Results from the PARIS array at the Nuball1 and Nuball2 campaigns in IJCLab

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INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

Colloque GANIL, 2023, Soustons

Presentation plan

PARIS project – short information

PARIS coupled to Nuball1

PARIS coupled to Nuball2

Summary

PARIS project – short information

PARIS project

PARIS — 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 and Adam Maj;

M. Kmiecik: talk on possible Jacobi shapes in exotic nuc[illegible]

Spiral2

Letter of Intent for SPIRAL 2

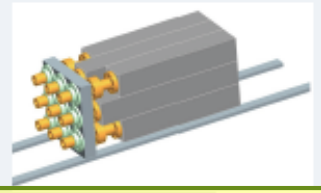
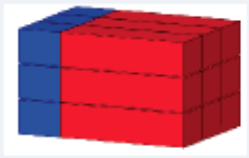
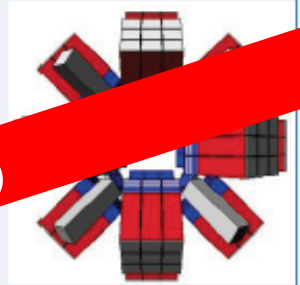
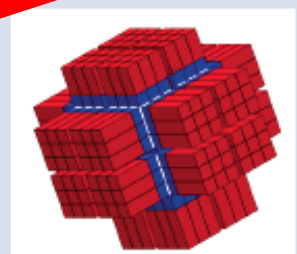
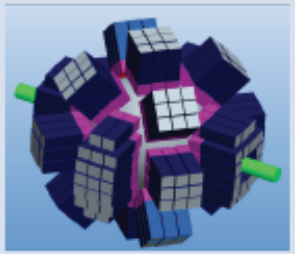
Title: High-energy γ-rays as a probe of hot nuclei and reaction mechanisms

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 *(EXL and R3B contact)*
David Jenkins, University of York (UK), dj4@york.ac.uk

GANIL contact person
Jean-Pierre Wieleczko, GANIL, wieleczko@ganil.fr

GANIL
SAC open session
October 19th, 2006

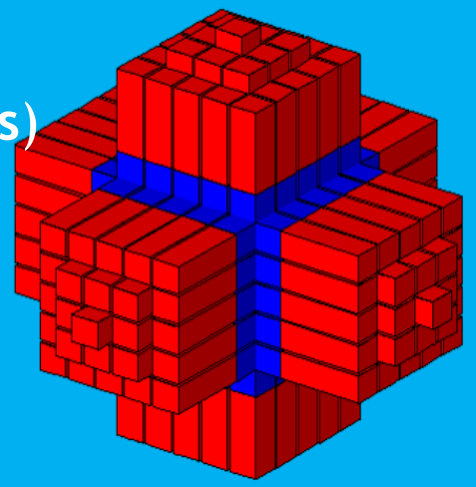
Photon Array for studies with Radioactive Ion and Stable Beam - PARIS

Phase 1 **2011/2012** PARIS cluster	1 cluster: 9 phoswiches		
Phase 2 **2021** **PARIS Demonstrator**	8 clusters 72 phoswiches		
2025? **PARIS 2π**	12 clusters: 108 phoswiches		
after2025	>24 clusters: phoswiches		

Today we have ~ 10 clusters (90 detectors)

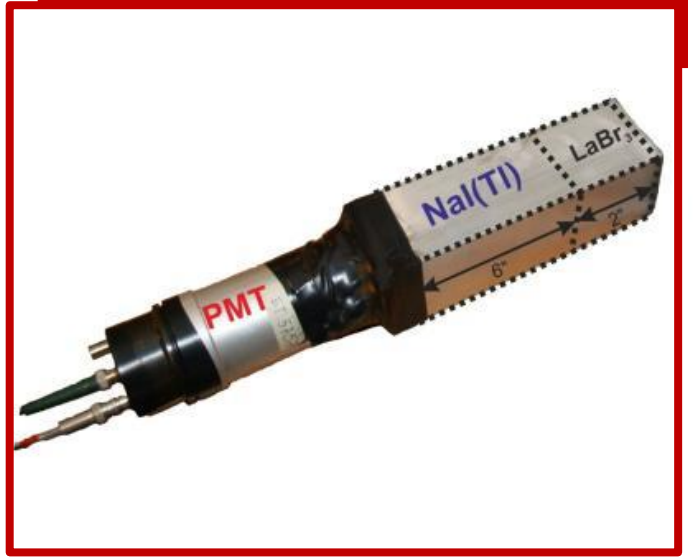
PARIS is made of clusters:
Cluster = 9 phoswiches of $LaBr_3$:NaI or $CeBr_3$:NaI
Digital electronic basing on V1730 digitizer, which can be coupled to NUMEXO2 boards. Also other electronic used, by example FASTER digitizers (NFS exp. and @IJCLab)

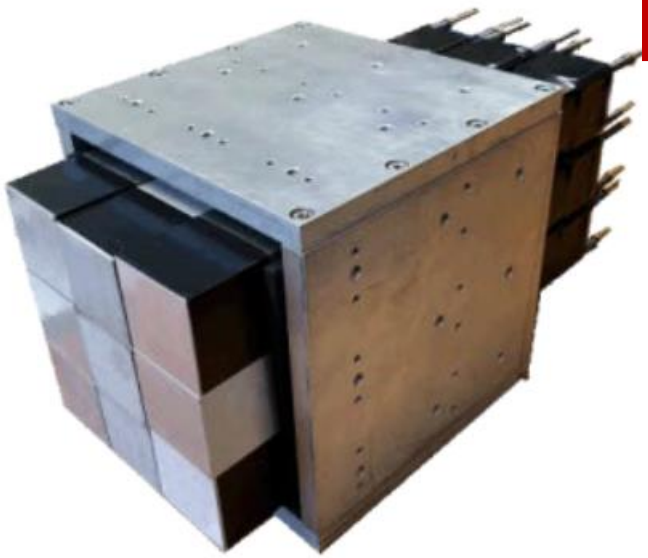
Goal of the new MoU
4π mini-cube
(150 phoswiches)

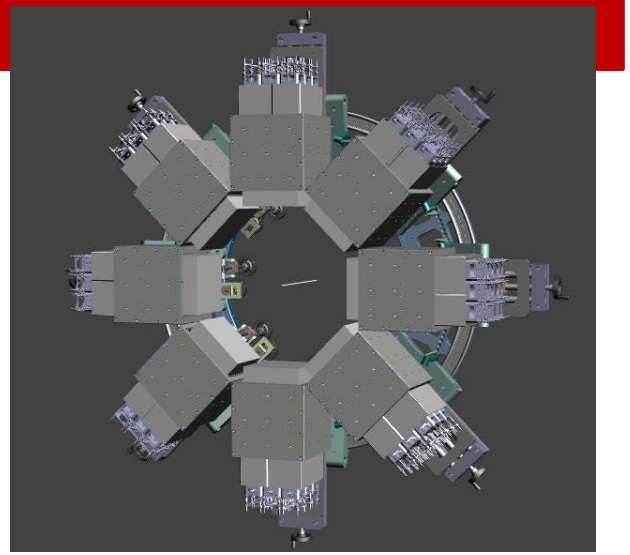


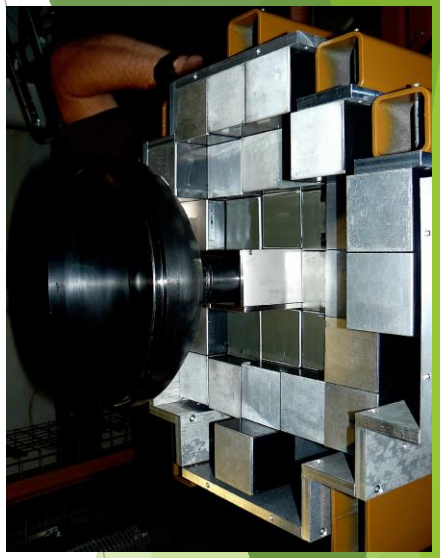
PARIS is made of rectangular phoswiches ($LaBr_3$/$CeBr_3$+NaI) arranged in clusters

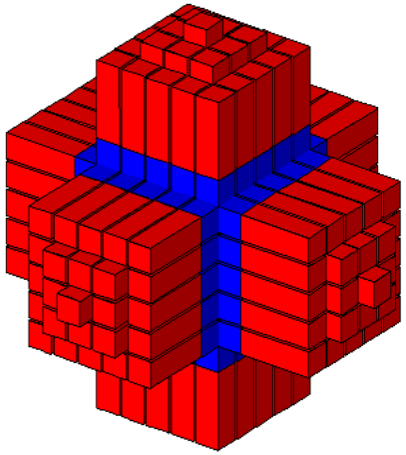
(9 phoswiches each) - this allows cubic, wall or semi-spherical

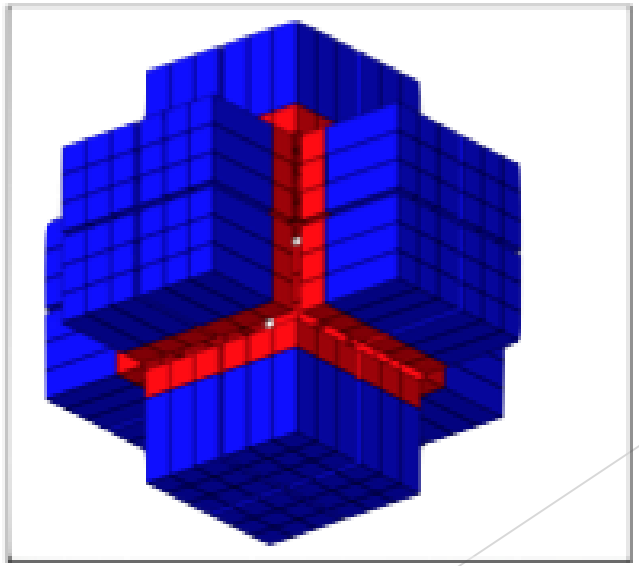


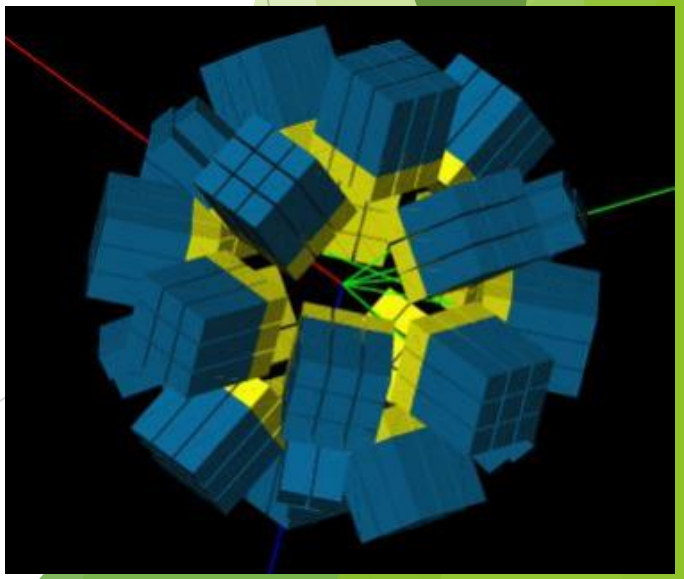












PARIS organization

10 PARTNERS:
IN2P3 (France), COPIN (Poland), GANIL/SPIRAL2 (France), TIFR/BARC/VECC (India), IFIN HH (Romania), INFN (Italy), UK, Turkey, GSI/FAIR Darmstadt

PARIS Steering Committee

- **Angela Bracco (INFN, Italy)**
- **Wilton Catford (UK)**
- **Oliver Dorvaux (IN2P3, France)**
- **Sefa Ertuerk (Turkey)**
- **Bogdan Fornal (COPIN, Poland) - Vice-Chair**
- **Juergen Gerl (GSI/FAIR, Germany)**
- **Marek Lewitowicz (GANIL, France) - Chair**
- **Vandana Nanal (India)**
- **Mihai Stanoiu (Romania)**

PARIS Project Manager

Adam Maj (Krakow)

Working Groups and their Coordinators

- **Piotr Bednarczyk** (Krakow) - Online user interface integration
- **Sergio Brambilla** (Milano) - Electronic and DAQ integration
- **Michał Ciemała** (Krakow) - Physics event generators, off-line data analysis and data management
- **Oliver Dorvaux** (Strasbourg) - Detectors
- **Iolanda Matea** (Orsay) - Mechanical integrations
- **Oliver Stezowski** (Lyon) - Simulations and characterization

PARIS Collaboration Council (21 institutions)

F. Camera (INFN and U. Milano) - chair and PARIS spokesman
C. Bhattacharya (VECC Kolkata), W. Catford (U. Surrey), M. Cinausero (LNL Legnaro), S. Courtin (IPHC Strasbourg), Zs. Dombradi (ATOMKI Debrecen), C. Ducoin (IPN Lyon), S. Ertuerk (U. Nigde), N. Gelli (U. Florence), J. Gerl (GSI), A.K. Gourishetty (IIT Roorkee), D. Jenkins (U. York), M. Kmiecik (IFJ PAN Krakow), B. Kumar Nayak (BARC Mumbai), M. Labiche (STFC Daresbury), V. Nanal (TIFR Mumbai), P. Napiorkowski (HIL Warsaw), M. Ploszajczak (GANIL), M. Stanoiu (IFIN-HH Bucharest), J. Wilson (IPN Orsay)

PARIS detectors in experiments

So far PARIS was used in a number of experiments performed at

a) GANIL 2017:

@VAMOS,AGATA: Lifetime measurements of excited states in neutron-rich C and O isotopes : a stringent test of the three body forces, *S. Leoni, B. Fornal, M. Cieamła et al.*

b) GANIL 2022:

@VAMOS: Insight into fission from the gamma probe: Going beyond current status with PARIS@VAMOS, *Ch. Schmitt, A. Lemassson, M. Cieamła et al., talk on Wednesday by Christelle Schmitt*

@LISE: Study of deformed and spherical 2^+ states via Coulomb excitation and first time measurement of PDR in ^{34}Si, *R. Lica, S. Calinescu, O. Sorlin, et al.*
Study of Proton/Neutron contribution along Silicium isotopic chain, S. Grévy, R. Thomas, O. Sorlin, et al.
@NFS:Nuclear structure studies using neutron inelastic scattering reactions, example of the pygmy resonance in ^{140}Ce, *M. Vandebrouck, I. Matea et al.,* previous talk by Marine Vandebrouck

PARIS detectors in experiments

So far PARIS was used in a number of experiments performed

b) 3 exp at CCB in IFJ PAN Krakow (2 clusters + 4 Large LaBr3 + KRATTA + DSSSD) 2016-2021
next talk by Maria Kmiecik

c) 13 exp at IPN / IJCLab Orsay (1-8 clusters, standalone and with nuBall and nuBall2, BEDO, Corset, …) (2016-2023)

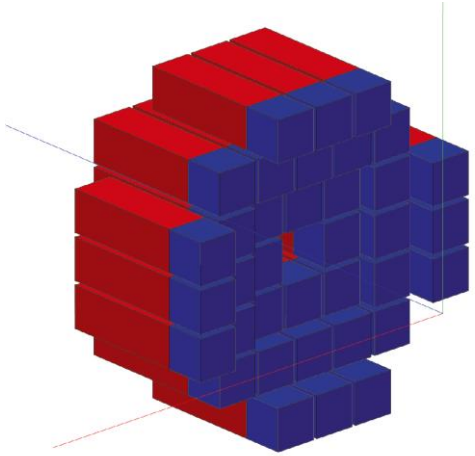
Plans for PARIS campaigns:
June 2023 - end of 2024: 2 clusters in Mumbai
October 2023 – 2024: 3 clusters in Krakow
from January 2025 - possible PARIS-AGATA campaign at LNL Legnaro
after 2026: possible new campaign at GANIL

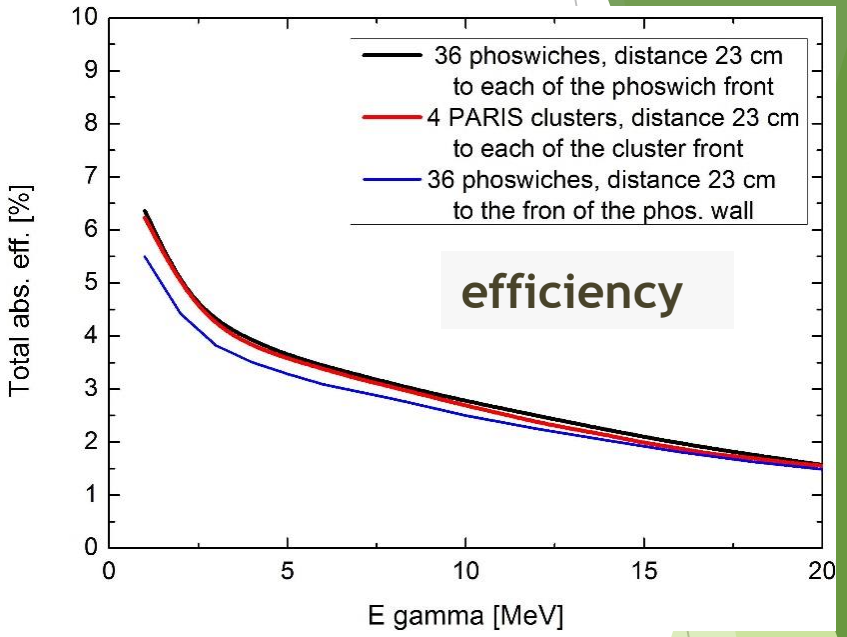
PARIS coupled to Nuball1

PARIS configuration in IPN/IJCLab experiment (Nuball1 + PARIS)

33 **PARIS** detectors („wall" configuration
at backward angles at 23 cm):

11 $CeBr_3$:NaI phoswiches,
22 $LaBr_3$:NaI phoswiches.





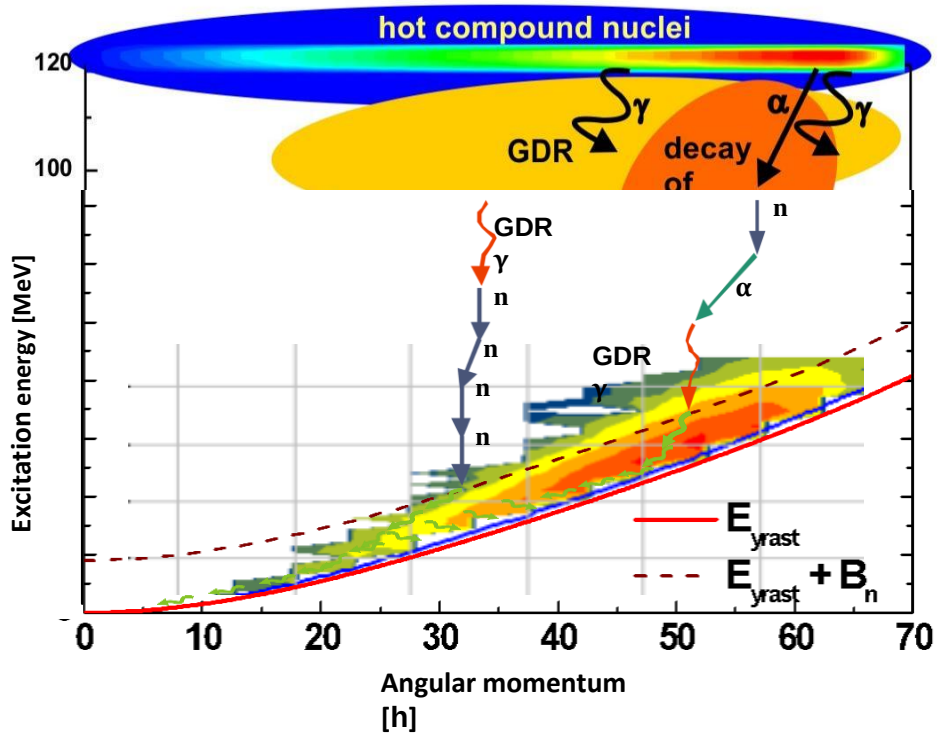
Good energy resolution for low and high energy γ-rays ~ 35 keV @ 1.332 MeV
Excellent Time resolution (below ~ 1 ns)
Large efficiency for high energy γ-rays

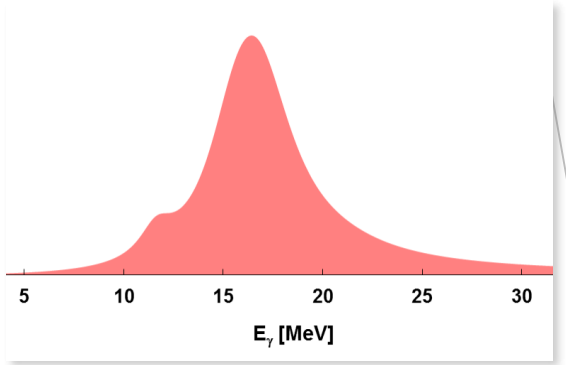
PARIS

nu – ball

“Feeding of low-energy structures of different deformations by the GDR decay: the nuBall array coupled to PARIS”

Link between deformation of hot compound nucleus and deformation of cold evaporation residue by the measurement of GDR decay of compound nucleus





- GDR high energy gamma rays
  - hot nucleus shape
- low energy transitions
  - deformation of excited residue

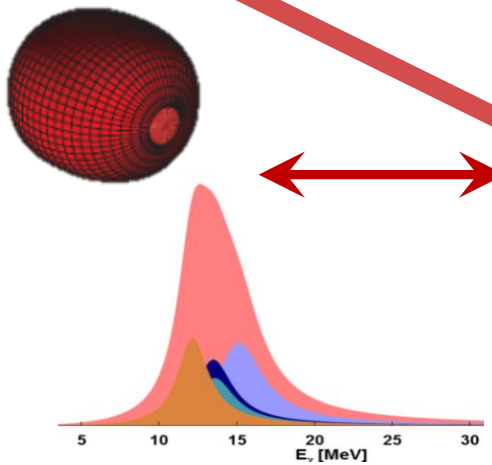
Choosing the particular decay path
by coincidence measurement of high and low-energy γ rays

The ^{192}Pt* decay to ^{188}Pt residue

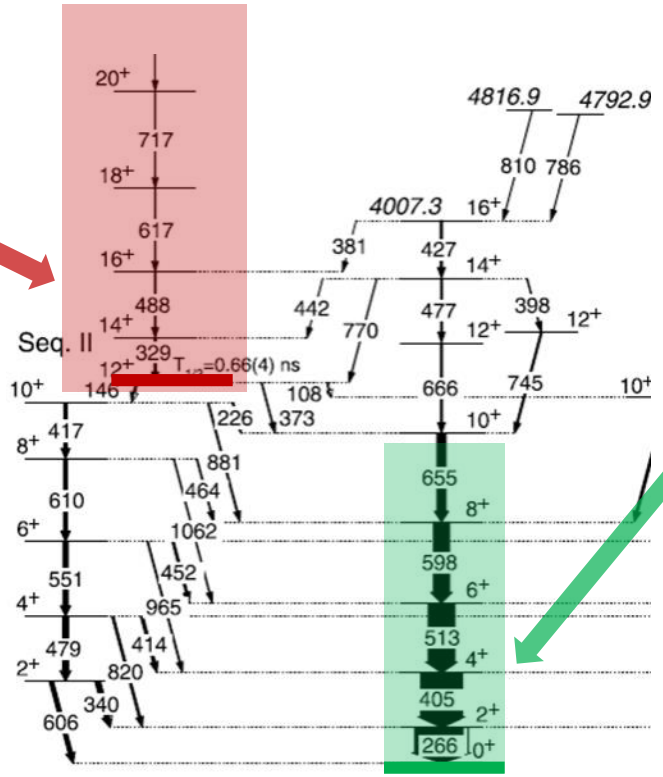
High-energy γ rays from ^{192}**Pt*** CN decay in **4n channel** in coincidence with low-energy transitions in ^{188}**Pt**

How the deformation changes along the decay path?

β=0.16 and γ=−40°
triaxial

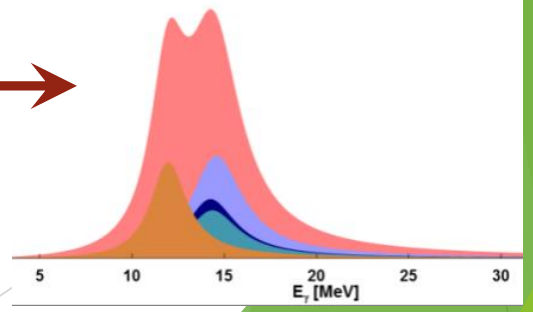


Gate on transitions



β =0.18 and γ=−6°
near prolate

GDR strength functions for CN decaying to particular states of ^{188}Pt

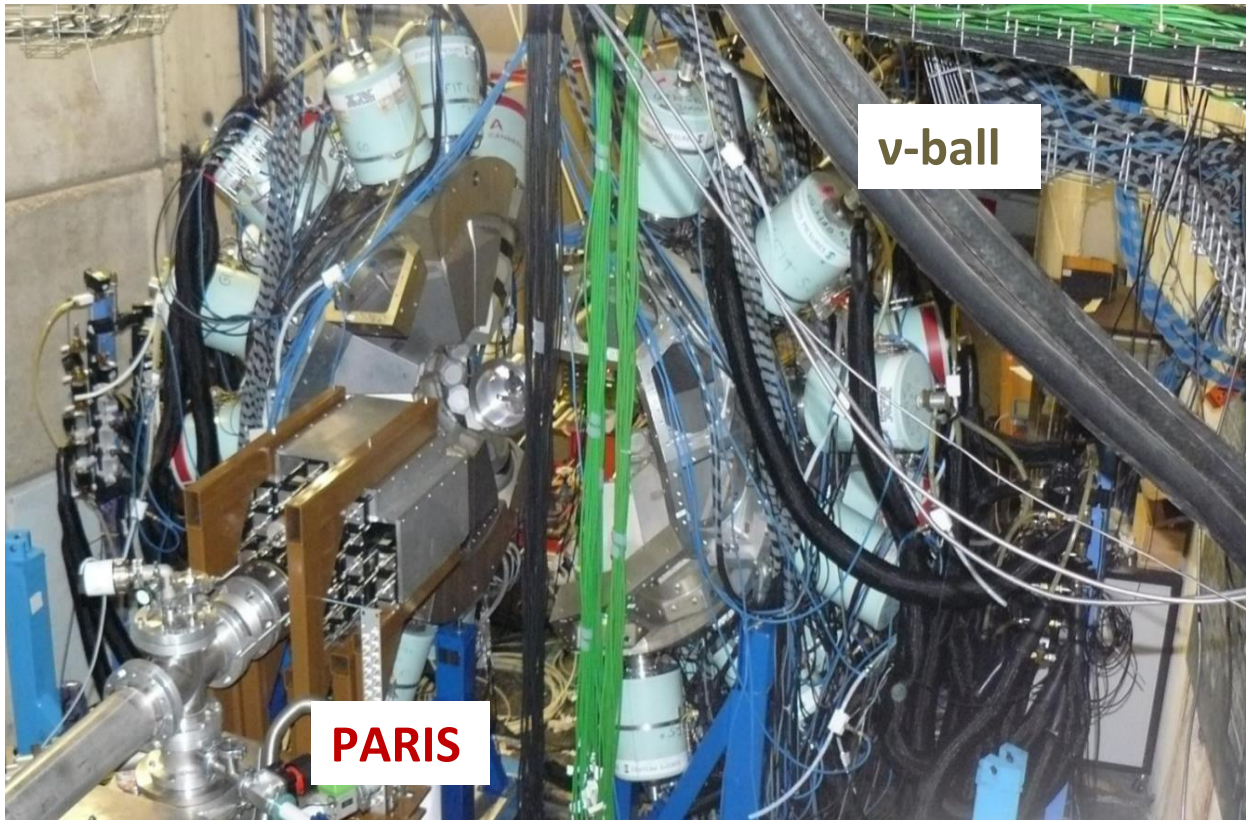


S. Mukhopadhyay et al., Phys. Lett. B 739, 462 (2014)

The nuBall + PARIS experiment at IPN / IJCLab

v-ball array: 33 Clovers +10 Coaxial HPGe
coupled to 33 **PARIS** detectors:
11 $CeBr_3$:NaI phoswiches,
22 $LaBr_3$:NaI phoswiches.

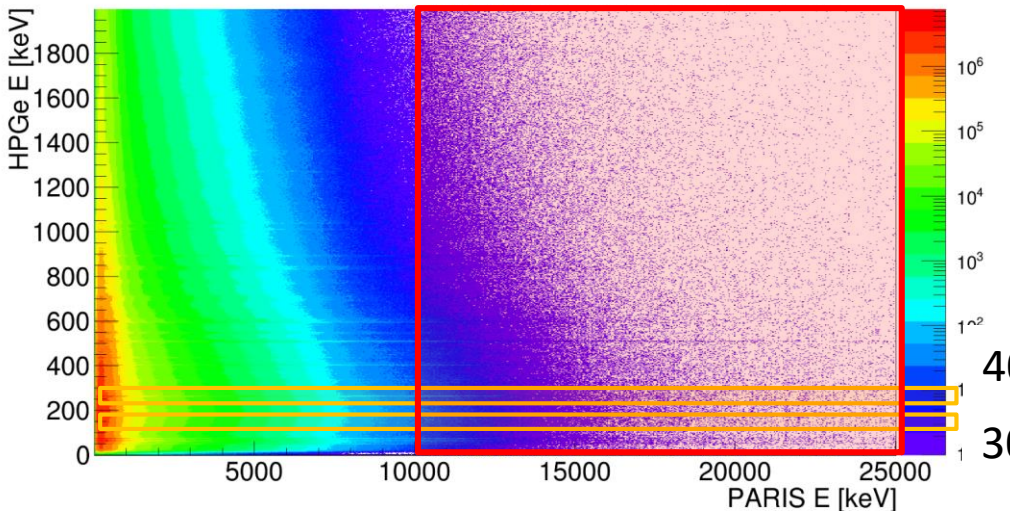
Triggerless DAQ by FASTER digitizer

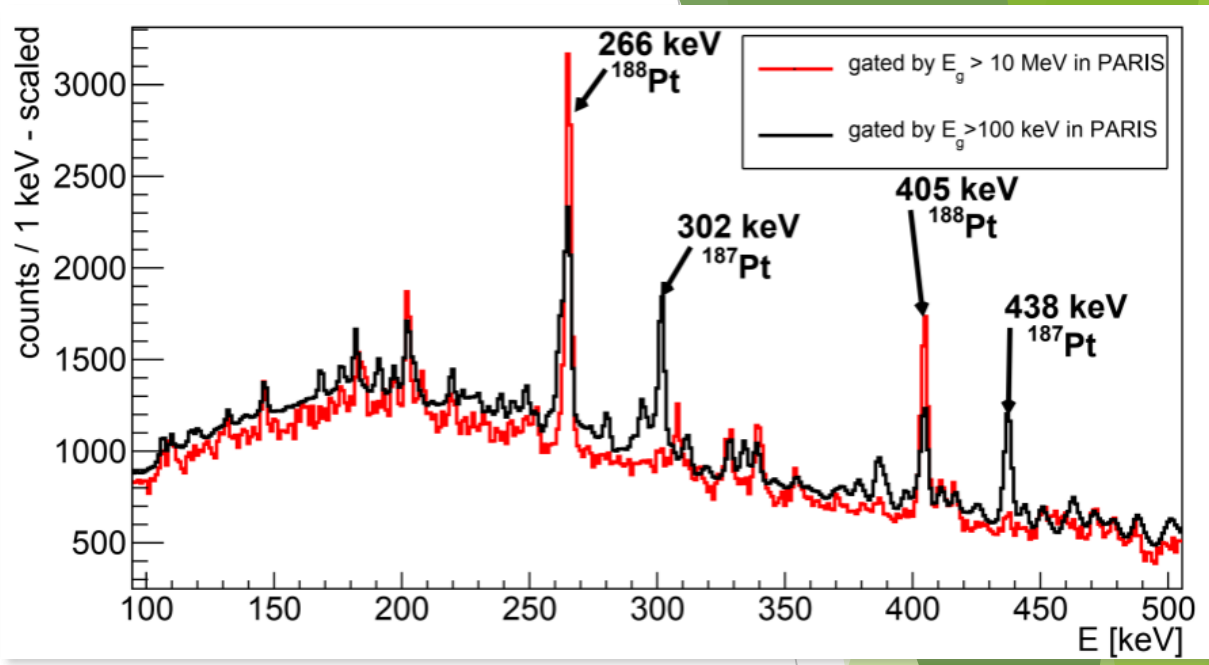


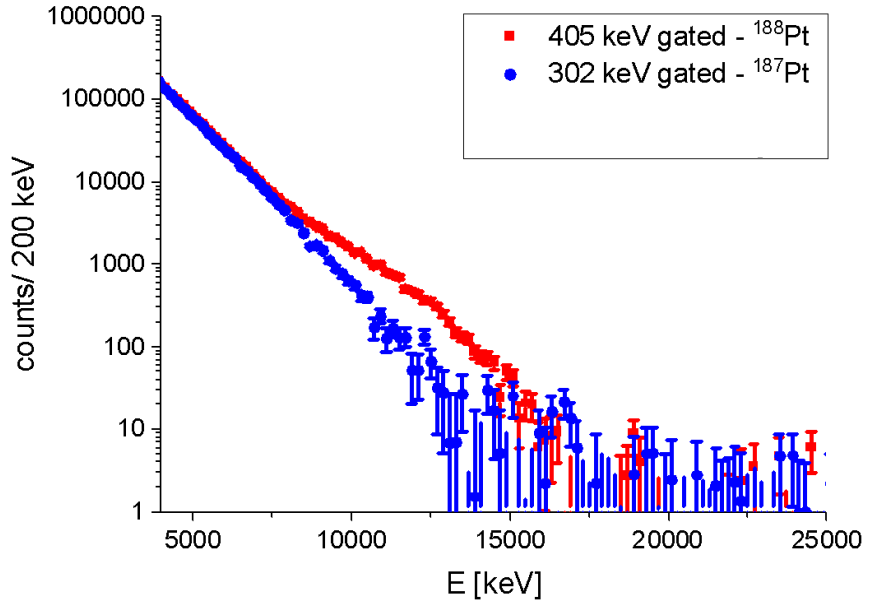
$^{18}O + {}^{174}Yb \rightarrow {}^{192}Pt$

- Beam energy: 90 MeV
- E* = 59 MeV
- T = 1.5 MeV
- L_{max} = 38 ħ
- Target thickness:
  1.5 mg/cm^2
- AmBe+Ni
  used for high energy
  callibration (up to 9 MeV)

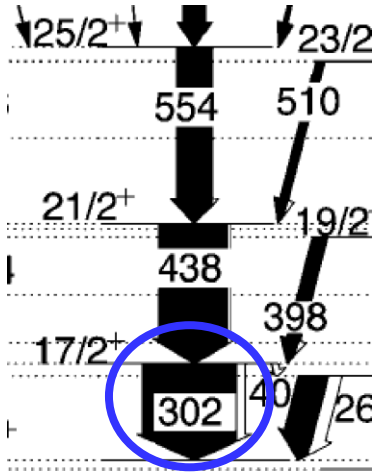
γ - γ HPGe vs PARIS

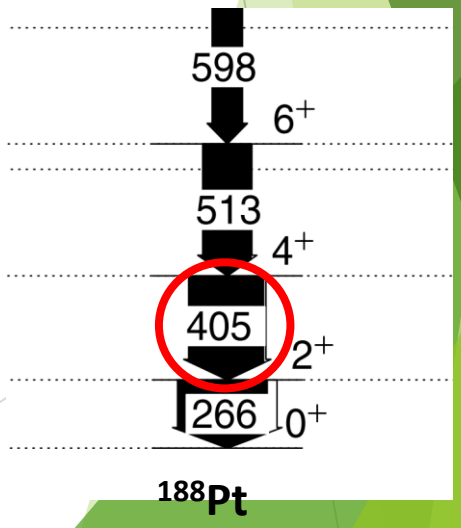




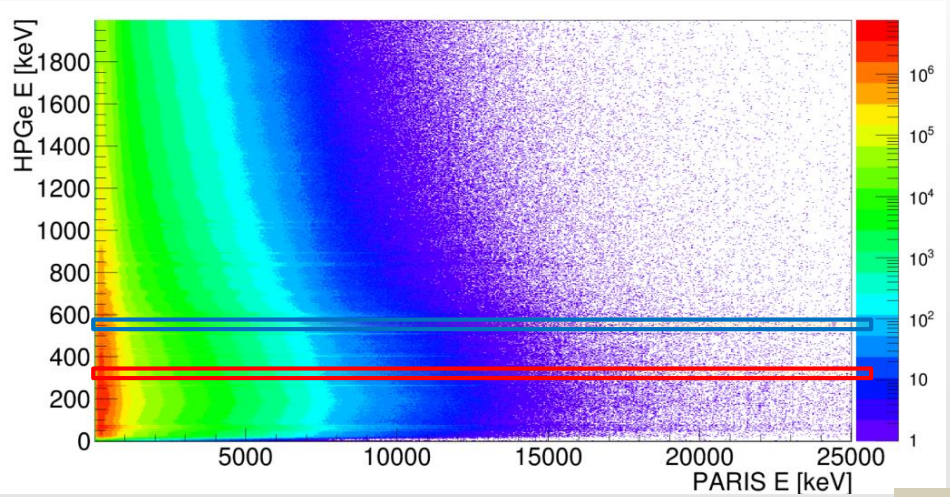


90 MeV ^{18}O + ^{174}Yb → ^{192}Pt



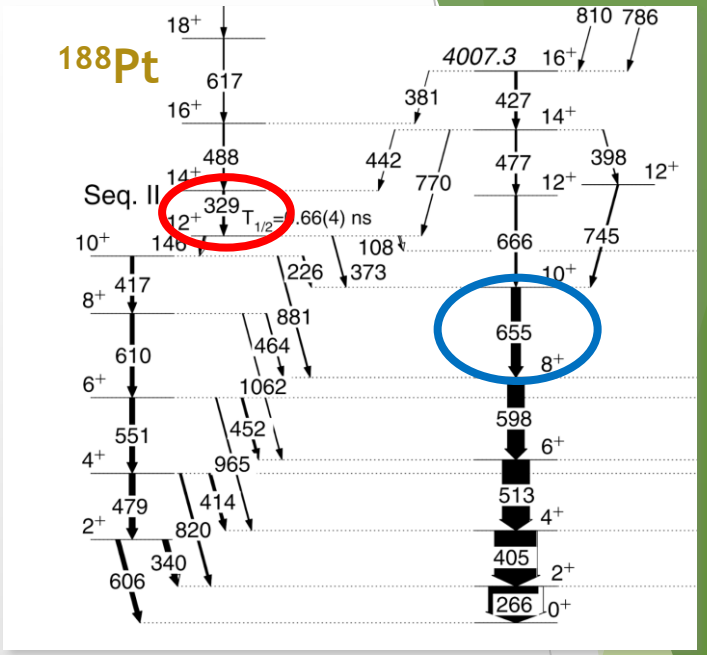


selection prolate / triaxial band

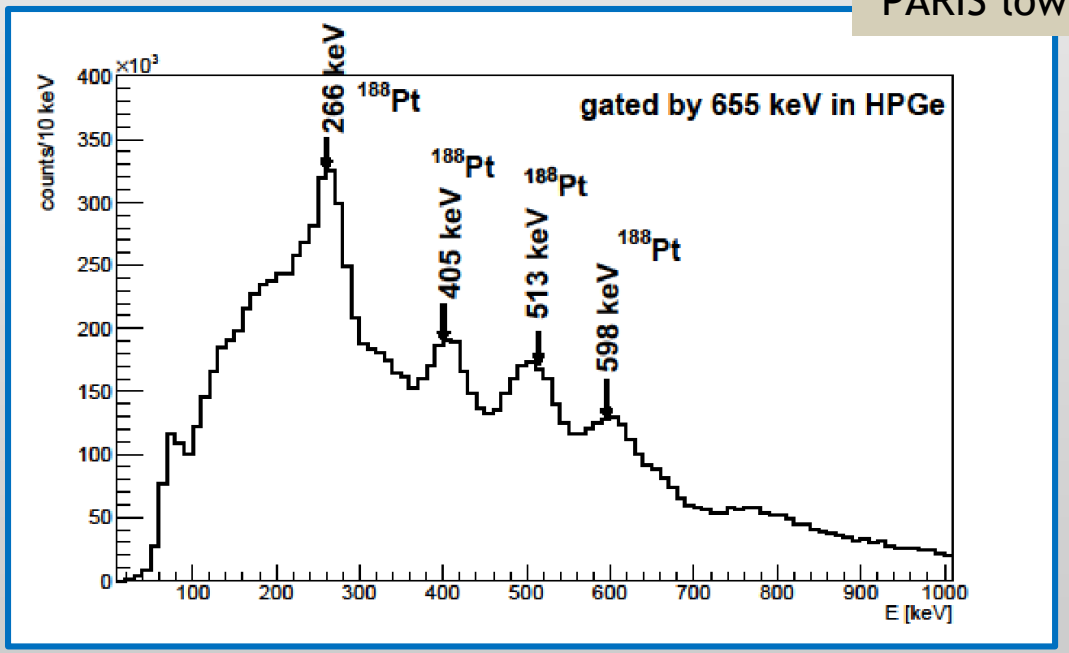


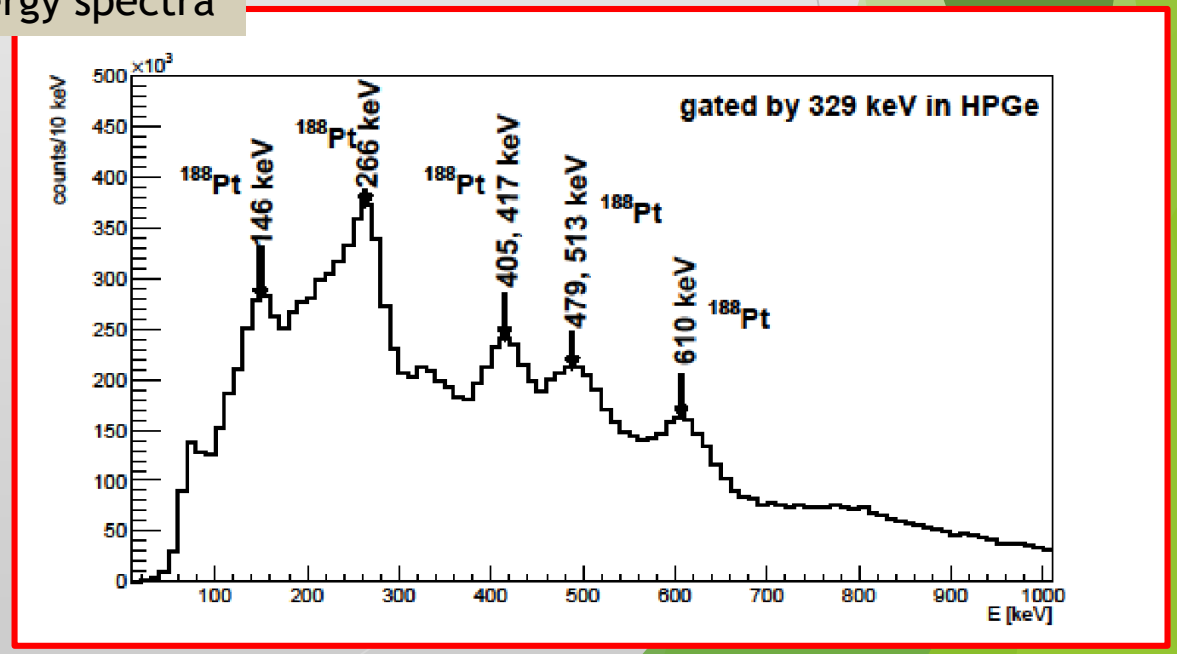
655 keV

329 keV

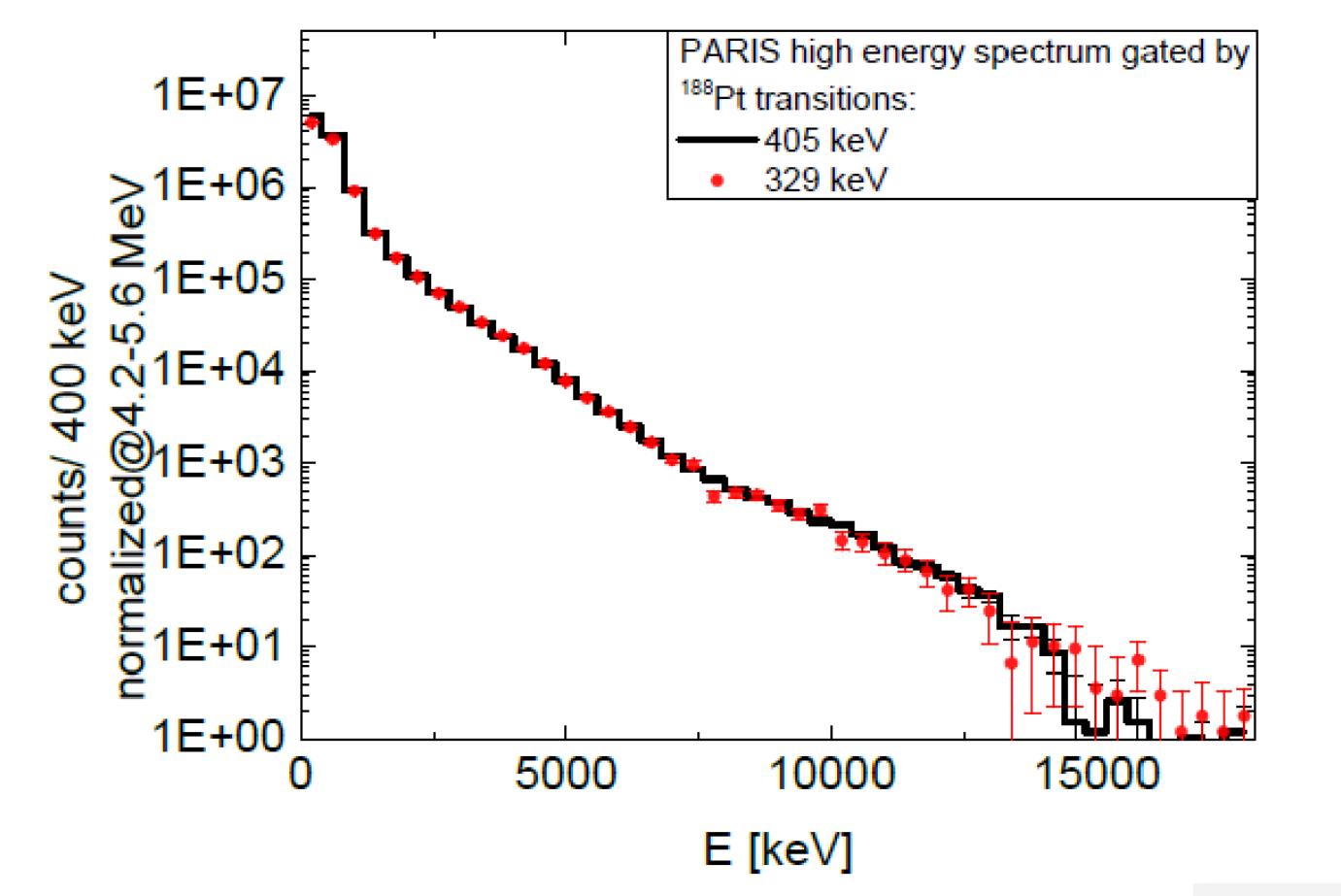


PARIS low energy spectra

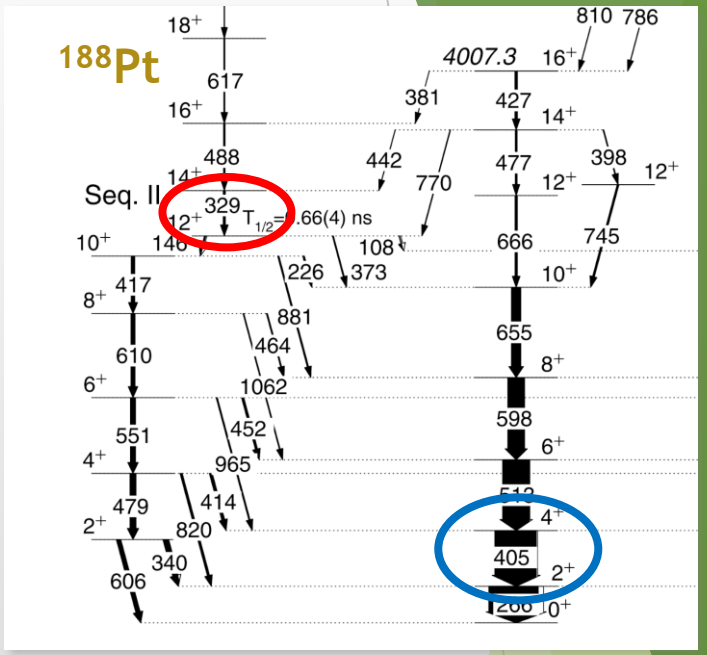




high-energy γ rays



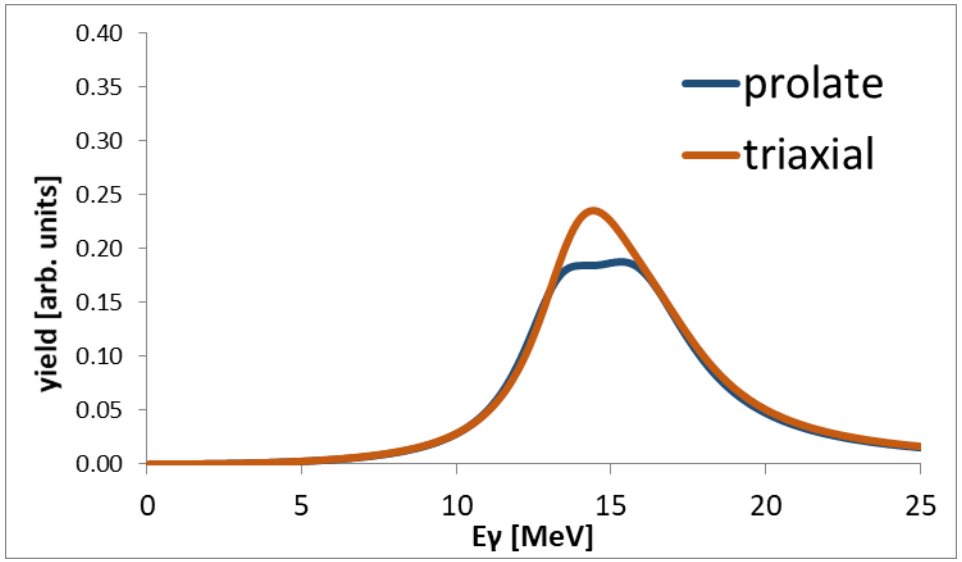
PARIS high energy spectra



GDR spectra from the CN decay to various residual states – very similar

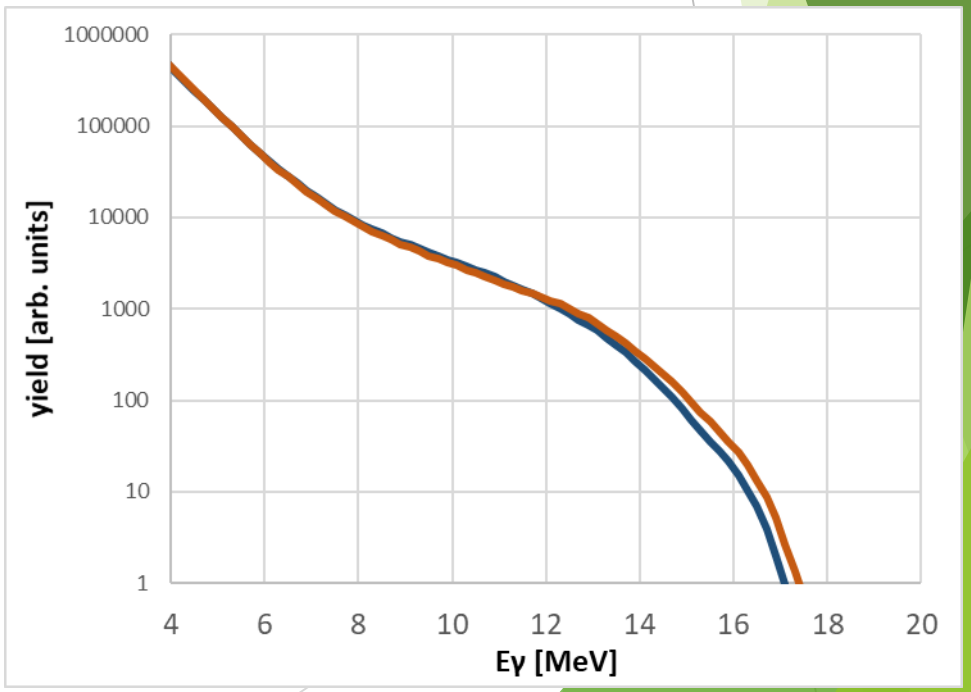
Analysis – Statistical model – GEMINI++

The GEMINI++ Monte Carlo statistical code by ***R.J. Charity, Phys. Rev. C82, 014610 (2010)***
with added GDR Decay ***M. Ciemała et al. Acta Phys. Pol. B44, 611 (2013)***
Used in the analysis by example in: ***M. Ciemala et al. Phys. Rev. C91, 054313 (2015)***

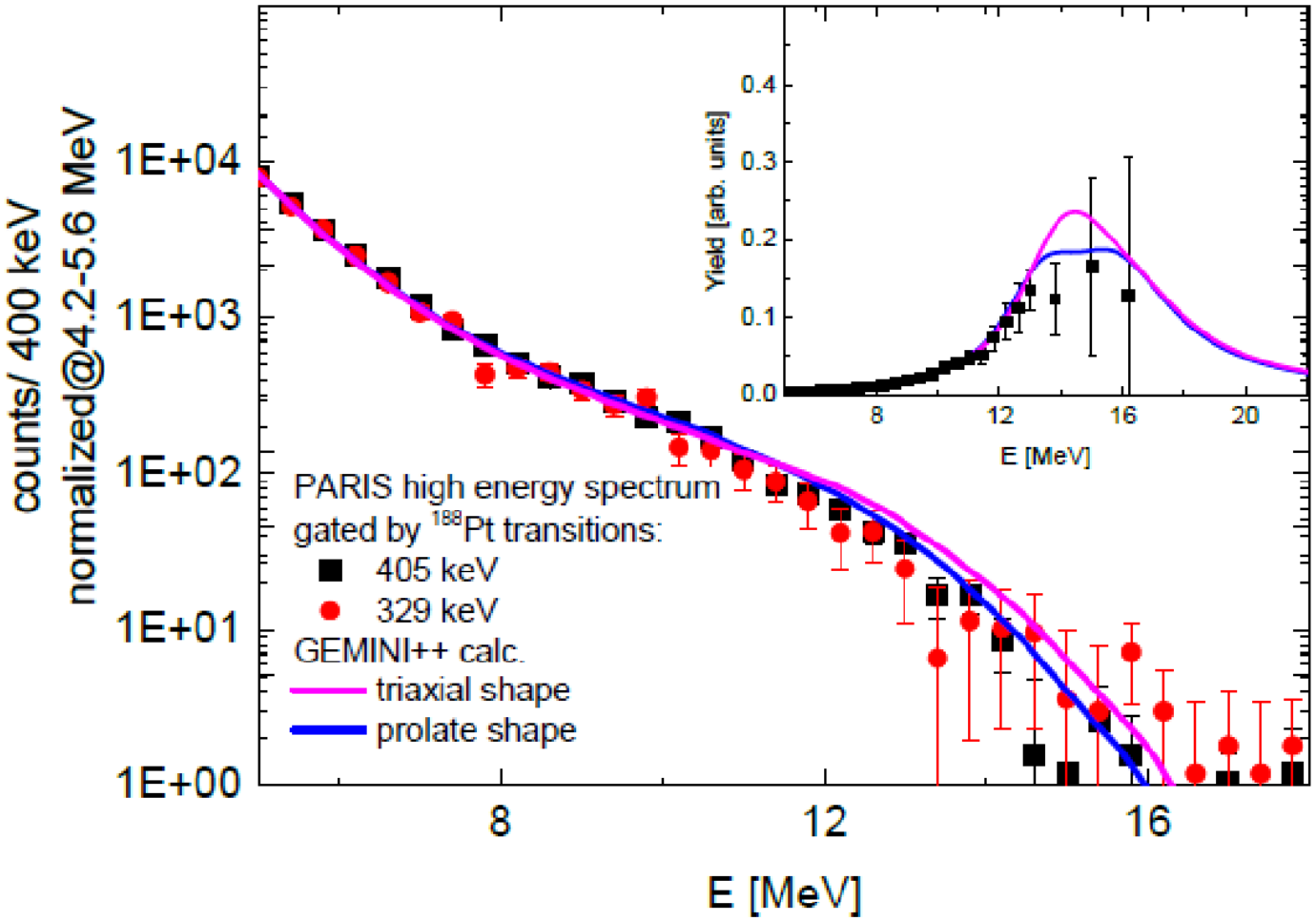


β=0.16 and γ=–40°
triaxial

β =0.18 and γ=–6°
near prolate



Comparison to statistical model



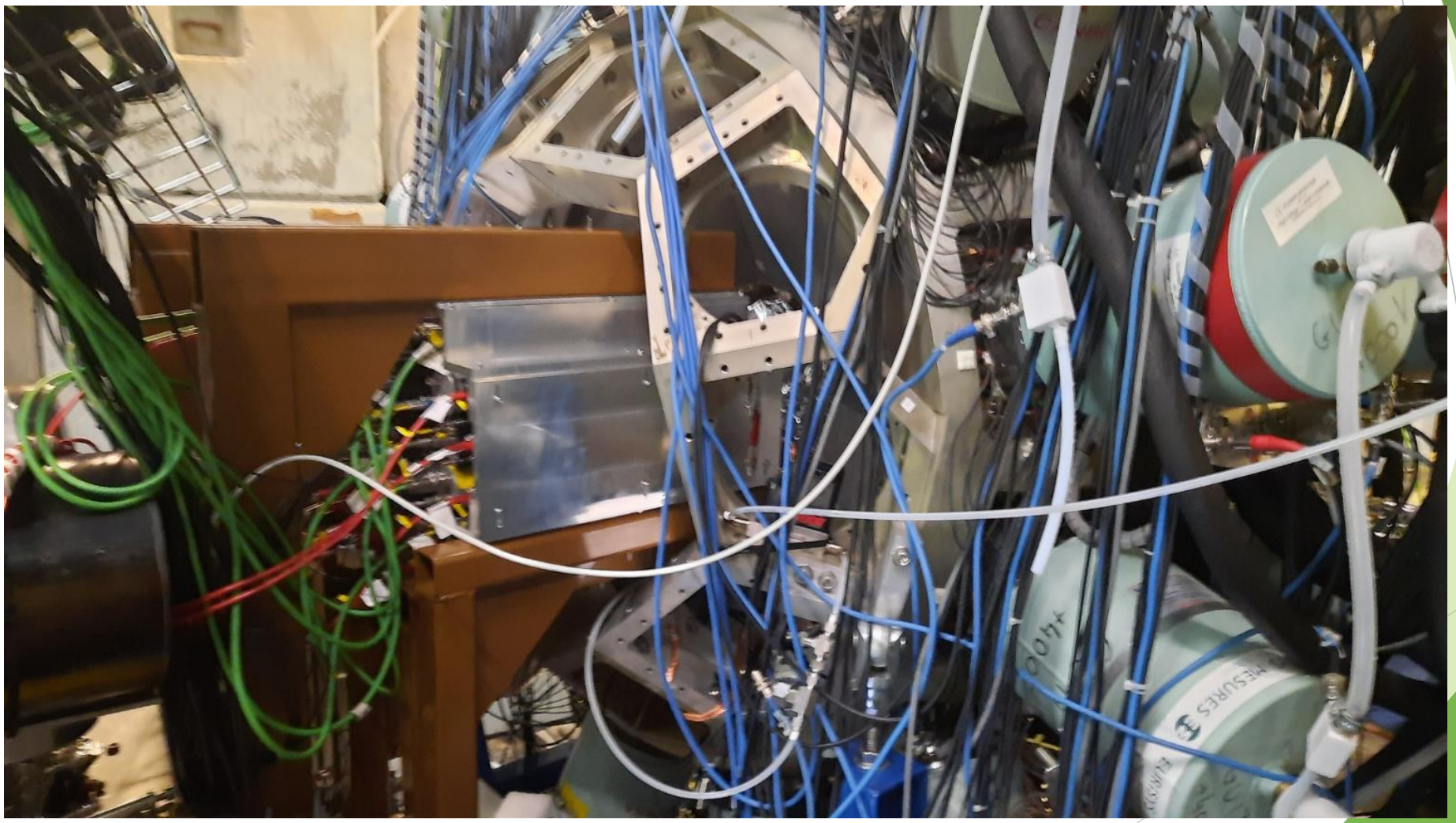
Better agreement to experimental data is seen for the calculations assuming prolate-like shape of the nucleus.

Suggestion that either:
the assignment of the triaxial deformation for 12+ isomer is wrong
or
the nucleus does not preserve the shape during the decay.

M. Ciemała et al., Acta Phys. Pol B Proc. Suppl. 16, 4-A3 (2023)

PARIS coupled to Nuball2

The PARIS + NuBall2 experiments
from November 2022 to June 2023



PARIS + NuBall2 experiments

- 2022 List of experiments:

N-SI-122, November 2022: M. Ciemała et al. “Links between ^{80}Sr compound nucleus’ shape and its residue’s deformation studied with the GDR”

- 2023 List of experiments:

N-SI-129, January 2023: J. Wilson et al. “Detailed spectroscopy of fission isomers in Uranium isotopes”

N-SI-131, January 2023: G. Pasqualato et al., “Evidence for enhanced collectivity in ^{58}Fe examined through Coulomb excitation”

N-SI-85, March/April 2023: P.J. Napiorkowski et al., „Coulomb excitation of super-deformed band in ^{40}Ca”

N-SI-125, March 2023: M. Lebois et al., “Neutron-gamma de-excitation of fission fragments level lifetimes in exotic neutron-rich nuclei “

N-SI-136, May 2023: J. Wilson et al. “Search for the fission shape isomer in ^{232}Th”

N-SI-128, June 2023: M. Matejska-Minda et al. „Investigation of high spin structures in ^{44}Ti and ^{42}Ca via discrete and continuum gamma spectroscopy”

N-SI-137, June 2023: K. Hadyńska-Klęk et al, “- Emergence of the collectivity near magic nuclei: Coulomb excitation of ^{62}Ni”

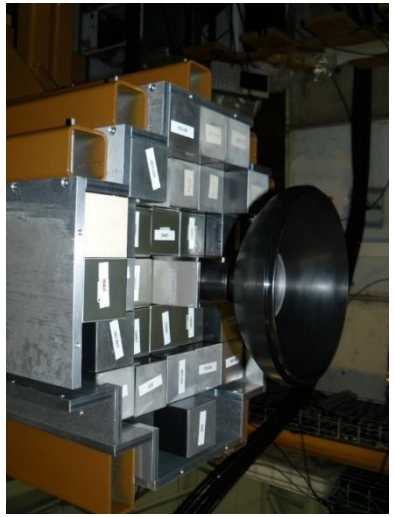
N-SI-122: Links between ^{80}Sr compound nucleus' shape and its residue's deformation studied with the GDR using Nu-Ball2+PARIS

Spokesperson: M.C.

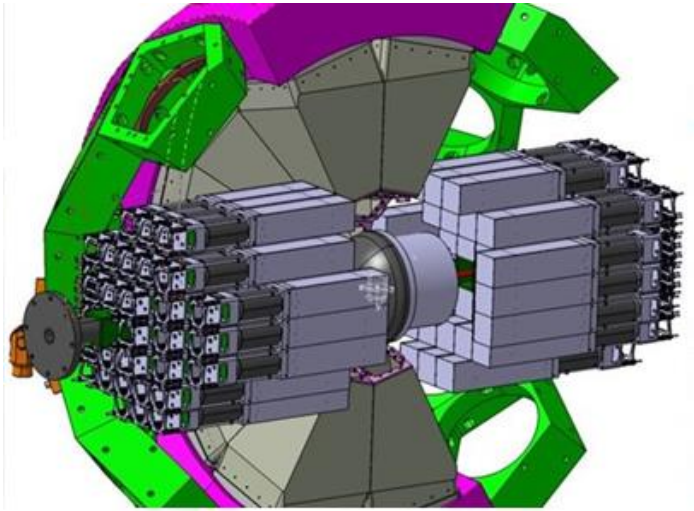
Study:

- links between deformation of hot compound nucleus ^{80}Sr and different deformation of the final state of the ^{76}Kr residues;
- population of states of different deformation fed by high-energy γ–rays from GDR decay.

By measurement of high-energy gamma rays from the GDR decay in hot **^{80}Sr** compound nucleus by **PARIS array** (in wall geometry) in coincidence with discrete gamma transitions in **^{76}Kr** evaporation residue by **nu-Ball2 array.**



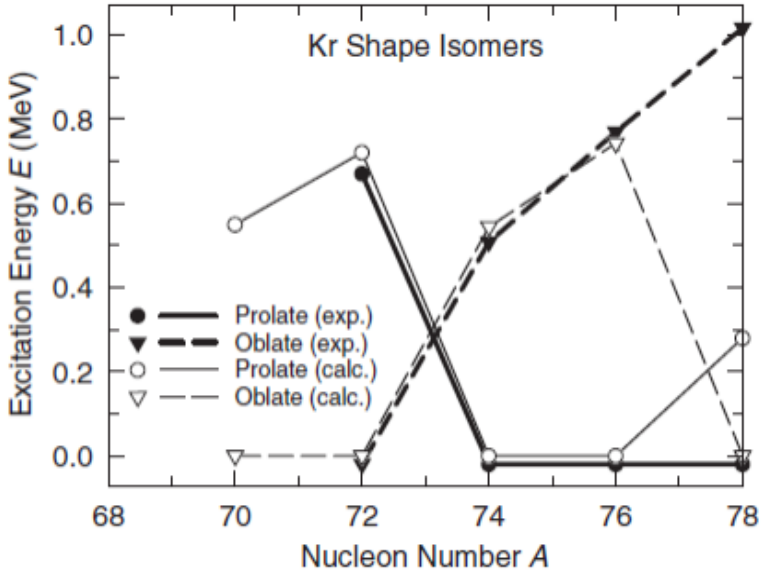
PARIS@Nu-Ball



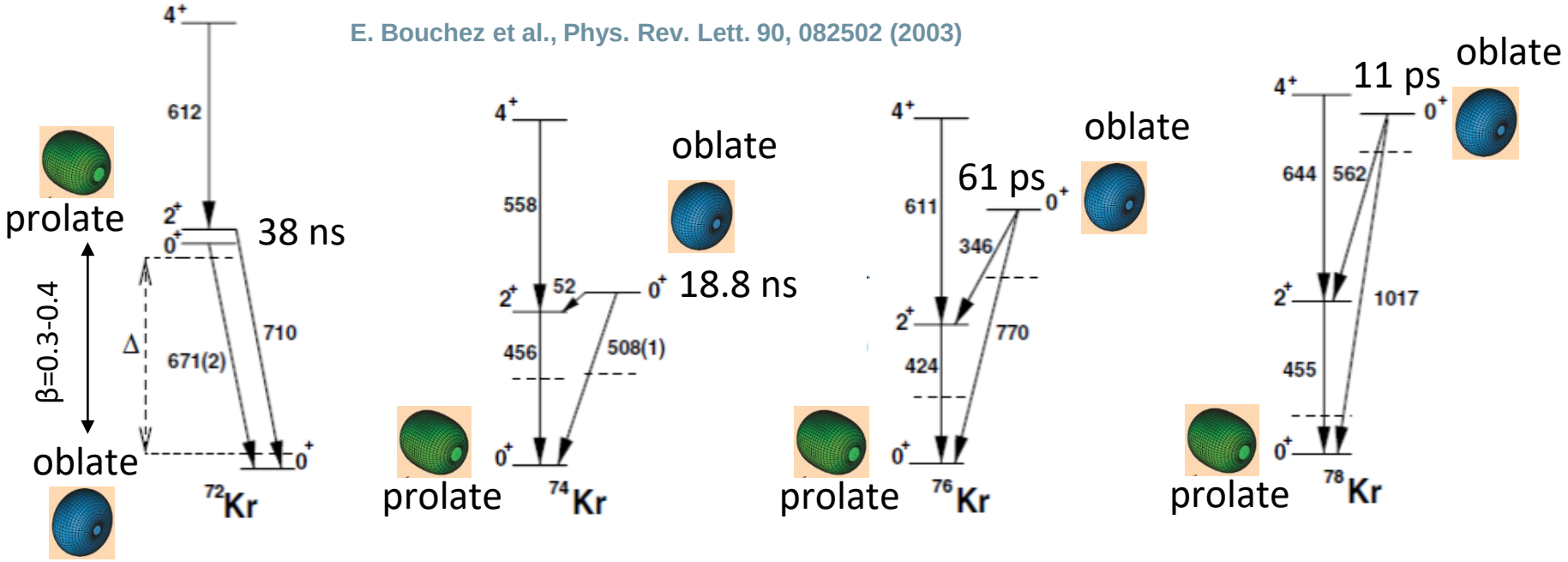
PARIS@Nu-Ball2

Shape coexistence $^{72\text{-}78}$Kr

P. Möller et al., Phys. Rev. Lett. 103, 212501 (2009)



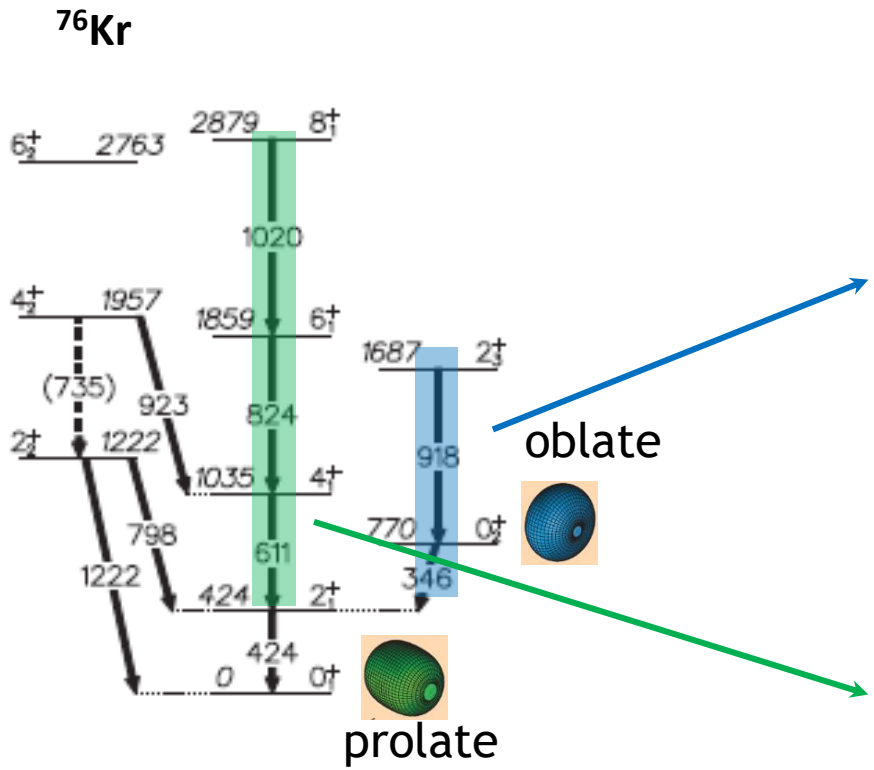
E. Bouchez et al., Phys. Rev. Lett. 90, 082502 (2003)



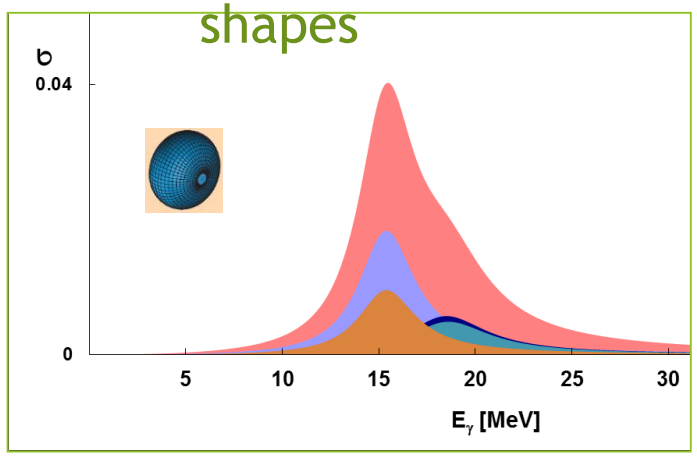
The GDR excited in ^{80}Sr CN

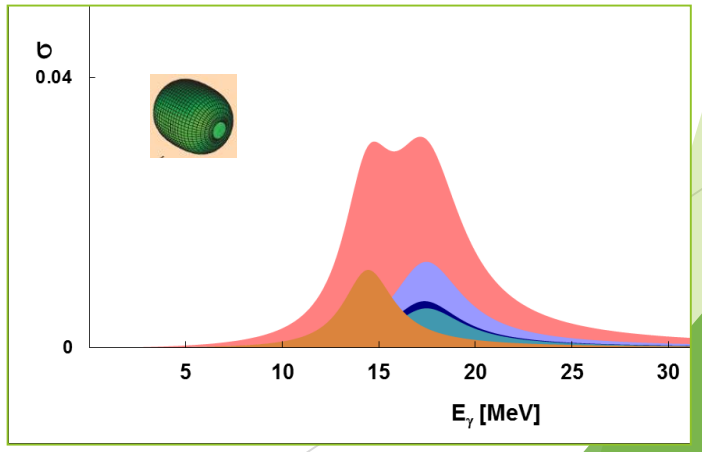
High-energy gamma rays from the GDR decay in hot ^{80}Sr compound nucleus measured in coincidence with discrete gamma transitions in ^{76}Kr evaporation residue

E. Clement et al., Phys. Rev. C 75, 054313 (2007)



GDR line-shapes





result: GDR strength → nuclear shape

The PARIS + NuBall2 experiment

Performed Nov 2022

Reaction:

^{16}O @ 95 MeV on $^{64}Zn \rightarrow {}^{80}Sr^{*} \rightarrow {}^{76}Kr$

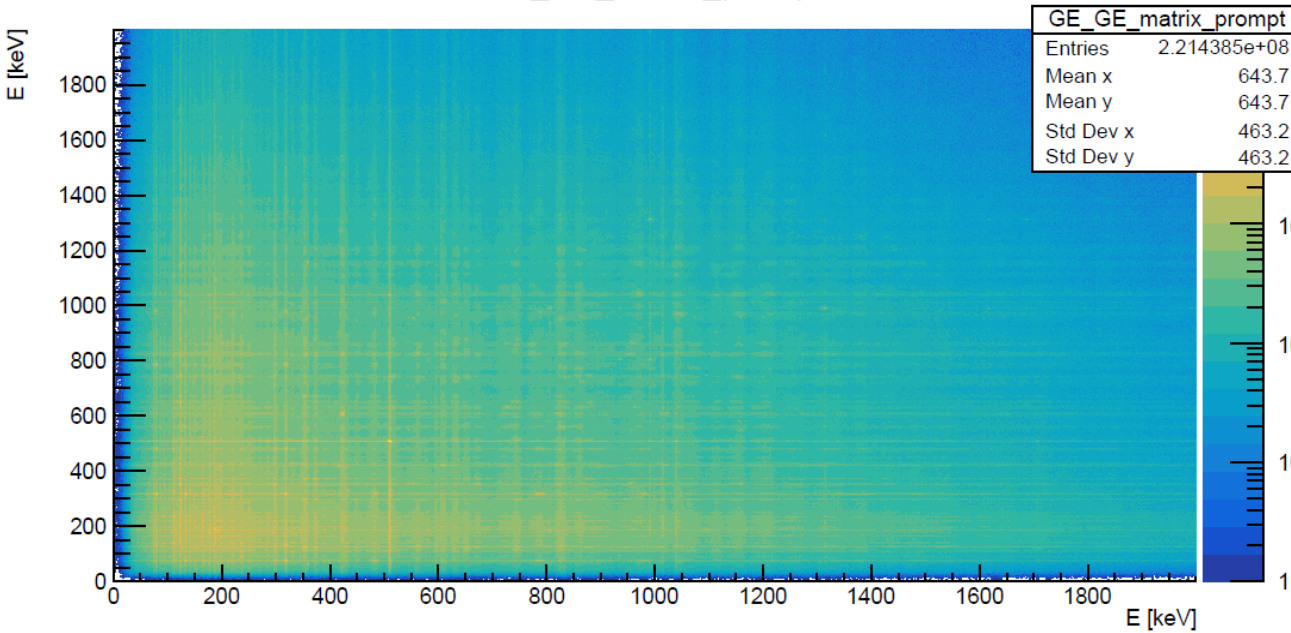
Setup:

- **nu-Ball2 array:** Ge detectors around 90 degrees, ~4.5% efficiency at 1MeV
- **2 × 36 PARIS phoswiches**
  3% (at 23 cm) efficiency for 15 MeV gamma rays

Measurement:

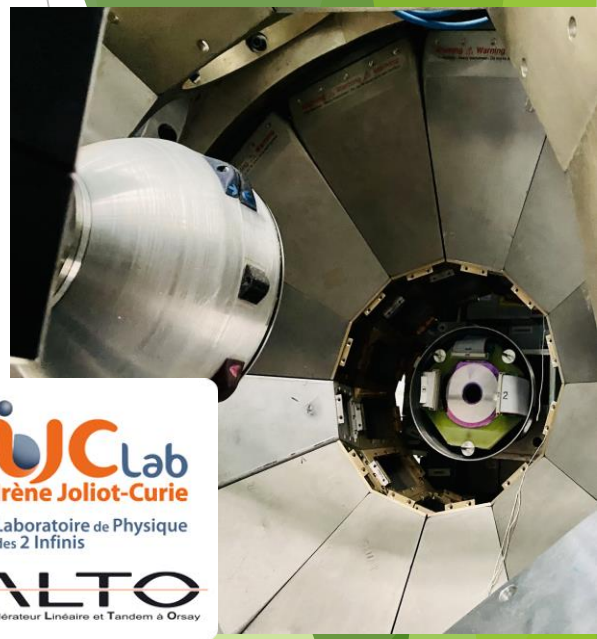
- high-energy gamma rays from the GDR Decay in hot ^{80}Sr compound nucleus by PARIS array (in wall geometry)
- discrete gamma transitions in ^{76}Kr evaporation residue by nu-Ball2 array
- Event-by-event FOLD – (PARIS and nu-Ball2)

GE_GE_matrix_prompt

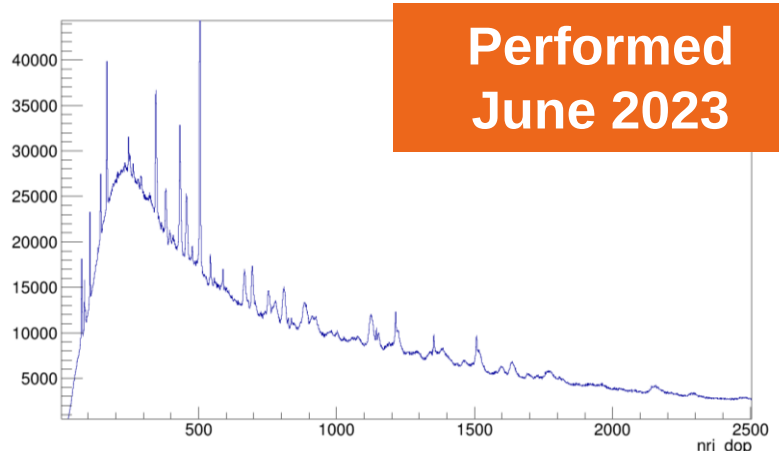


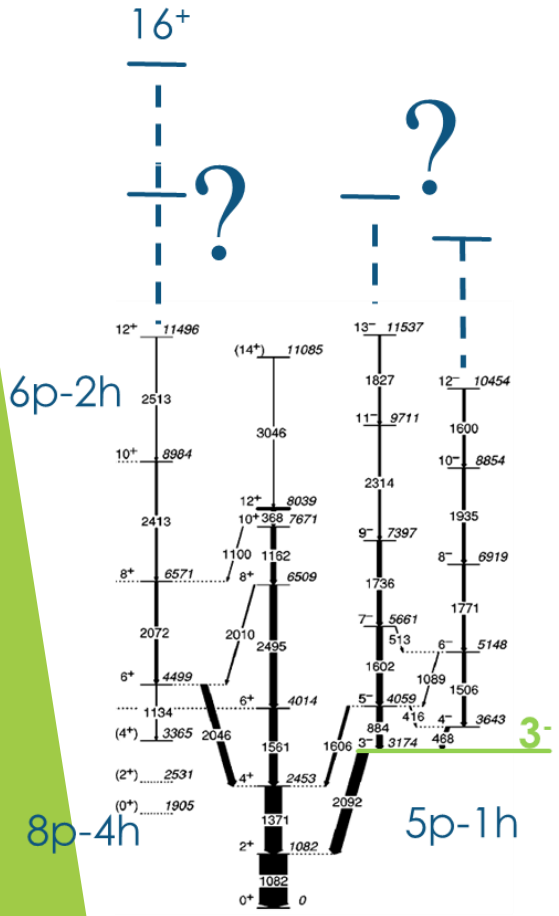
N-SI-128: Investigation of high spin structures in ^{44}Ti and ^{42}Ca via discrete and continuum gamma spectroscopy using Nu-Ball2+PARIS+Warsaw DSSD

Spokesperson: Magdalena Matejska-Minda

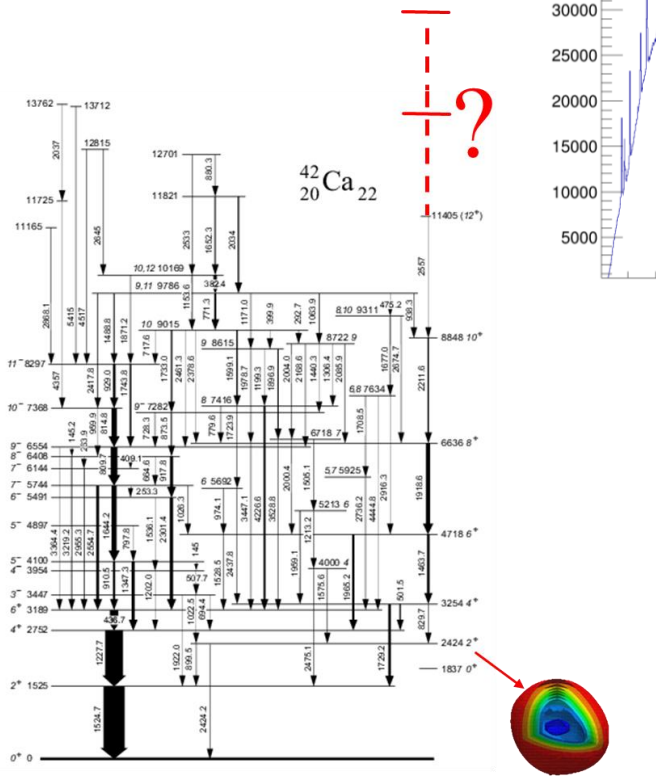


Performed June 2023





C.D. O'Leary et al., Phys. Rev. C **61**,064314 (2000).



M. Lach et al., Eur Phys J. A **16**, 309 (2003).

β_2=0.43(4), γ=13(+5,−6)°

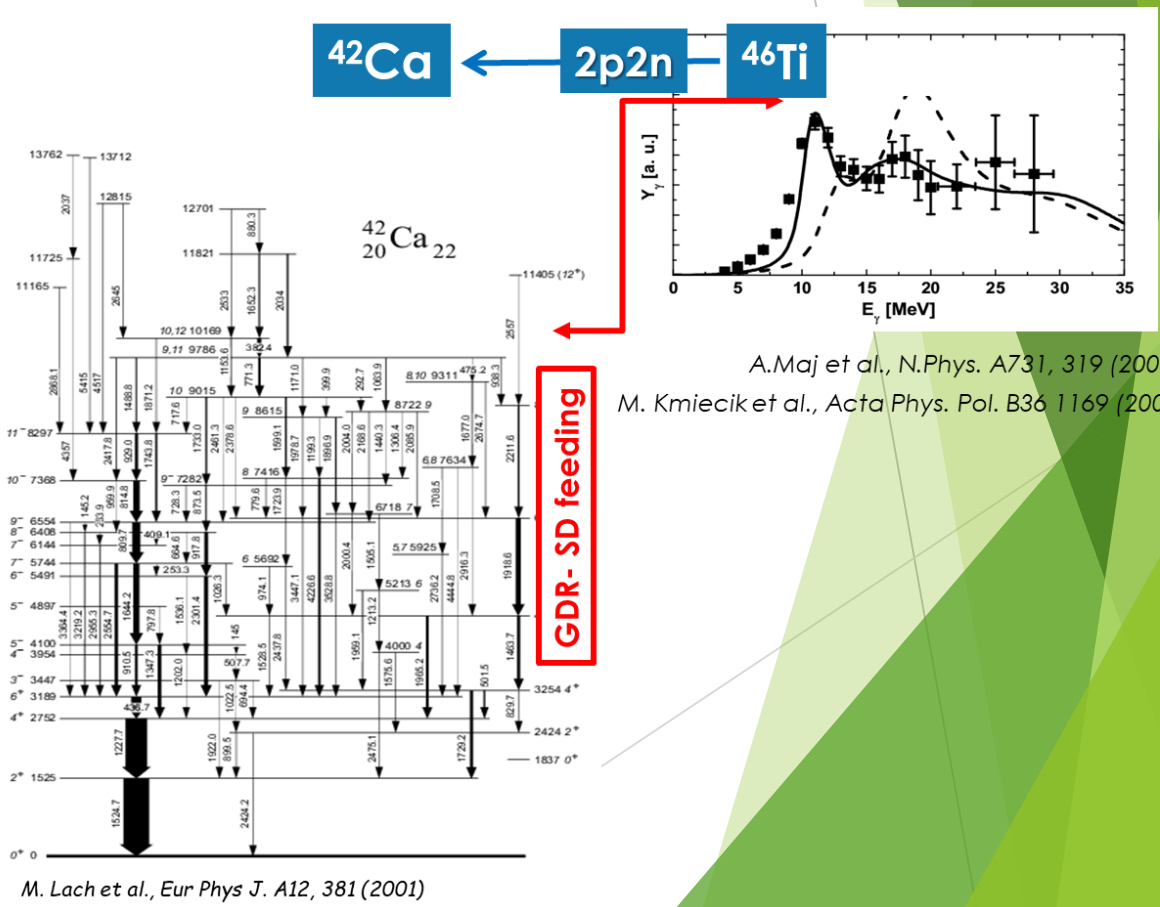
The aim of the measurement:

- Re-examine at high spins ^{42}Ca and ^{44}Ti, in order to **extend the known and unknown structures** up to or beyond the terminating states.
- Investigating discrete and high energy gamma rays – link between deformed states (resonances) in a hot CN and yrast SD in a cold ER **by coincident measurement of continuum and discrete gamma-rays**.

N-SI-128: Investigation of high spin structures in ^{44}Ti and ^{42}Ca via discrete and continuum gamma spectroscopy using Nu-Ball2+PARIS+Warsaw DSSD

Survival of large deformation of ^{46}Ti

- The low energy GDR component ~10MeV seems to feed preferentially the highly-deformed band in ^{42}Ca
- This suggest that very deformed shape of hot CN persist in the entire evaporation process
- Investigating discrete and high energy gamma rays – link between deformed states (resonances) in a hot CN and yrast SD in a cold ER



A.Maj et al., N.Phys. A731, 319 (2004)

M. Kmiecik et al., Acta Phys. Pol. B36 1169 (2005)

M. Lach et al., Eur Phys J. A12, 381 (2001)

Summary

- Travelling detector PARIS was coupled to Nuball1 (one experiment), and for longer campaign with Nuball2 eight experiments all at IJCLab.

- The PARIS + nuBall experiment aiming to measure γ-decay of GDR from hot CN (^{192}Pt) in coincidence with discrete transitions from residues (^{188}Pt).
- Both data sets: of GDR measured in coincidence with residues characterized by near prolate and triaxial show very similar behavior. Data analyzed using statistical model GEMINI++ code show better agreement for the calculations assuming prolate-like shape of the nucleus. This might suggest either that shape of the nucleus is not always preserved during the decay, or wrong experimental assignment of the tri axial deformation of the 12+ isomer.
- During Nuball2+PARIS campaign two related experiments were conducted. Study of shape evolution from hot ^{80}Sr compound nucleus to states of various deformation in ^{76}Kr evaporation residue and investigation of high spin structures in ^{44}Ti and ^{42}Ca via discrete and continuum gamma spectroscopy. Both providing datasets collected with more efficient experimental setup nuBall2+PARIS (with 72 PARIS detectors).

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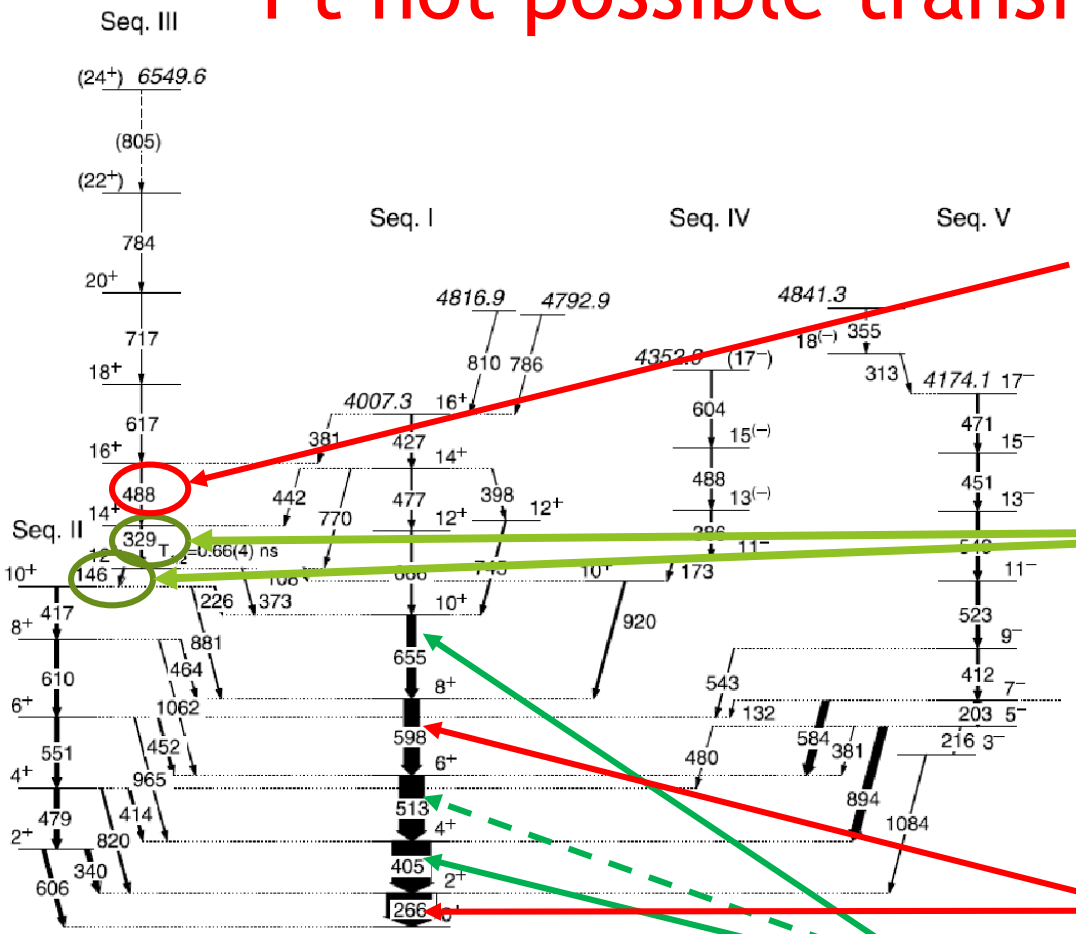
^{188}Pt possible transitions for gating

^{188}Pt not possible transitions for gating



Also 488 keV from Seq IV

Good candidates

Mixed ^{187}Pt and ^{188}Pt

Clean ^{188}Pt