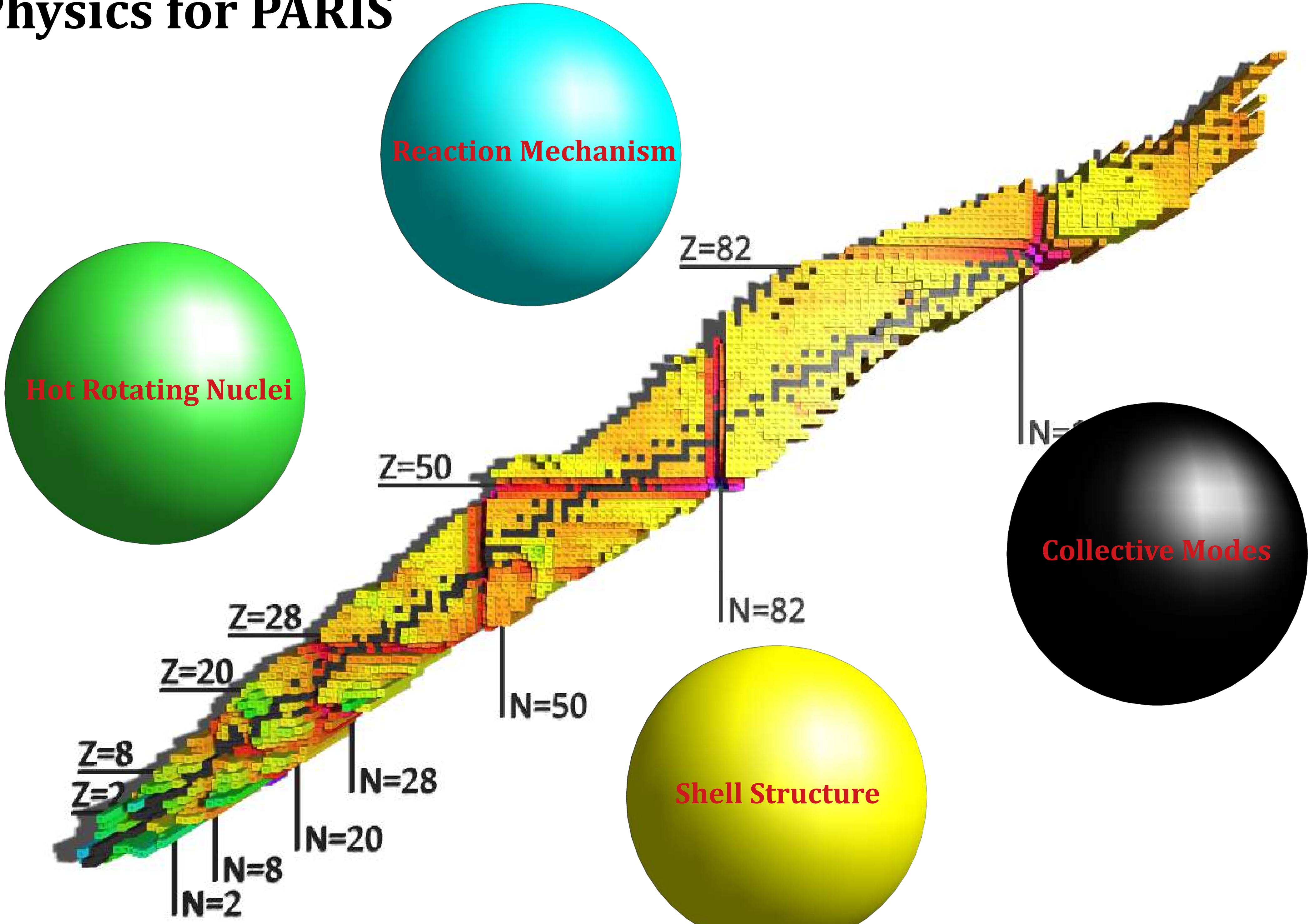
PARIS

(Photon Array for studies with Radioactive Ions and Stable beams)

Iolanda MATEA, for PARIS France

Physics for PARIS



(reviewed in O. Sorlin's talk)

PARIS SPIRAL2 LoI8 (2006)

Jacobi and Poincare shape transitions (+AGATA)

Studies of shape phase diagrams of hot nuclei – GDR differential methods

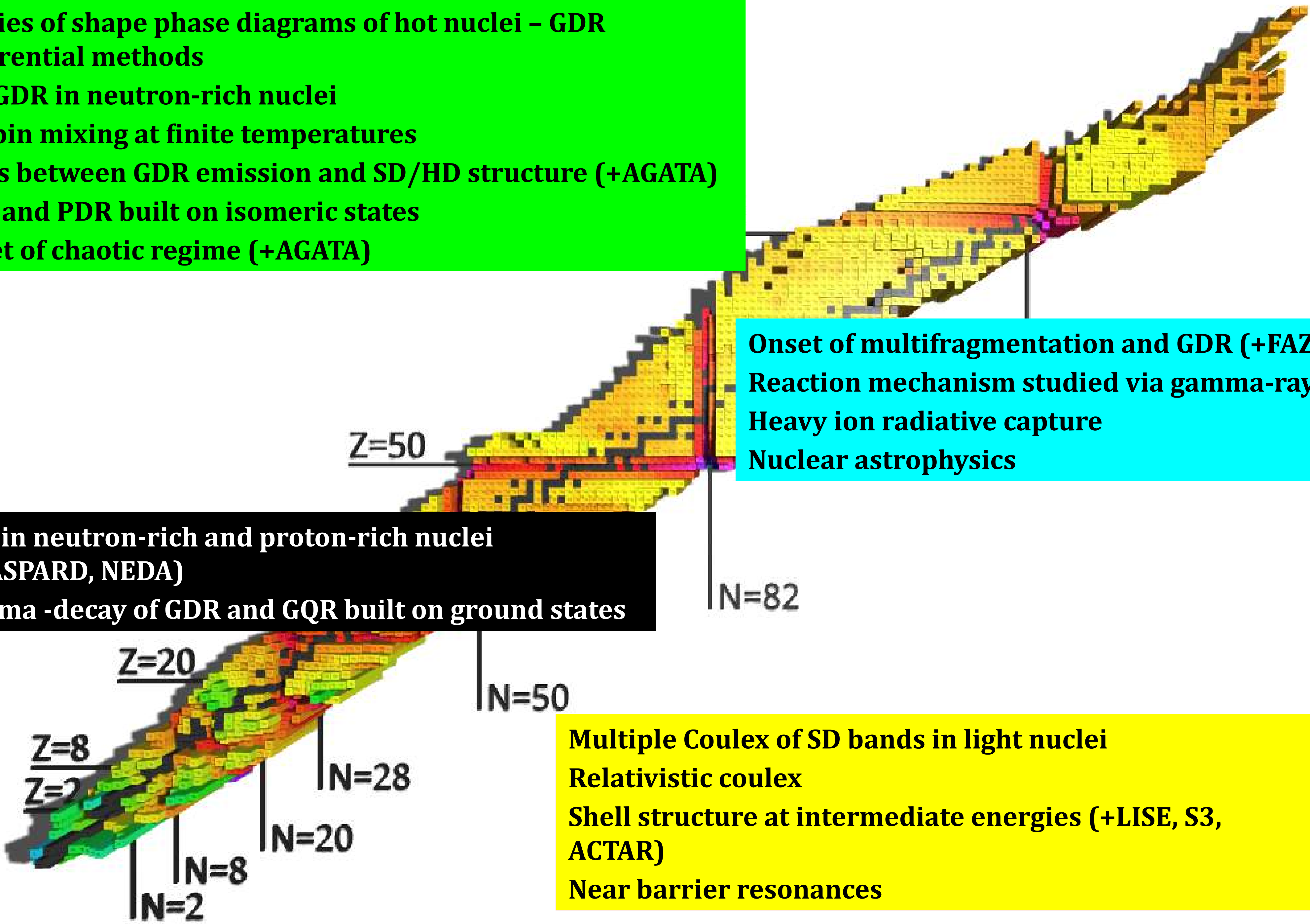
Hot GDR in neutron-rich nuclei

Isospin mixing at finite temperatures

Links between GDR emission and SD/HD structure (+AGATA)

GDR and PDR built on isomeric states

Onset of chaotic regime (+AGATA)



Onset of multifragmentation and GDR (+FAZIA)

Reaction mechanism studied via gamma-rays

Heavy ion radiative capture

Nuclear astrophysics

PDR in neutron-rich and proton-rich nuclei (+GASPARD, NEDA)

Gamma -decay of GDR and GQR built on ground states

Multiple Coulex of SD bands in light nuclei

Relativistic coulex

Shell structure at intermediate energies (+LISE, S3, ACTAR)

Near barrier resonances

Physics Case	Recoil mass	v/c [%]	E_γ range [MeV]	$\Delta E_\gamma/E_\gamma$ [%]	$\Delta E_{sum}/E_{sum}$ [%]	ΔM_γ	Ω coverage	ΔT [ns]	Ancillaries	Comments
Jacobi transition	40-150	<10	0.1-30	4	<5	4	2π-4π	<1	AGATA HI det.	High eff. Beam rej.
Shape Phase Diagram	160-180	<10	0.1-30	6	<5	4	2π-4π	<1	HI det.	High eff. Differential method Beam rej.
Hot GDR in n-rich nuclei	120-140	<11	0.1-30	6	<8	4	2π-4π	<1	HI det.	Beam re.
Isospin mixing	60-100	<7	5-30	6	-	-	4π	<1	HI det.	High eff. Beam rej.
Reaction dynamics	160-220	<7	0.1-25	6-8	<8	4	2π	<1	n-det. FF det.	Complex coupling
Collectivity vs. multi-fragmentation	120-200	<8	5-[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	LCP det. HI det.	Complex coupling
Radiative capture	20-30	<3	1-[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	HI det.	High eff.
Multiple Coulex	40-60	<7	2[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]5	AGATA CD det.	Complex coupling
Astrophysics	16-90	0.1	0.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Outer PARIS shell as active shield	High eff. Back-ground
Shell structure at intermediate energies (SISSI/LISE)	16-40	20-40	0.5-4	3	-	-	3π	<<1	SPEG or VAMOS	High eff. Low I_{beam} γ- γ coinc
Shell structure at low energies (separator part of S^3)	30-150	10-15	0.3-3	3	-	-	3π	<<1	Spectrometer part of S^3	High eff. Low I_{beam} γ- γ coinc
Relativistic Coulex	40-60	50-60	1-4	4	-	1	Forward 3π	<<1	AGATA HI analyzer	Ang. Distr. Lorentz boost

Beta ≈ 10% and DM/M < 4

DT < 1 ns

DEg/Eg: ~ 4-5 %

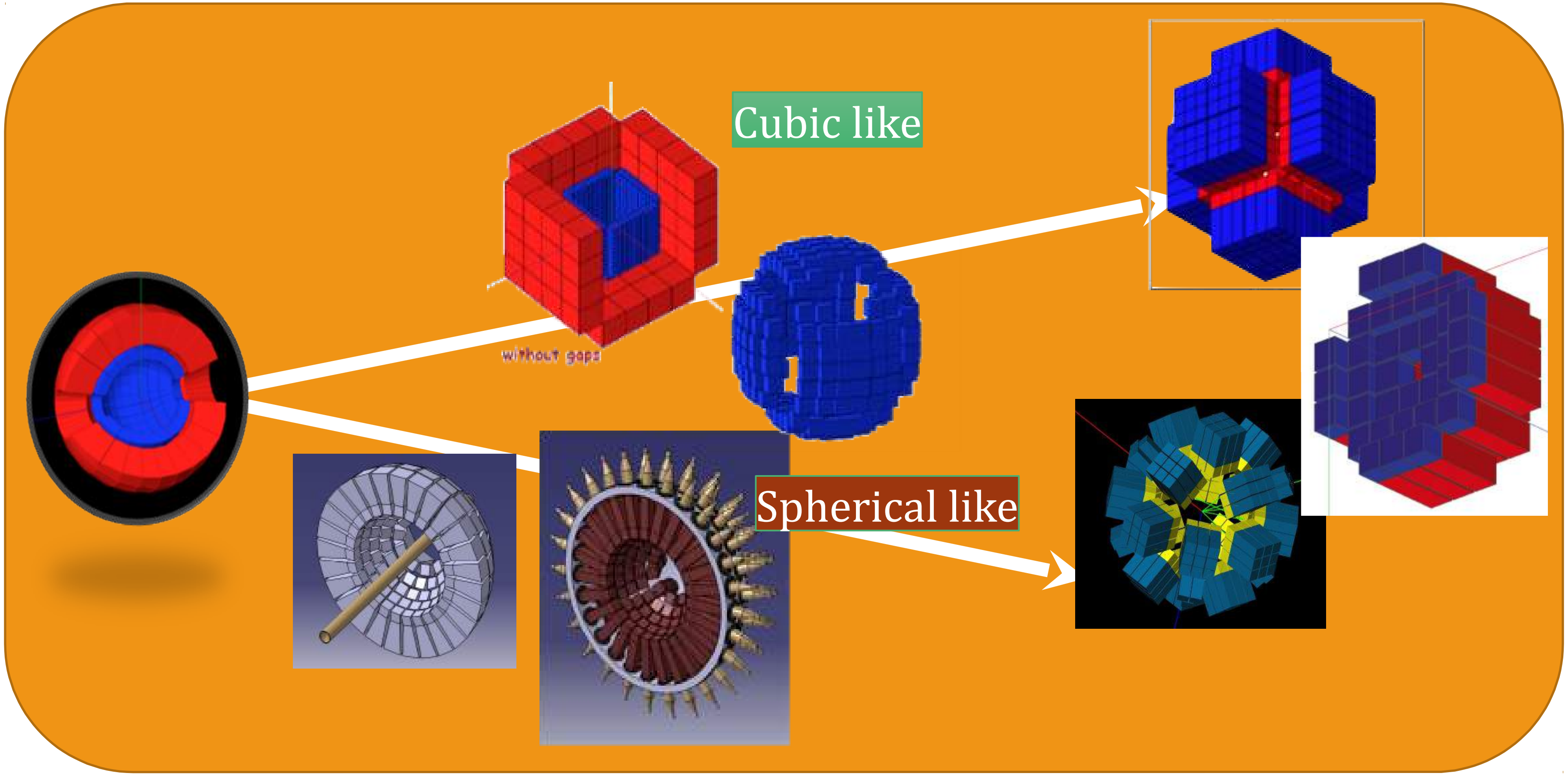
high efficiency up to 15 MeV

PARIS : two shells design

→ **inner shell**, highly granular, for use as multiplicity filter, sum-energy, medium energy resolution, fast timing, Doppler correction …

→ **outer shell** for high energy gamma detection

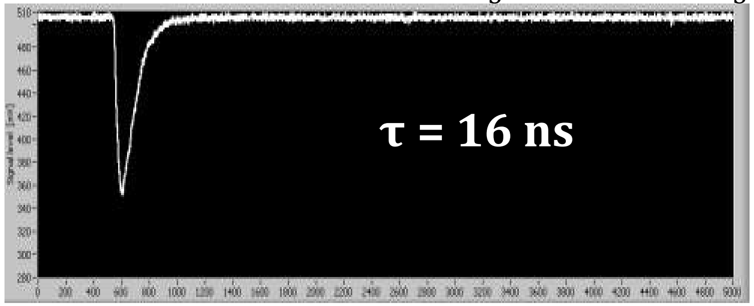
→ two shells for efficient add-back reconstruction



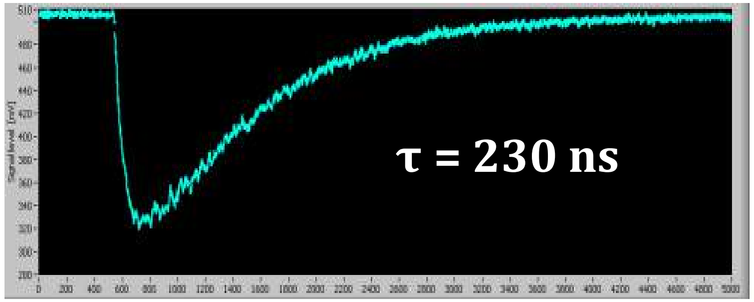
This project was developed jointly by physicists from France, Poland and Italy.

Phoswich/cluster concept

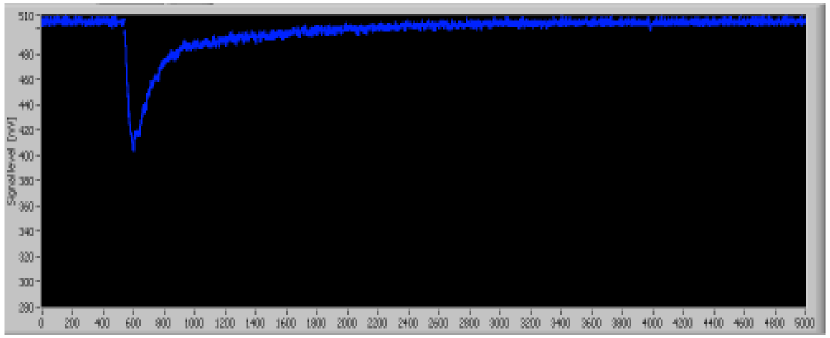
Interaction only in LaBr$_3$:Ce or CeBr$_3$

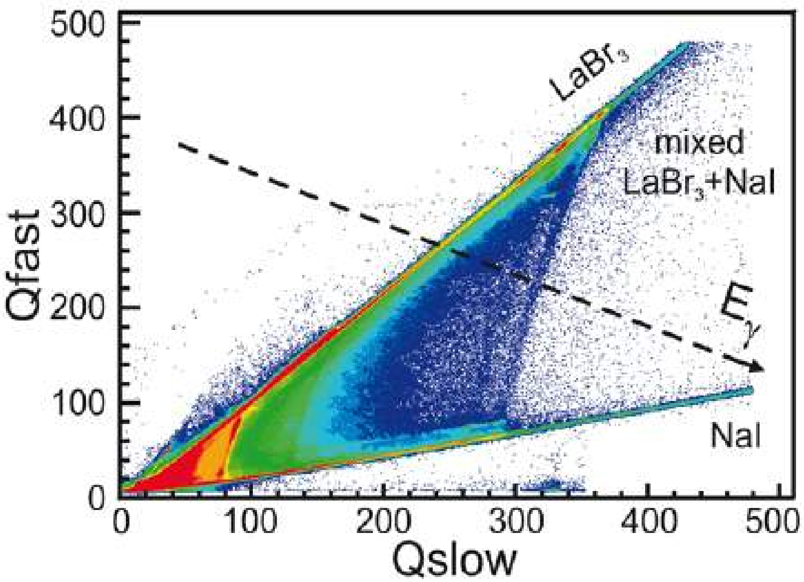


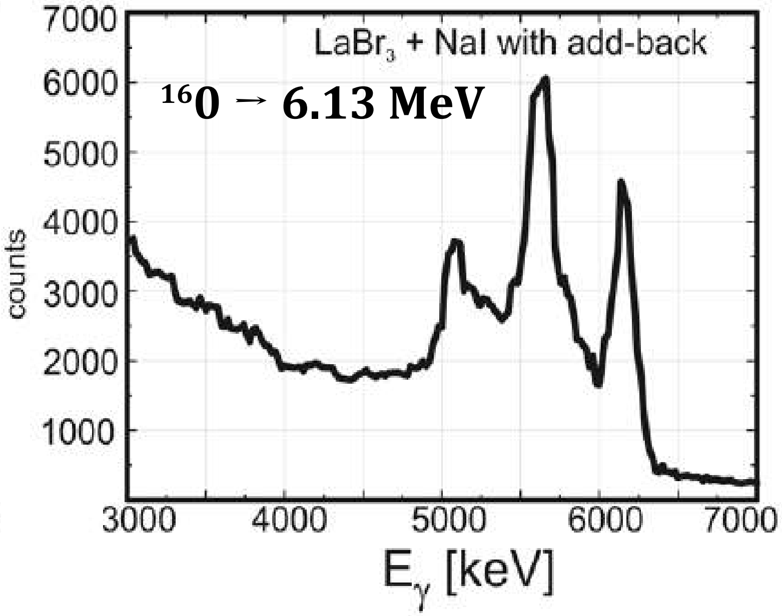
Interaction only in NaI:Tl

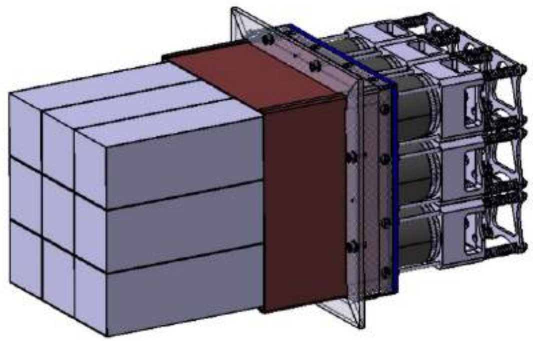


Mixed interaction

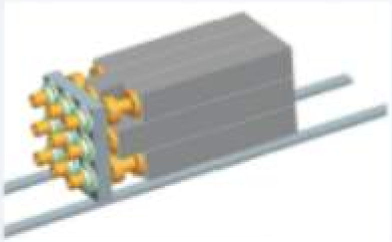
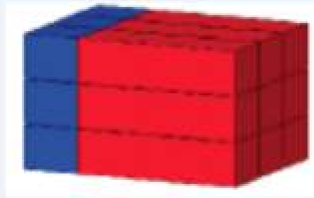
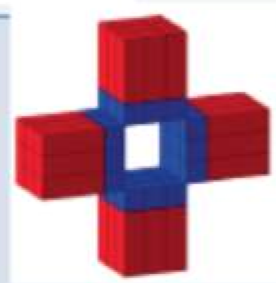
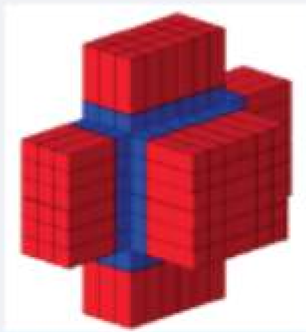
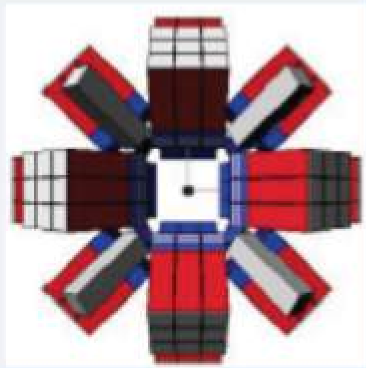
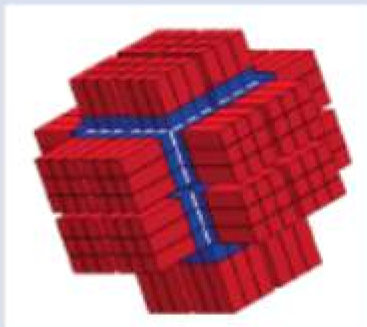








PARIS phases and cost estimates

Phase 1 **2011/2012** **PARIS Prototype**	1 cluster: 9 phoswiches (ANR PROVA)	 	250 k€
Phase 2 **2015** **PARIS Demonstrator**	~ 9 clusters (81 phoswichs)		1900 k€
Phase 3 2022 **PARIS 2π**	12 clusters: 108 phoswiches	 	2500 k€
Phase 4 2025 ? **PARIS 4π**	≥24 clusters: ≥216 phoswiches	 	5000 k€

PARIS organisation

PARIS Steering Committee
(nominated by the MoU partners):
IN2P3 France: O. Dorvaux
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

Working Groups and their Coordinators
(proposed by PPM and aproved by PSC):

Geant4 simulation: **O. Stezowski**
Detectors: **O. Dorvaux**
Electronics and DAQ: **P. Bednarczyk**
Mechanical integrations: **I. Matea**
Data analysis: **S. Leoni**
New materials: **F. Camera**
New Physics case: **I. Mazumdar**

PARIS Management Board:
PARIS Project Manager + WG coordinators

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

PARIS Collaboration Council
(nominated by the MoU institutions)
Franco Camera (INFN, Italy) - chair and PARIS spokesman
Chandana Bhattacharya (VECC Kolkata, India)
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)
David Jenkins (University of York, UK)
Maria Kmiecik (IFJ PAN Krakow, Poland)
Basant Kumar Nayak (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)

PARIS

Photon Array for studies with Radioactive Ions and Stable beams

Memorandum of Understanding

GOAL: Phase 2

AMENDMENT n°1

TO
Memorandum of Understanding

PARIS

Photon Array for studies with Radioactive

GOAL: Phase 2 ++

(2013 - 2021)

MoU Amendment (extraction)

Signature collection from partners in progress

Party or Country	Funds committed (before December 2017) (k€)	Personnel resources committed (before December 2017) (person-month)	Planned (2018-2021) new capital investment (k€)	Planned (2018-2021) Personnel resources (person-month)	Total capital investment (k€)	Total personnel resources (person-month)
FRANCE–IN2P3	292	36	200	48	492	84
FRANCE-GANIL	64	12	80	3	144	15
POLAND	300	30	160	40	460	70
INDIA	217	36	103	36	320	72
UK	42	11	21	11	63	22
ITALY	64	20	170	20	234	40
TURKEY	27	10	40	10	67	20
ROMANIA	64	5	36	10	100	15
DUBNA			85*	10	85*	10
GSI			25	9	25	9
Total	**1070**		**920**		**1990**	

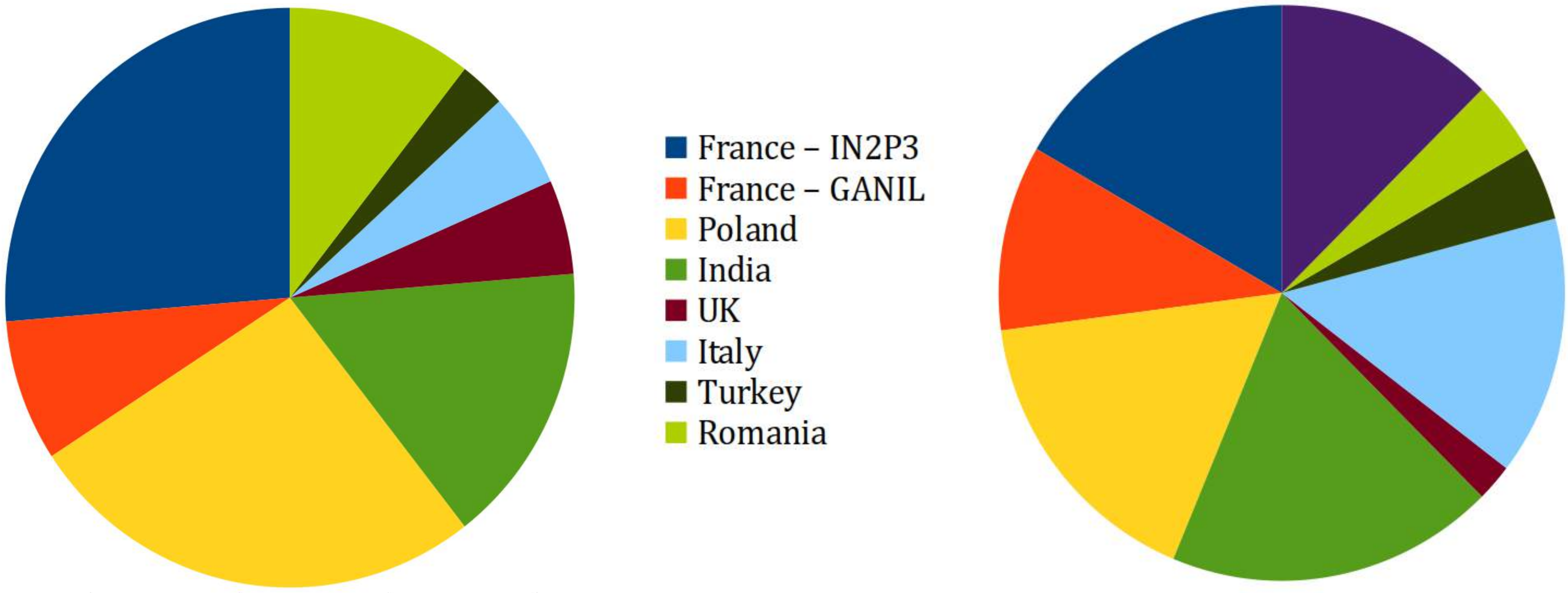
NEW MEMBERS

* Under financial support by grant of Plenipotentiary of the Government of the Poland Republic to JINR

Table 5.1 Summary table of the proposed capital investment, personnel resources for PARIS system and the planned sharing between the participating collaborating institutions of each Party (extracted from the amendment to the PARIS Demonstrator MoU).

Detector ownership (past, present and future projections)

(PARIS MoU and MoU amendment)



2012 - 2017

2018 - 2021

Manpower : IN2P3 et GANIL

IPHC
3 pers-month

IPNO
4.5 pers-month

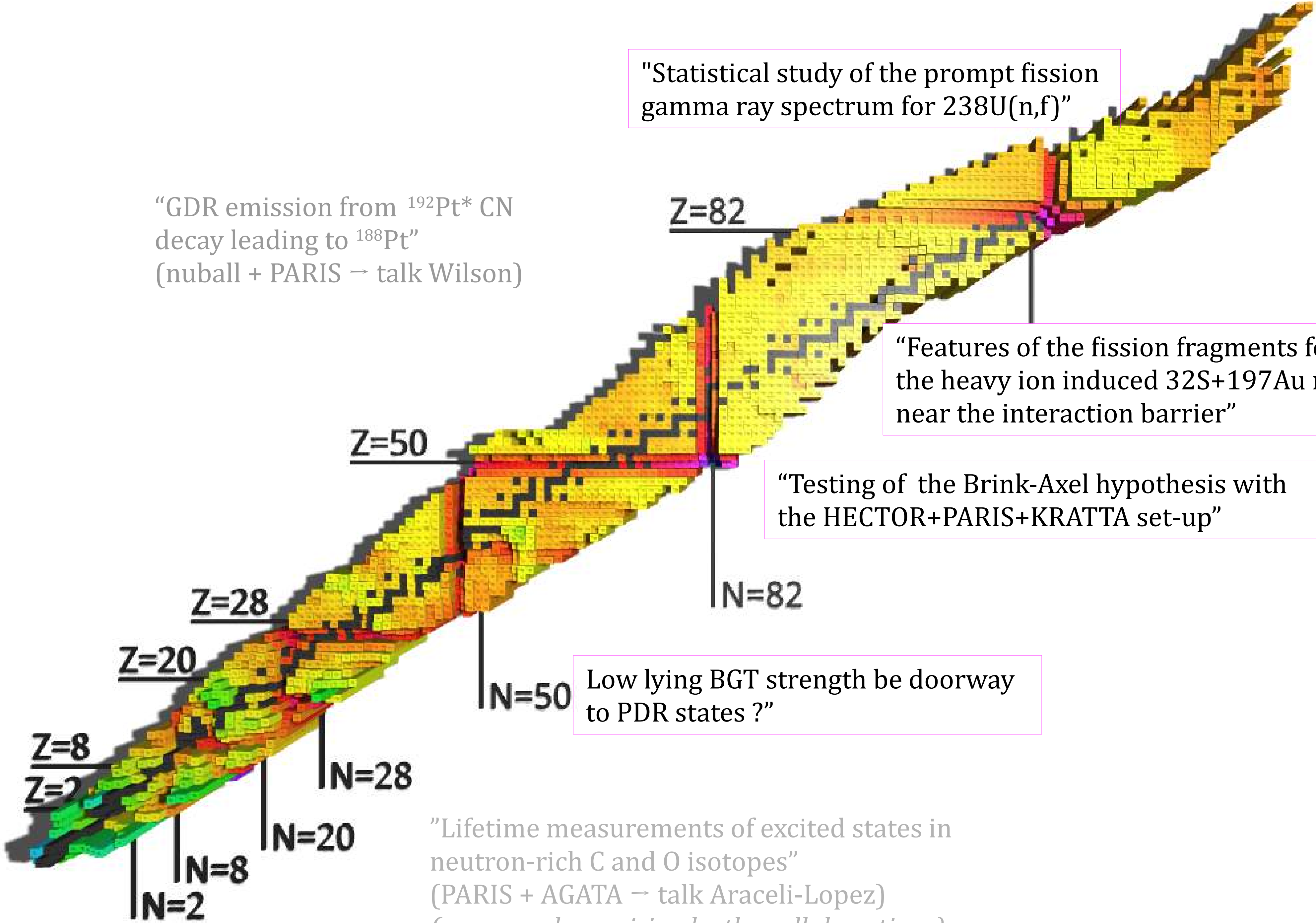
IPNL
4 pers-month

GANIL
2 pers-month

PARIS is in a construction phase : manpower investment at the lowest !

(based of 2018 NSIP declaration)
(only most active persons are mentioned)

Physics with PARIS : highlights



"Statistical study of the prompt fission gamma ray spectrum for 238U(n,f)"

"GDR emission from $^{192}Pt^*$ CN decay leading to ^{188}Pt"
(nuball + PARIS → talk Wilson)

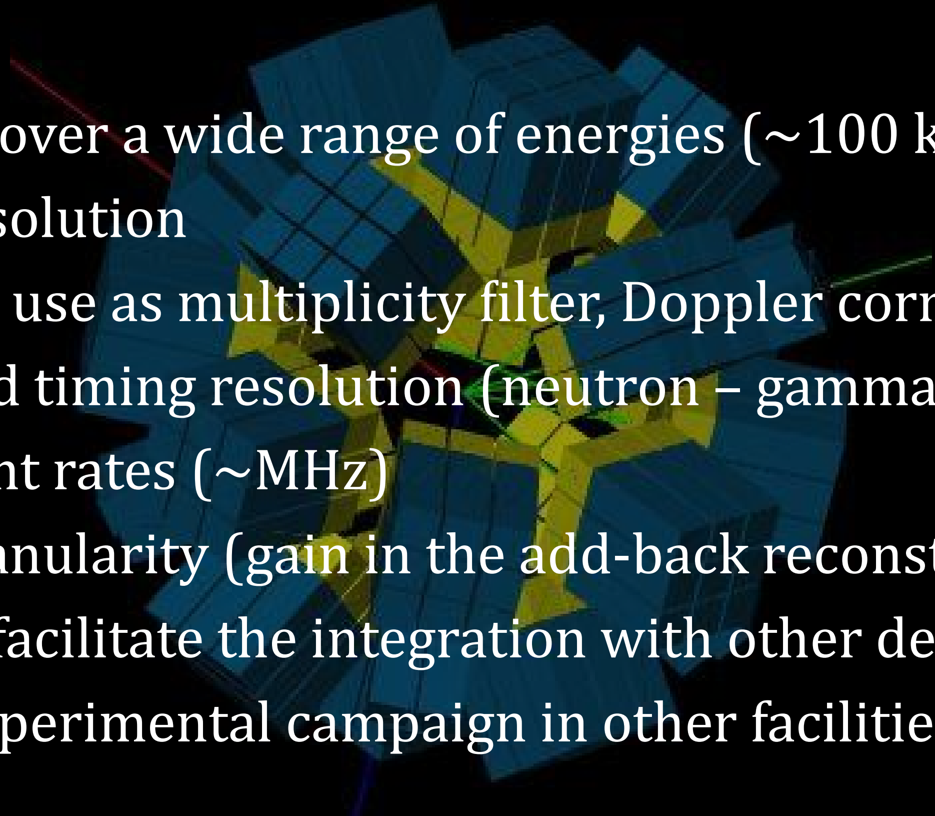
"Features of the fission fragments formed in the heavy ion induced 32S+197Au reaction near the interaction barrier"

"Testing of the Brink-Axel hypothesis with the HECTOR+PARIS+KRATTA set-up"

Low lying BGT strength be doorway to PDR states ?"

"Lifetime measurements of excited states in neutron-rich C and O isotopes"
(PARIS + AGATA → talk Araceli-Lopez)
(paper under revision by the collaborations)

PARIS strong points :



→ high efficiency over a wide range of energies (~100 keV to 30 MeV)
→ good energy resolution
→ granularity (for use as multiplicity filter, Doppler correction …)
→ sub-nanosecond timing resolution (neutron – gamma discrimination)
→ stand high count rates (~MHz)
→ some depth granularity (gain in the add-back reconstruction)
→ modularity (to facilitate the integration with other detectors)
→ mobility (for experimental campaign in other facilities)

Prompt gamma and neutron emission for ^{238}U induced fission with fast neutrons at different energies (ALTO)

Courtesy of L. Qi

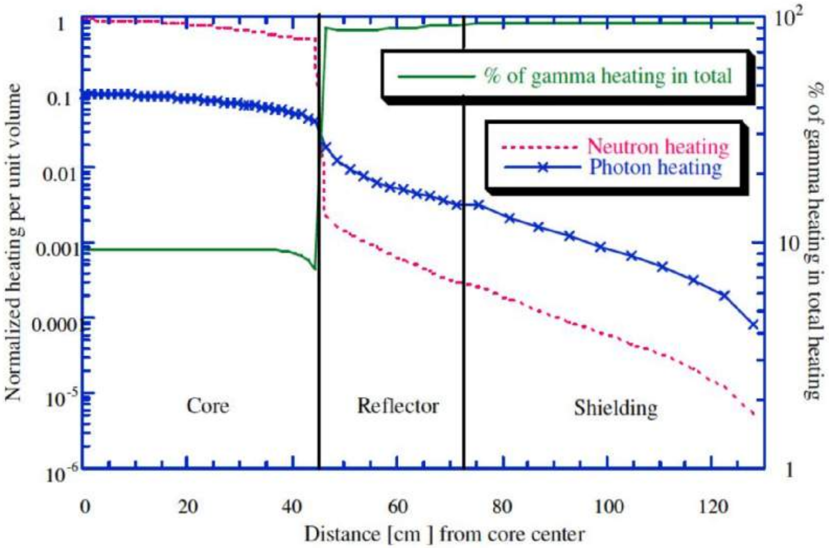
Two-fold motivation:

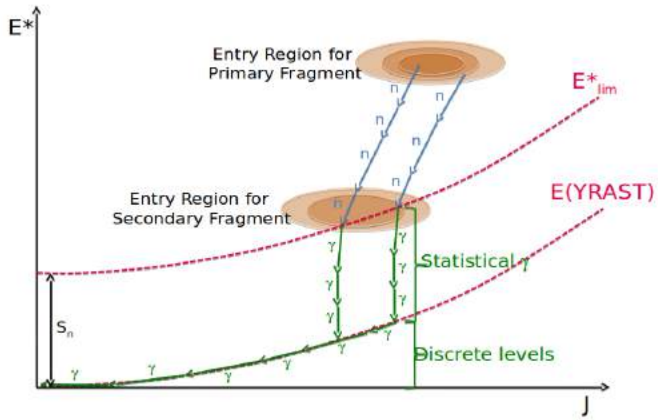
1. Reactor Physics

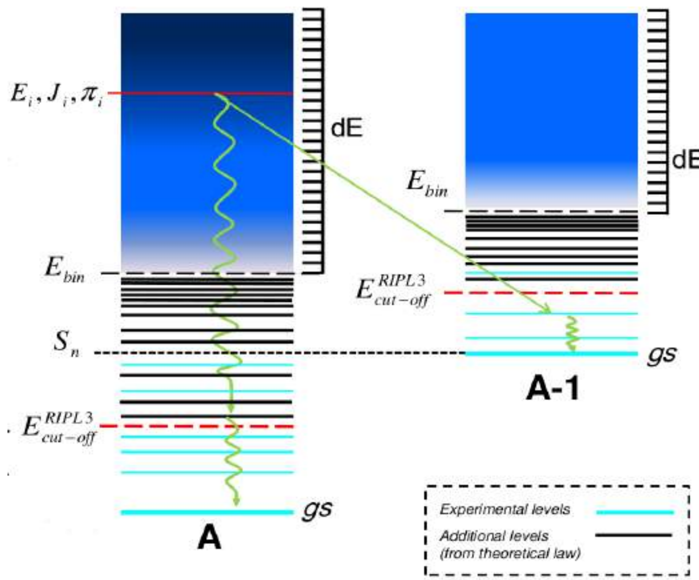
- 5% release in fission is done through PFG and γ-heating can be underestimated by up to 28%
- design of Gen. IV reactors: fast neutron reactors – nuclear data are scarce out of thermal regime

2. Fundamental Physics

- understanding the fission process, like energy partition in fission or generation of $\vec{J}$
- study of level density function, γ-strength function, competition between n and γ emission (needed for validation of different competing codes like GEF, FREYA, CGMF, FIFRELIN)



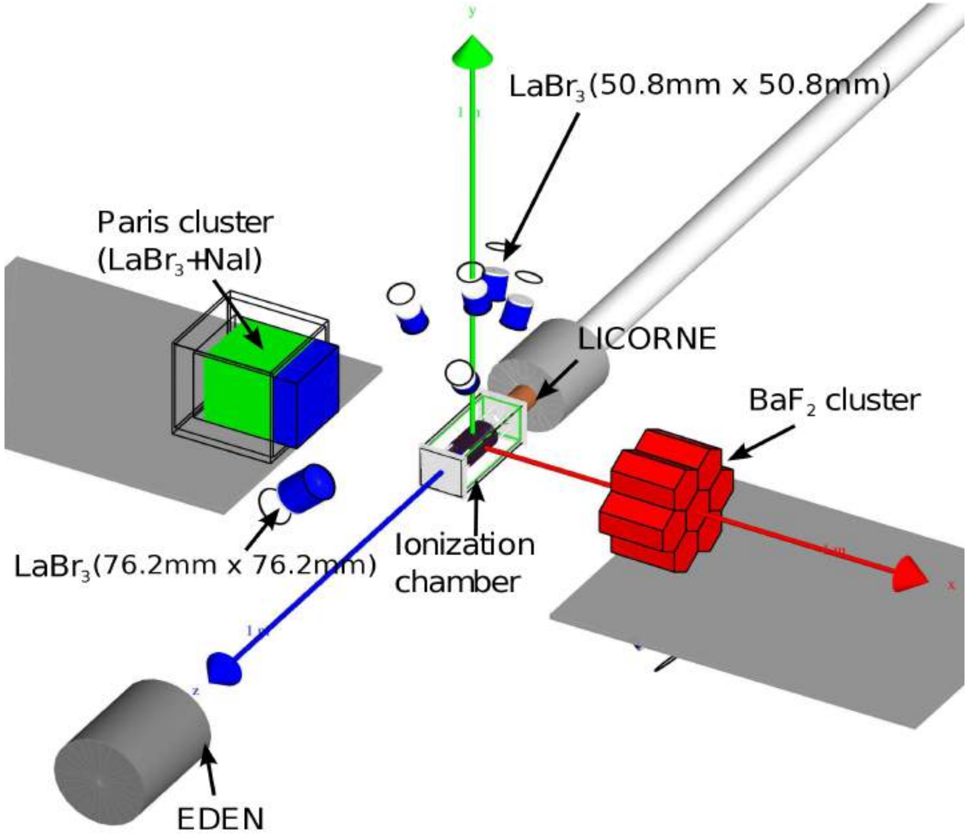




Prompt gamma and neutron emission for ^{238}U induced fission with fast neutrons at different energies (ALTO)

Courtesy of L. Qi

→ aiming at measuring spectral characteristics (M_γ, $E_{\gamma\ tot}$ and ε_{ph}) for different fissioning systems



→ ^{252}Cf source measurements (test data)

→ E_n = (1.9; 4.8) MeV – induced fission on ^{238}U

(→ also studied induced fission of fast n on ^{239}Pu)

Prompt gamma and neutron emission for ^{238}U induced fission with fast neutrons at different energies (ALTO)

Courtesy of L. Qi

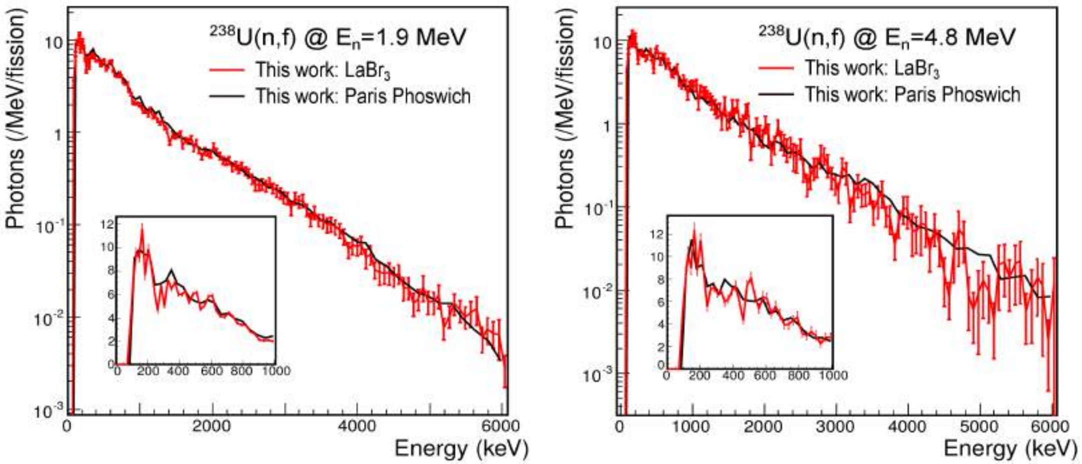


TABLE III. Summary of PFGS characteristics for the ^{238}U(n,f) reaction at two incident neutron energies.

	E_n (MeV)	$M_\gamma(/fission)$	$E_{\gamma,tot}(MeV)$	$\epsilon_\gamma(MeV)$
This work	1.9	6.54±0.19	5.25±0.20	0.80±0.04
	4.8	7.31±0.46	6.18±0.65	0.84±0.11
J-M.Laborie	1.7	7.05±0.20	5.92±0.24	0.84±0.03
et al. [7]	5.2	7.25±0.35	5.73±0.40	0.79±0.04
M.Lebois	2.4	7.62±0.25	5.78±0.29	0.77±0.03
et al. [8]	3.3	10.08±0.14	7.55±0.15	0.75±0.01

Phys.Rev. C 98, 014612 (2018)
Second paper under prep.

Conclusions:

→ low energy PFGS different for different energies : change in fragment population

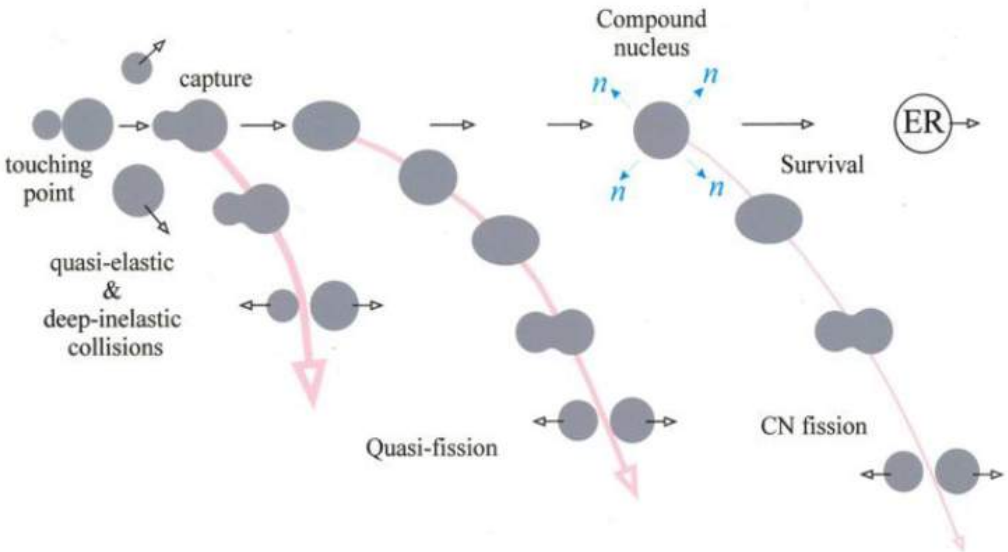
→ softening of the HE part of PFGS suggests that the increased total excitation energy goes to the heavy fragments : hints on the excitation energy sharing mechanism ...

→ spectral characteristics stay constant with increased neutron energy : extra excitation energy is mainly evacuated by prompt neutron evaporation. As a consequence, the fast reactors in Generation-IV don't need significant changes in the modeling of gamma heating transportation

Motivation and Goal :
Challenging fission around the interaction barrier

$^{32}S+^{197}Au \rightarrow ^{229}Am^{*}$, $E^{*} \approx 43$ MeV

- Coupling of 3 detection systems: CORSET + ORGAM + PARIS;
- Extracting details on the shell effects characterizing two competing processes **fusion-fission (CNF)** and **quasi-fission (QF)** : (A, TKE) correlation;
- Measurement of prompt γ-rays in coincidence with binary reaction fragments obtained in the reactions : *low and high energy* γ-rays for further insight.



- Are population and feedings of specific isotopes preferred in different mechanisms or CNF modes?
- How does the γ-ray multiplicity or the sum energy evolve with fragment mass A, TKE or their variances?

Courtesy of I.M. Harca

Experimental Setup: CORSET

$^{32}S + ^{197}Au \rightarrow ^{229}Am^*, E^* \approx 43$ MeV

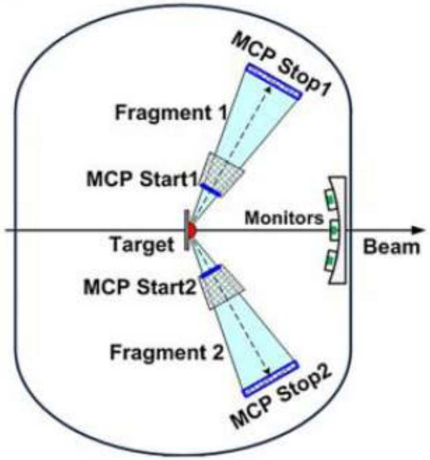
- CORSET:

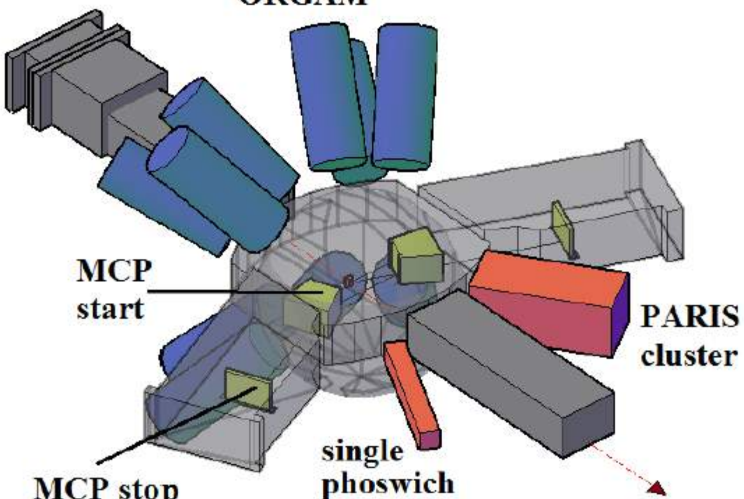
Measured parameters:

- ToF, X, Y

Extracted parameters :

- Velocity, energy, angles
- mass of fission fragments





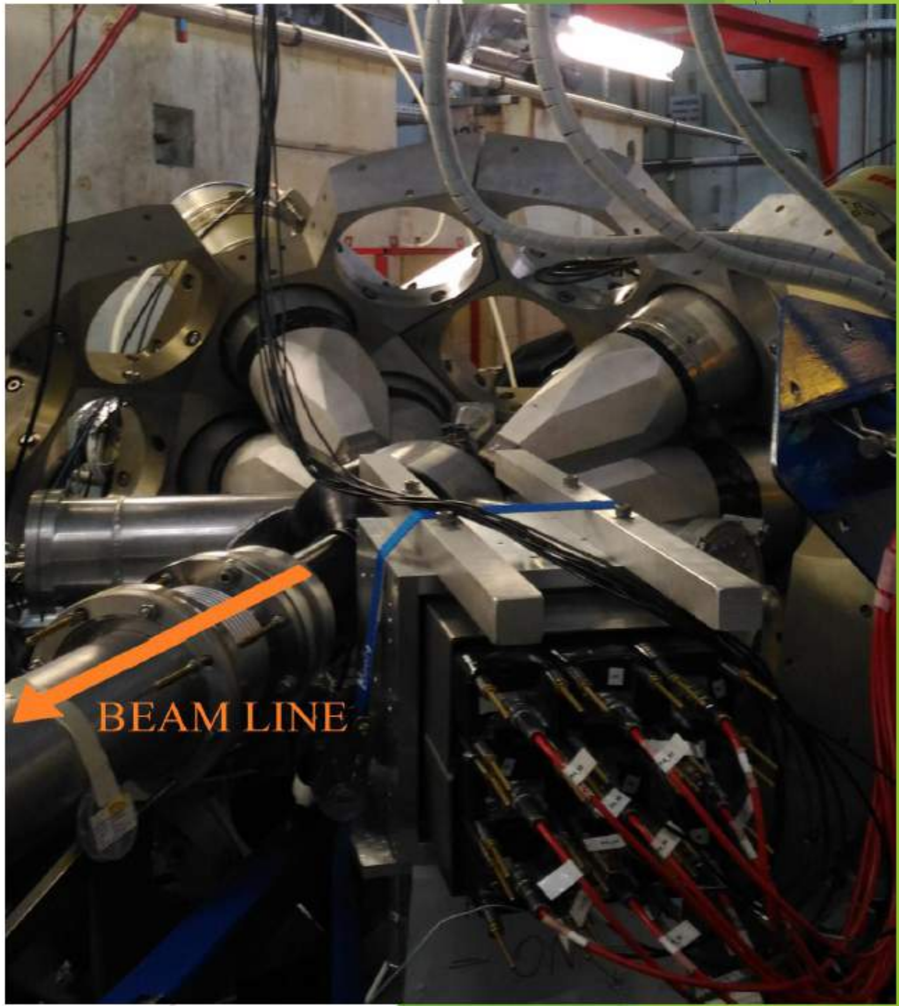
Parameter	Value
The Coulomb barrier (in lab. sys)	167 MeV
Irradiation time	~4 days
Beam current	~90 nA
Collected statistics for fission fragments	274448
Excitation energy of the CN	~43 MeV

Courtesy of I.M. Harca

Experimental Setup: Coincident FF - γ-rays

- ORGAM: Prompt γ–rays coincident with FF
- PARIS: Prompt γ–rays (HE part) coincident with FF.

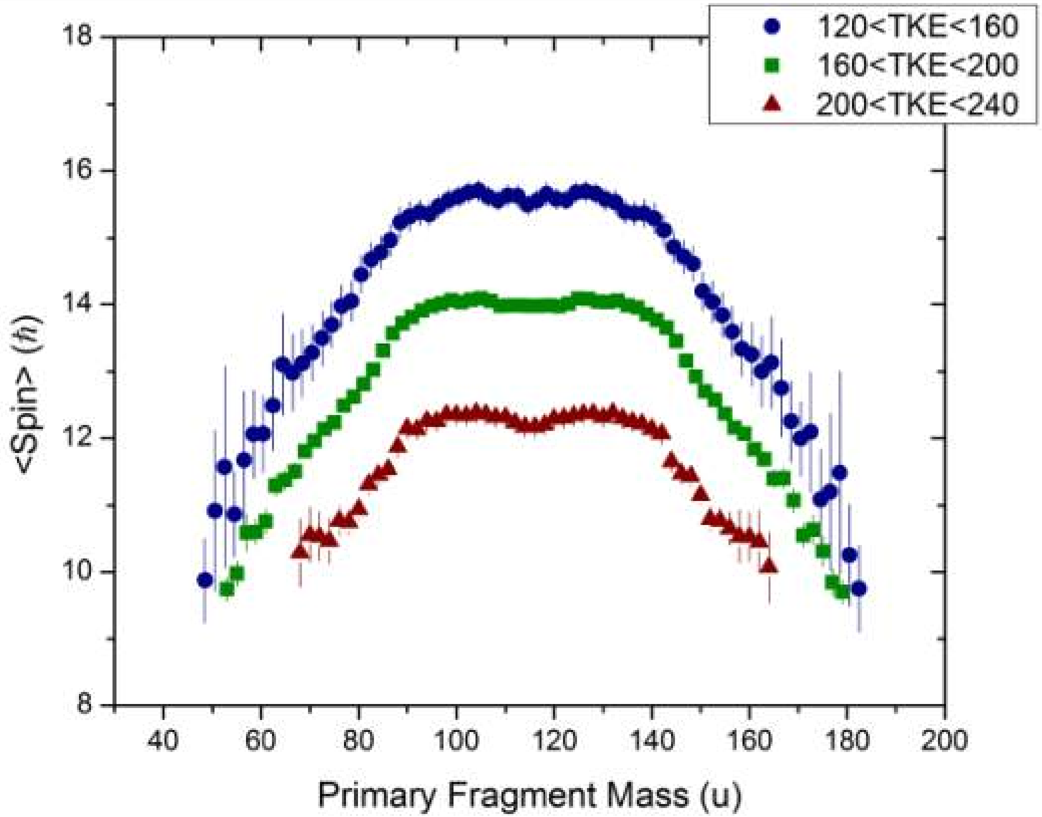
Parameter	ORGAM	PARIS
Number and type of Detectors	10 x Ge + BGO shielding	10 x LaBr3(Ce)-NaI(Tl) *(phoswich)*
Photo-peak Efficiency	~1%	~1%
Energy resolution	2.6(3.4)keV @121(1408)keV	62keV @1332keV
Dynamical range	$E_\gamma < 2.5MeV$	$E_\gamma < 15MeV$



Courtesy of I.M. Harca

Prompt gamma rays as a probe of nuclear dynamics (ALTO)

→ **Unique** investigation tool (using PARIS) of the energy deformation at different stages of fusion-fission and quasi-fission processes



→ First measurement of the nuclei spin as function of the fission fragment mass distribution for different selection in the total kinetic energy of the considered system

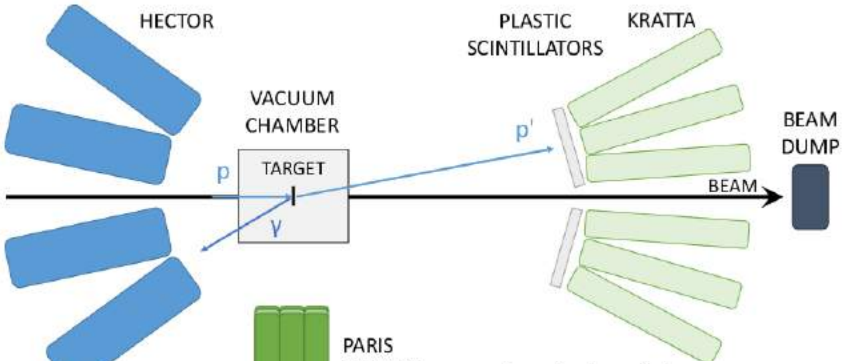
→ opportunity to develop a program around this topic

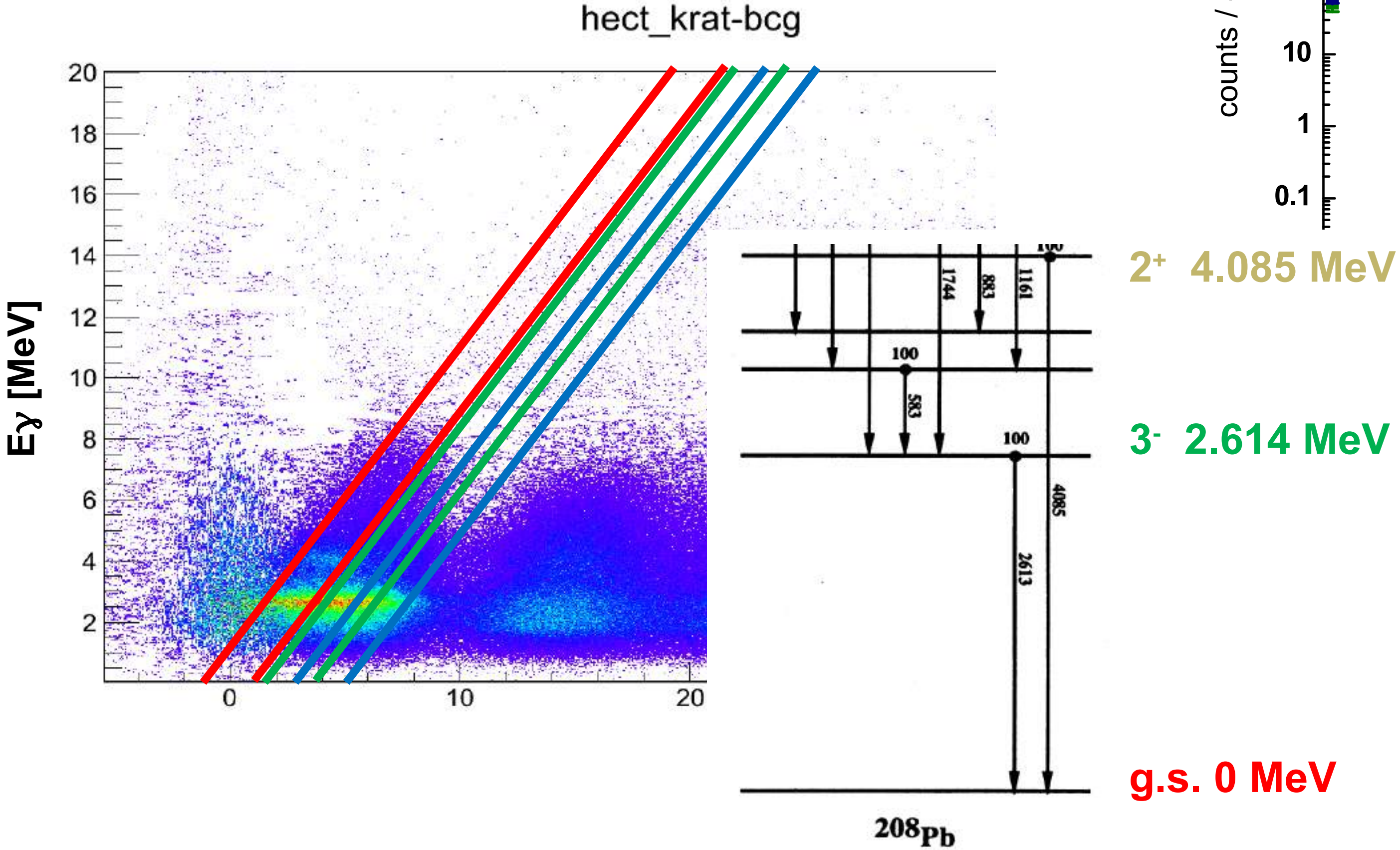
I. Harca et al., "Features of the fission-like fragments following the heavy ion induced 32S+197Au reaction near the interaction barrier" , in progress for publication in PRC (2019)

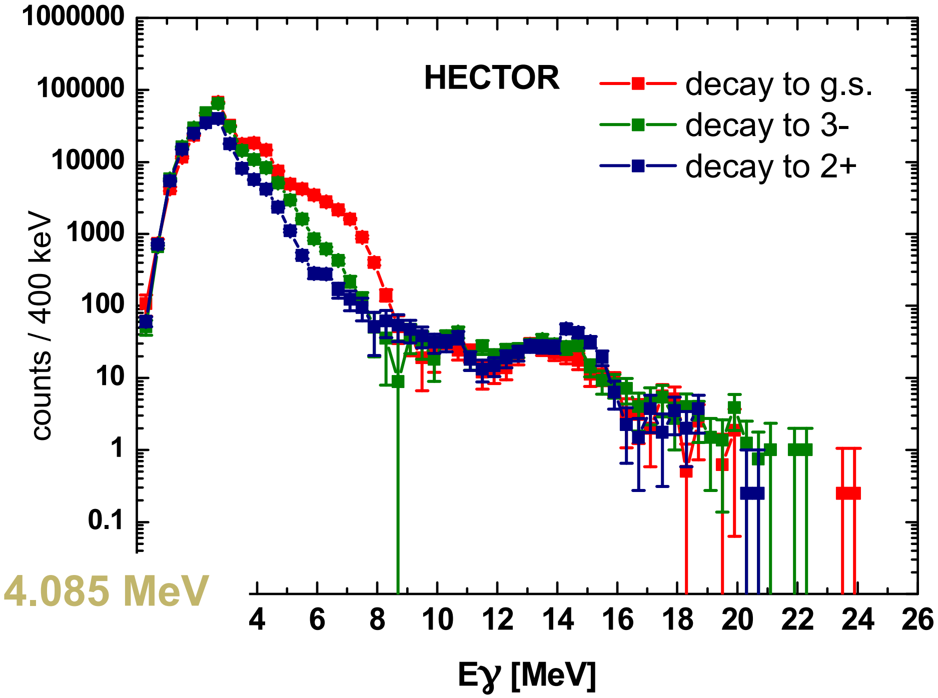
Testing the Brink-Axel hypothesis (CCB IFJ PAN)

Courtesy of A. Maj

→ GDR build on GS and excited states are equivalent.
What about the PDR ?





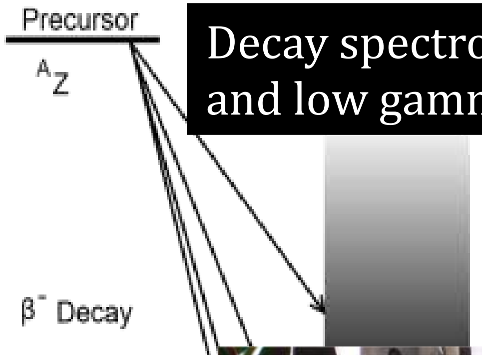


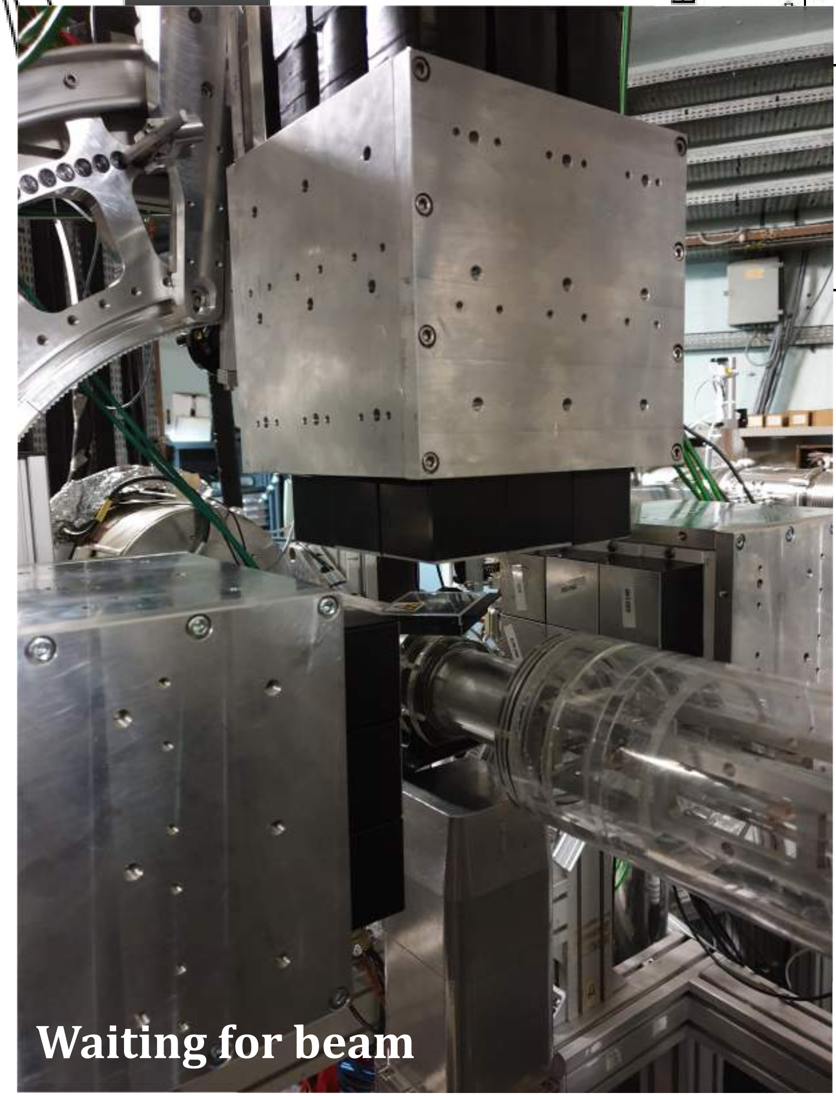
Axel-Brink Hypothesis
doesn't seem to hold for PDR

B. Wasileska et al., Acta Phys. Pol. B 50, 469 (2019)

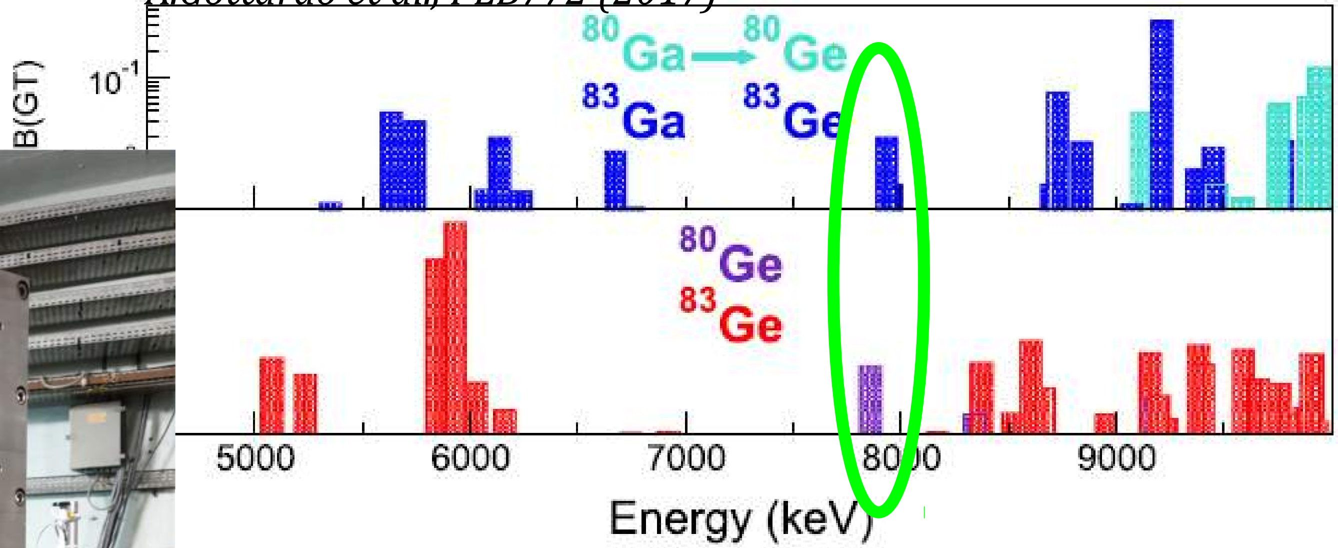
PDR along closed neutron shell isotonic chains
“Can pygmy GT be a doorway to pymy DR ?”
(I. Matea et al. - experiment ongoing)

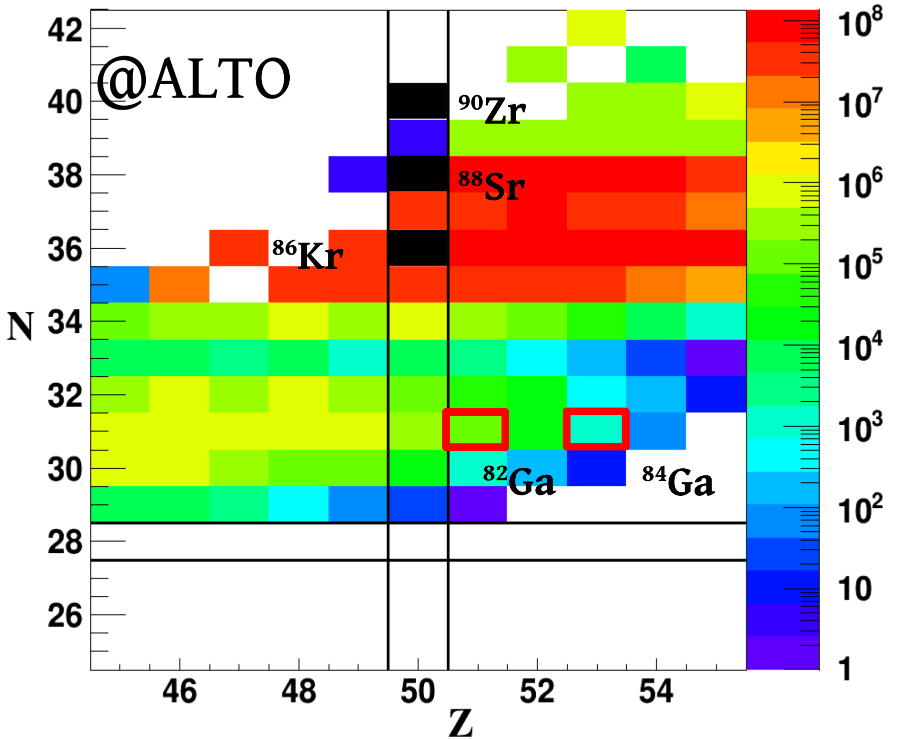
Decay spectroscopy with high and low gamma transitions





A.Gottardo et al., PLB772 (2017)





Past/Present/Future “séjours” of PARIS

GANIL/SPIRAL2 (France) → LoIs & Experiments

IPN/ALTO (France) → LoIs & Experiments

CCB IFJ PAN Krakow (Poland) → Experiments

SPES/LNL Legnaro (Italy) → LoIs

HISPEC/DESPEC FAIR (Germany) → LoIs

JINR/Dubna (Russia) → (future) Experiments

TIFR/BARC (India) → (future) Experiments

There will be a PARIS collaboration meeting in 2019 (autumn)
(organized by F. Camera and A. Maj)
with the goal to discuss new/updated PARIS physics

Strengths High performances detection system in terms of : - efficiency in wide photon energy range - energy and timing resolutions - modularity and granularity - mobility - simultaneously sensitivity to photons and neutrons - easy to integrate with other detectors	**Weakness** - no home-base of detectors - limited fund to complete Phase4 (4pi) - PARIS standard electronic still not defined - limited numbers of FTE, but ...
Oportunities Nice opportunities for synergies with different partners Readiness for physics with new facilities	**Threats** - Unknown crystal ageing - not many provider for phoswich like for PARIS crystals (Saint Gobain/Scionix)