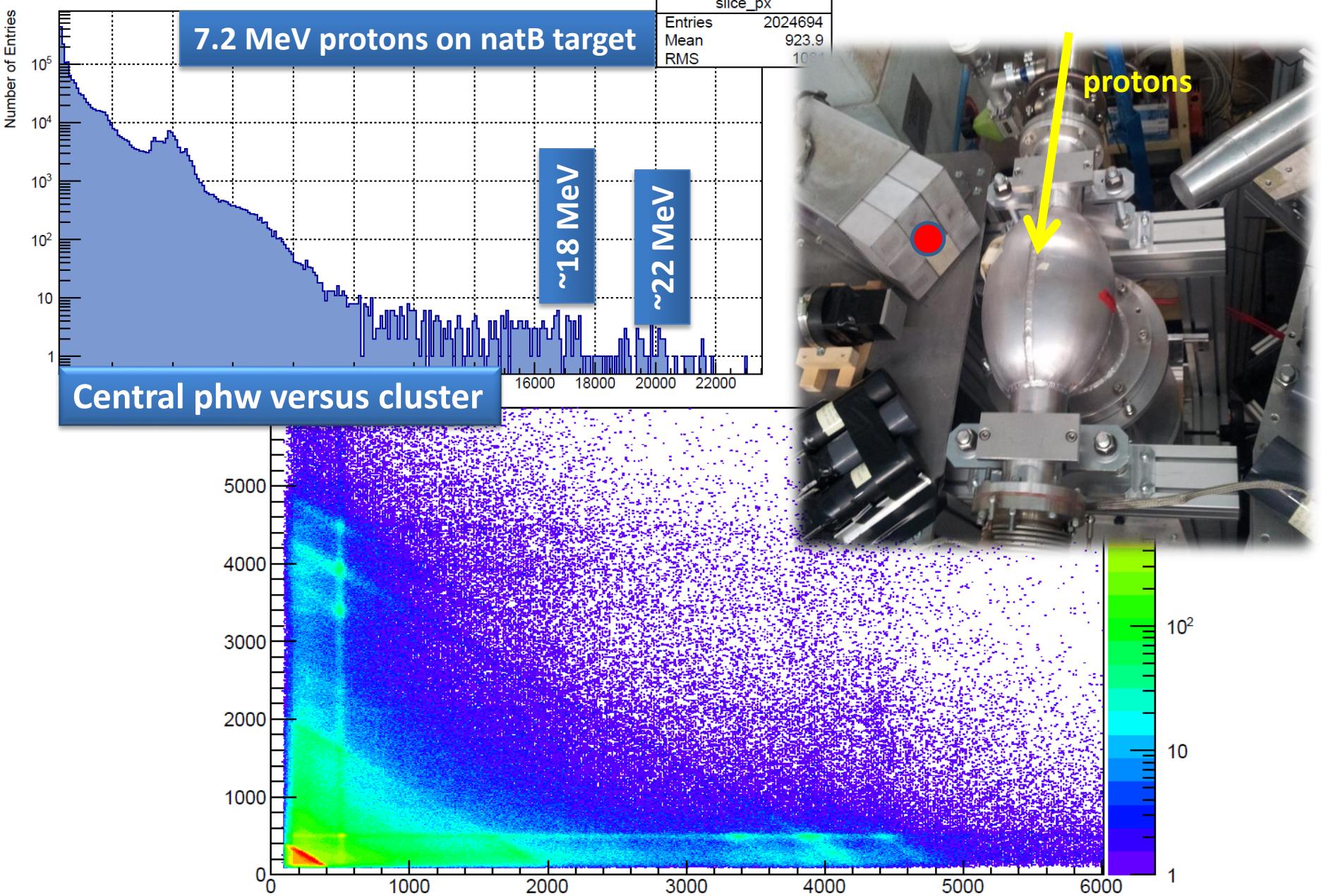
$^{23}Na(p,\gamma)^{24}Mg$: (1.4 MeV, 2.2 MeV, 8.9 MeV, 11.6 MeV) gammas

$^{23}Na(p,\gamma)^{24}Mg$: (1.4 MeV, 2.2 MeV, 8.9 MeV, 11.6 MeV) gammas

Low proton energy for a Tandem facility (need careful analysis)
 $K(p,\gamma)^{40}Ca$: (3.1 MeV, 5.7 MeV) gammas

Electronics (not yet a dedicated PARIS electronic/acquisition):

- ➔ TNT2 cards redout of the dynodes : 100 MHz after PA shaper → energy and time stamp
- ➔ BaFPRO – energy, time and PSD analysis



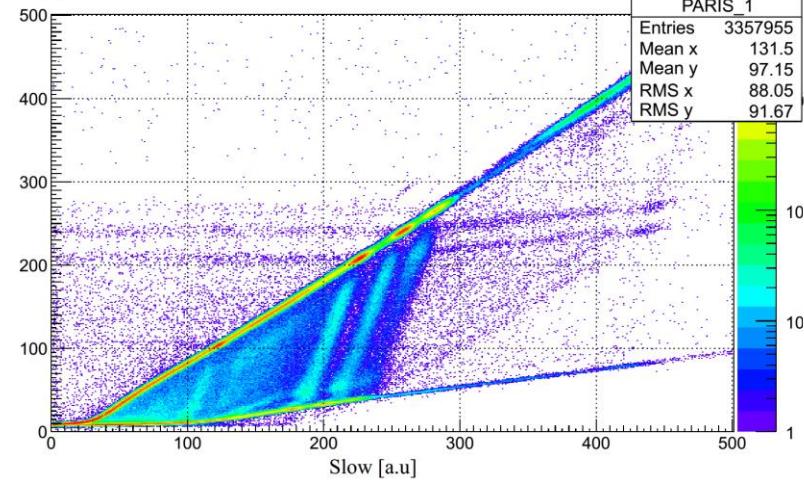
ELBE facility, Dresden 10-12 December, 2013



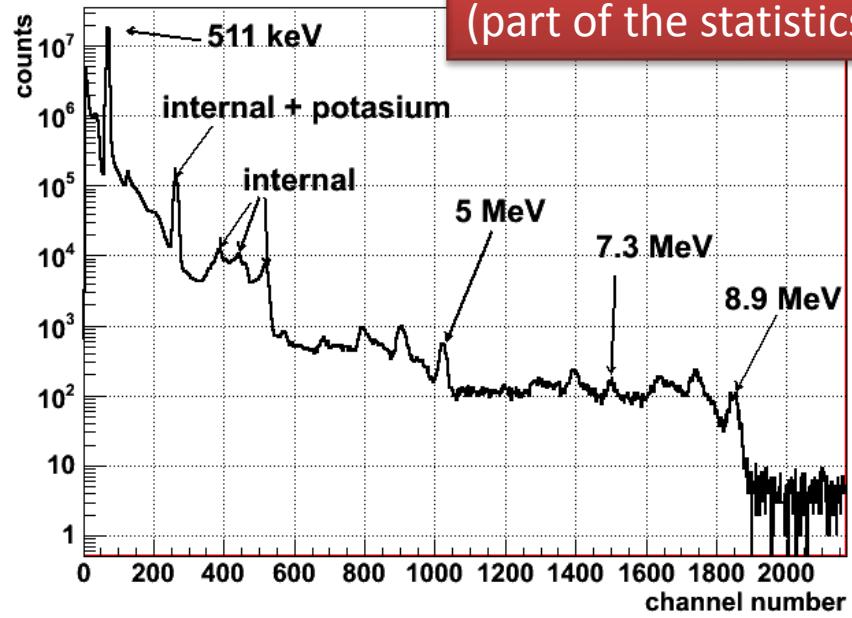
NRF experiment (Mazumdar, Maj, Schwengner)

Fast [a.u.]

PARIS_1

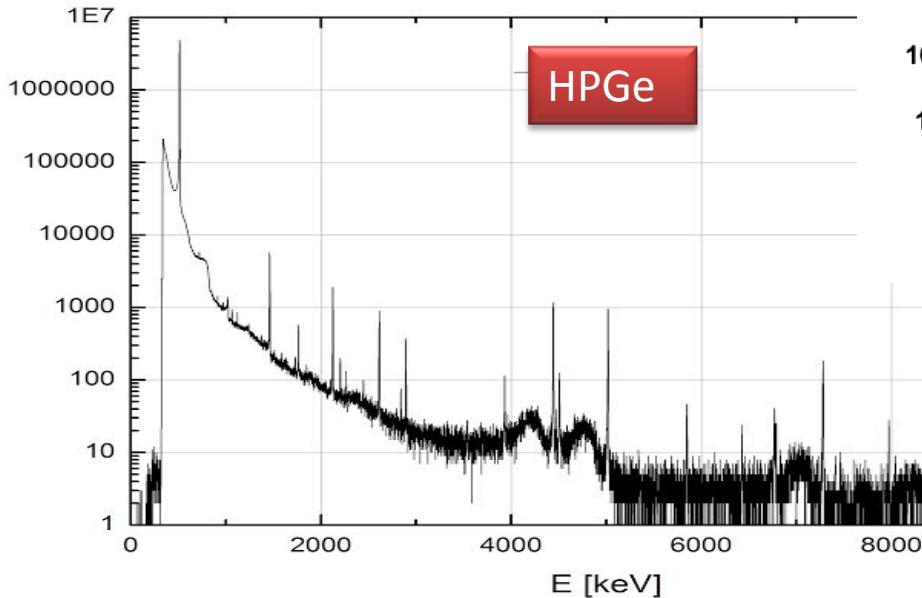


1 Phoswich
(part of the statistics)



counts / 1 keV

HPGe



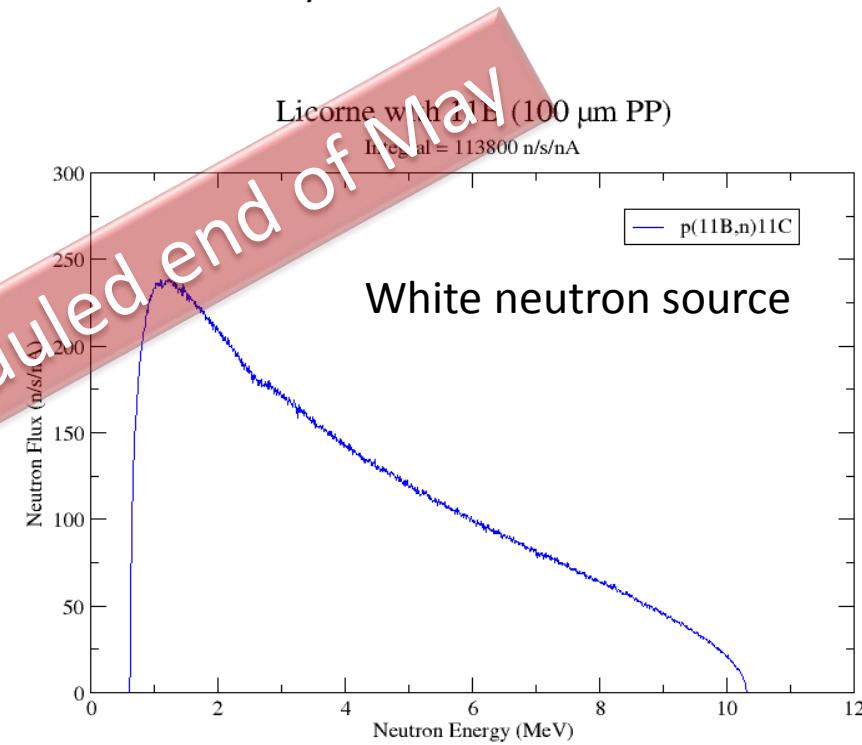
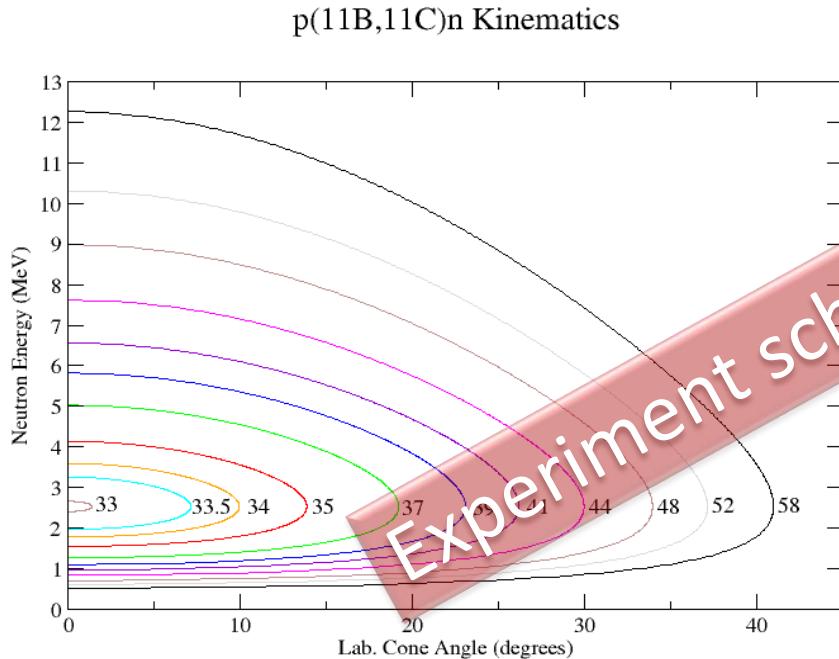
Beam 15 MeV electrons:
brehmstallung gamma beam
on ^{11}B target

An important part of the physics program of PARIS deals with fusion-evaporation reactions.

The good timing resolution of PARIS (LaBr₃:Ce part) allows simultaneous detection of n/gamma.
NEUTRON ENERGY SPECTRUM ? ...

LICORNE : presently p(⁷Li,⁷Be)n reaction used → 0.5 to 4 MeV

For more energetic neutron beams: p(¹¹B,¹¹C)n reaction → 0.5 to 12 MeV
(reaction not yet tested at IPN !!!)



Experiment scheduled end of May

GANIL AGATA campaign: end 2015-2017

Lifetime measurements of excited states in neutron-rich C and O isotopes:a stringent test of the three body forces with the *AGATA+PARIS+VAMOS+Plunger* setup {S. Leoni (Milano), B. Fornal (Krakow), M. Ciemała (GANIL)}
(approved proposal)

Different Microscopic Calculations start to become available in A = 20 mass region

Ab initio: No-Core Shell Model (NCSM) or Multi-Body Perturbation (MBPT) with NN or NNN
Shell Model: Empirical or realistic effective interactions

Lifetimes of 2+ states in $^{16-18}C$ and $^{20-22}O$

Nucleus	Excited state	Results of calculations (with various interactions)				Experiment [ps]
		tau [ps] (SM USDA)	tau [ps] (<i>ab initio</i> MBPT NN)	tau [ps] (<i>ab initio</i> NCSM NN)	tau [ps] (<i>ab initio</i> NCSM NNN)	
^{20}O	2^+_1	10.7	10.3			10.70(40)
	2^+_2	0.22	0.026			-
^{22}O	2^+_1	0.65	0.68			0.69(28)
	2^+_2	0.46	0.03			-
^{16}C	2^+_1			24		11.4(10) - 18.3(50)
	2^+_2			0.23	0.08	< 4
^{18}C	2^+_1			19.4		22.4(3.5)
	2^+_2			2.2	1.1	< 4.6

$\tau = 30 \text{ fs} - 10's \text{ ps}$

τ of the second 2^+ : Sensitivity to Microscopic Models and details of NN interactions



So far considered non-SPIRAL2 PARIS physics cases



GANIL (AGATA campagne – PARIS campaign manager: Ch. Schmitt)

- Lifetimes in A=18 region (Leoni, Fornal, Ciemala): AGATA, VAMOS, Plunger
- SD bands at high spins in the Ca region (Bednarczyk, de France): AGATA, Diamant
- SD bands in A=80 region (Cederwall): AGATA, Diamant

IPN/ALTO Orsay (PARIS campaign manager: I. Matea)

- Dynamics of heavy-ion collisions around the Coulomb barrier (Schmitt, Dorvaux): ORGAM, CORSET
- Measurements of prompt $\nu-\bar{\nu}$ pairs from neutron-induced fission (Wilson, Matea): LICORNE, ORGAM
- Coulomb inelastic scattering studies
- Cluster studies

Call for proposals: deadline 20th of February 2015

CCB Krakow

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

HIL Warsaw

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



So far considered non-SPIRAL2 PARIS physics cases



LNL/SPES Legnaro

- 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)
- Coulomb excitation tagged by beta decay: The onset of deformation in the n-rich Y isotopes (Kmiecik, Benzoni, Suzuki) GALILEO
- 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): GALILE



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: 5 phoswiches			1100 k€	Only if Phase 1 validated Funds: MoU Ph1Day1 exp@IPN Orsay
Phase 3 2017 PARIS 2π	12 clusters: 108 phoswiches			≈ 2 M€	Only if Phase 2 validated Funds: MoU, PARIS consortium Ph2Day1 exp. w AGATA and GASPAR Other exp.
Phase 4 ≈2019 PARIS 4π	≥24 clusters: ≥216 phoswiches			≈ 4 M€	Only if Phase 3 validated Funds: PARIS consortium Regular experiments in various labs

IPN Orsay

AGATA@GANIL

S3@GANIL

CCB Krakow

LNL/SPES

SPIRAL2 phase2

PARIS construction time line

Within PARIS Demonstrator MoU

- Presently PARIS has 17 phoswiches (5 of them are sent to SaintGobain for replacements/repair, be back January/February 2015)
- >9 additional phoswiches were ordered (to be delivered until January 2015)
- At the beginning of 2015: 26 phoswiches (ca. 3 clusters)
(France: 8, Poland: 9, India: 4, UK: 2, Italy: 2, Turkey: 1, Romania:?)
- Summer/autumn 2015: 4 clusters; Analogue electronics implemented, mechanical integration to AGATA ready
- In 2016: 5 clusters (?) – NUMEXO2 electronics verified

End of PARIS Demonstrator MoU

2015: New PARIS 2π MoU to be agreed and signed

- 2017 (probably): 8 clusters
- 2019: (hopefully) 12 clusters (2π PARIS)

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

PARIS Steering Committee (by nominations of the MoU partners):

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

A.Maj (Poland)

PARIS Project Manager

Working Groups and their Coordinators:

Geant4 simulation: O. Stezowski (Lyon)

Detectors: O. Dorvaux (Strasbourg)

Electronics and DAQ: P. Bednarczyk (Krakow)

Mechanical integrations: I. Matea (Orsay)

New materials: F. Camera (Milano)

Data analysis: S. Leoni (Milano)

New Physics case: I. Mazumdar (Mumbai)

GANIL campaign Spokesperson: C. Schmitt (GANIL)

PARIS Management Board:

PARIS Project Manager + WG coordinators

PARIS Collaboration Council:

David Jenkins (University of York, UK) - chair and PARIS spokesman
Sudhee R. Banerjee (VECC Kolkata, India)
Franco Camera (INFN and University of Milano, Italy)
Wilton N. Catford (University of Surrey, UK)
Marco Cinausero (LNL Legnaro, Italy)
Sandrine Courtin (IPHC Strasbourg, France)
Zsolt Dombradi (ATOMKI Debrecen, Hungary)
Camille Ducoin (IPN Lyon, France)
Sefa Ertuerk (Nigde, Turkey)
Juergen Gerl (GSI, Germany)
Anil K. Gourishetty (IIT Roorkee, India)
Maria Kmiecik (IFJ PAN Krakow, Poland)
Suresh Kumar (BARC Mumbai, India)
Marc Labiche (STFC Daresbury, UK)
Vandana Nanal (TIFR Mumbai, India)
Pawel Napiorkowski (HIL Warsaw, Poland)
Marek Ploszajczak (GANIL, France)
Mihai Stanoiu (IFIN-HH Bucharest, Romania)
Jonathan Wilson (IPN Orsay, France)

Many thanks to :

F. Azaiez, J. Bettane, G. Hull, M. Josselin, T. Zerguerras, **IPNO, France**

O. Dorvaux, C. Finck, P. Medina, M. Rousseau, **IPHC, France**

C. Schmitt, J.P. Wieleczko, **GANIL, France**

O. Stezowski , **IPN Lyon, France**

S.R. Banerjee, I. Mazumdar, V. Nanal, **TIFR/BARC/VECC, India**

M. Ciemala, M. Jastrzab, M. Kmiecik, A. Maj, M. Zieblinski, **IFJ PAN Krakow, Poland**

F. Negoita, M. Stanoiu, **HH-IFIN Bucharest, Romania**

D. Balabanski, **INRNE, Sofia, Bulgaria**

F. Camera, **INFN, Milano, Italy**

D. Jenkins, **U. of York, UK**

S. Erturk, **U, Nigde, Turkey**

P. Napiorkowski, **HIL Warsaw**

+ ...