# HISTARS: A High-Performance Detector for Nuclear Excited-State Lifetimes at HIE-ISOLDE

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IPARCOS

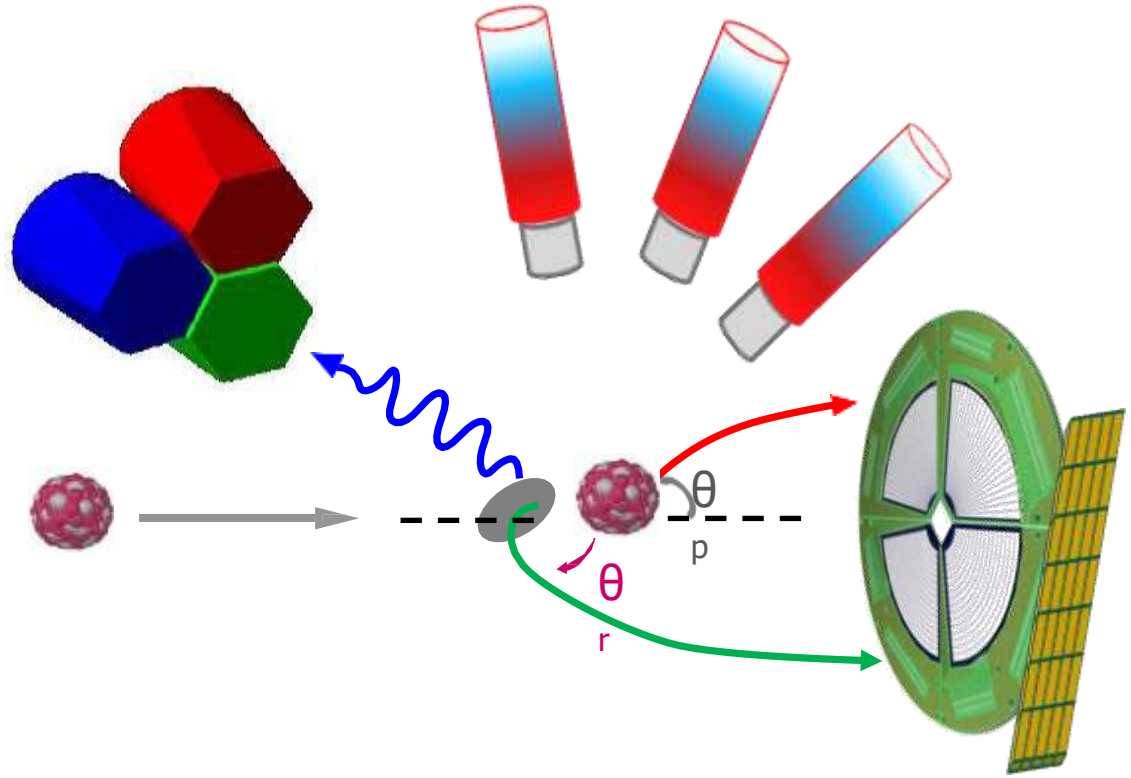
# HIE-ISOLDE Timing Array for Reaction Studies

Highly-sensitive detector for measuring the lifetimes of nuclear excited states populated in reactions at HIE-ISOLDE

Based on fast scintillators for the detection of both charged particles and gamma radiation with sufficient time response

Combine with existing instrumentation to achieve a performing hybrid array

Funded with nearly 1 M€ by the Spanish government for “new projects to be developed by Spanish research groups at CERN”



# Hybrid HPGe + $LaBr_3(Ce)$ arrays

**RoSPHERE array**
**at the Bucharest 9-MV tandem accelerator**

14 HPGe detectors with BGO shields arranged in 3 rings at 37º, 90º and 143º

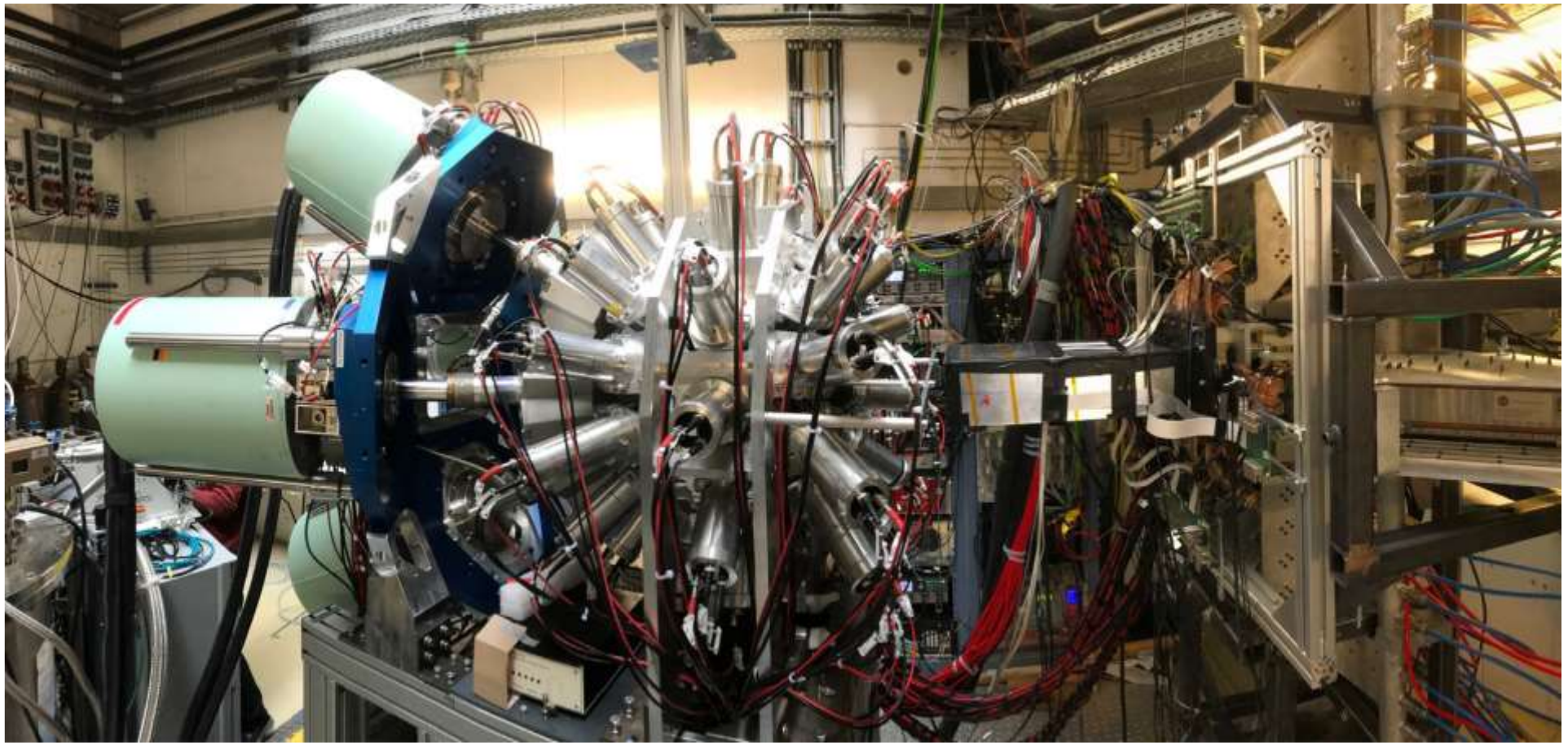
11 $LaBr_3(Ce)$ scintillation detectors at 70º, 90º and 110º

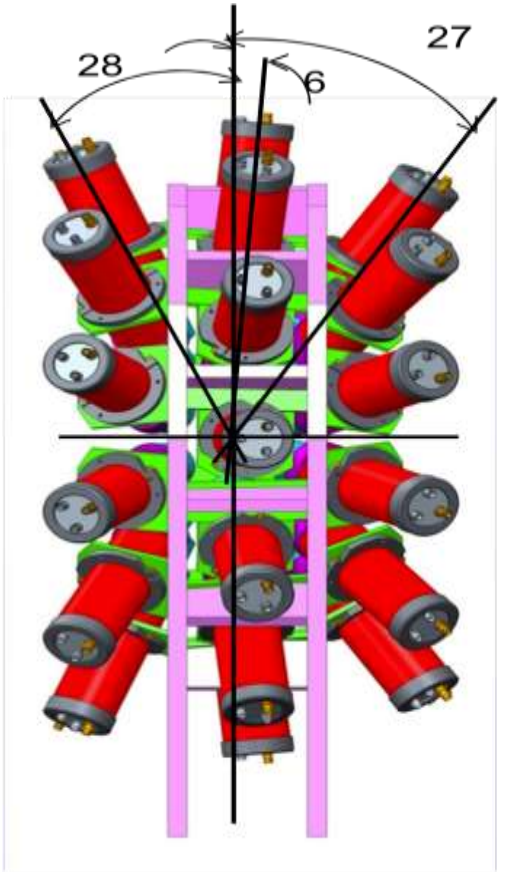
Fast timing measurements via $LaBr_3(Ce)$ γ-γ coincidences using a third γ in the HPGe

Absolute efficiency @ 1332 keV:
HPGe: 1.10(3)%
$LaBr_3(Ce)$: 1.75(5)%

# FATIMA + DESPEC at FAIR

## Coupling of 4 EUROBALL and 36 FATIMA UK detectors

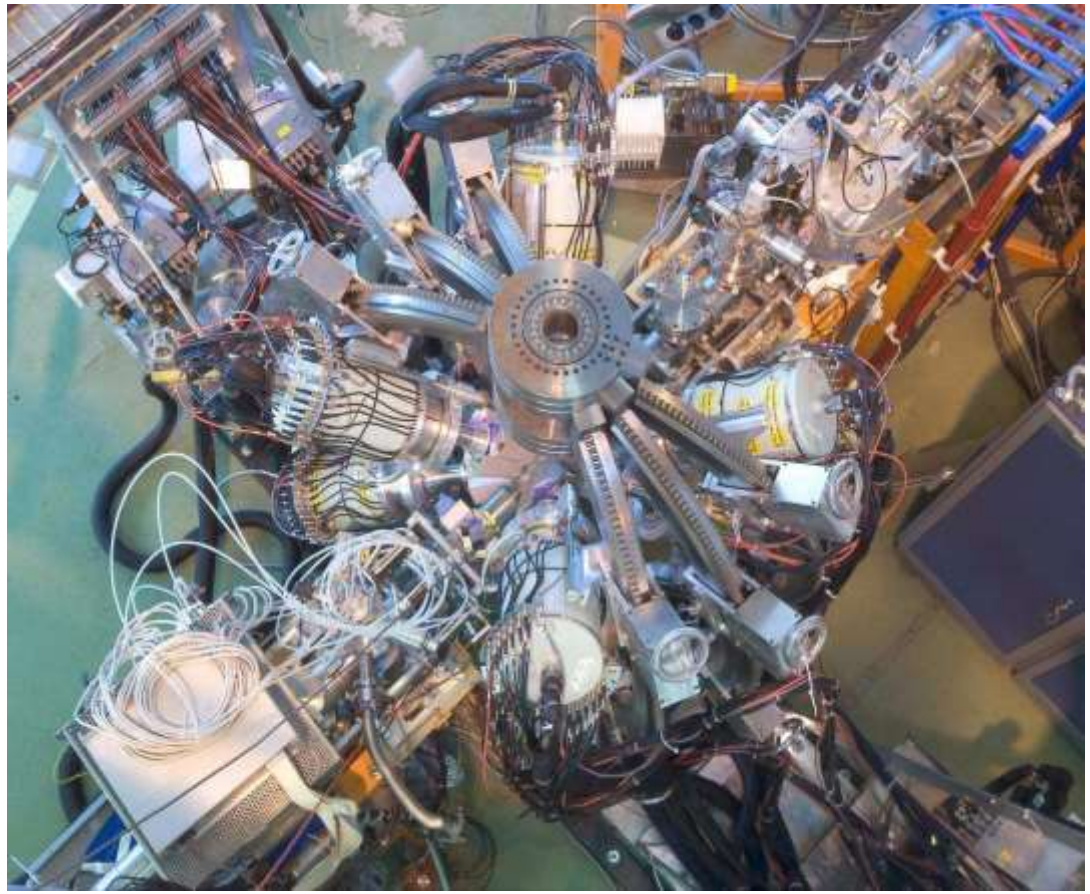





A.K. Mistry *et al.*, NIM A 1033 (2022) 166662

# HISTARS proposal for HIE-ISOLDE

Can low-energy reactions at HIE-ISOLDE be combined with fast timing measurements?



Coulomb excitation

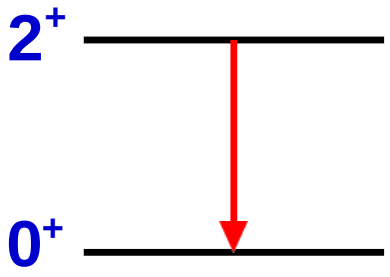
- Lifetimes (well) above 10 ps
- States in deformed nuclei
- Low-energy transitions
- Statistics

Transfer reactions

Other reactions

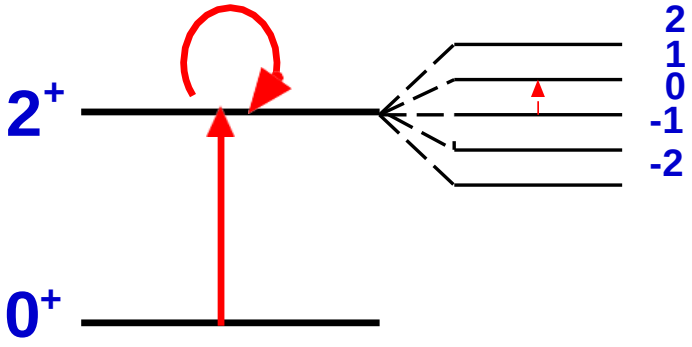
- Population of specific states: $0^+$, …

# Transition probabilities




$\langle 2^+ \,||\, E2 \,||\, 0^+ \rangle^2 \sim B(E2; 2^+ \rightarrow 0^+)$

$\langle 2^+ \,||\, E2 \,||\, 2^+ \rangle \sim Q_0$




Combining both provides information on quadrupole moments!

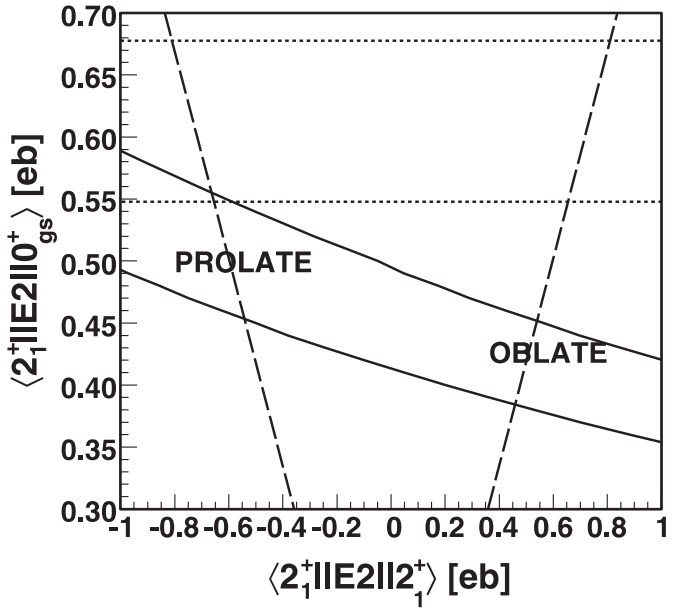
## Coulomb excitation

→ Investigate collective states

→ Coulex **cross sections** and angular distributions depend on quadrupole moments

## Lifetime measurements

→ Complementary measurements, provided by independent methods




J. Heese, Z. Phys. A – Atomic Nuclei 325, 45-53 (1986).

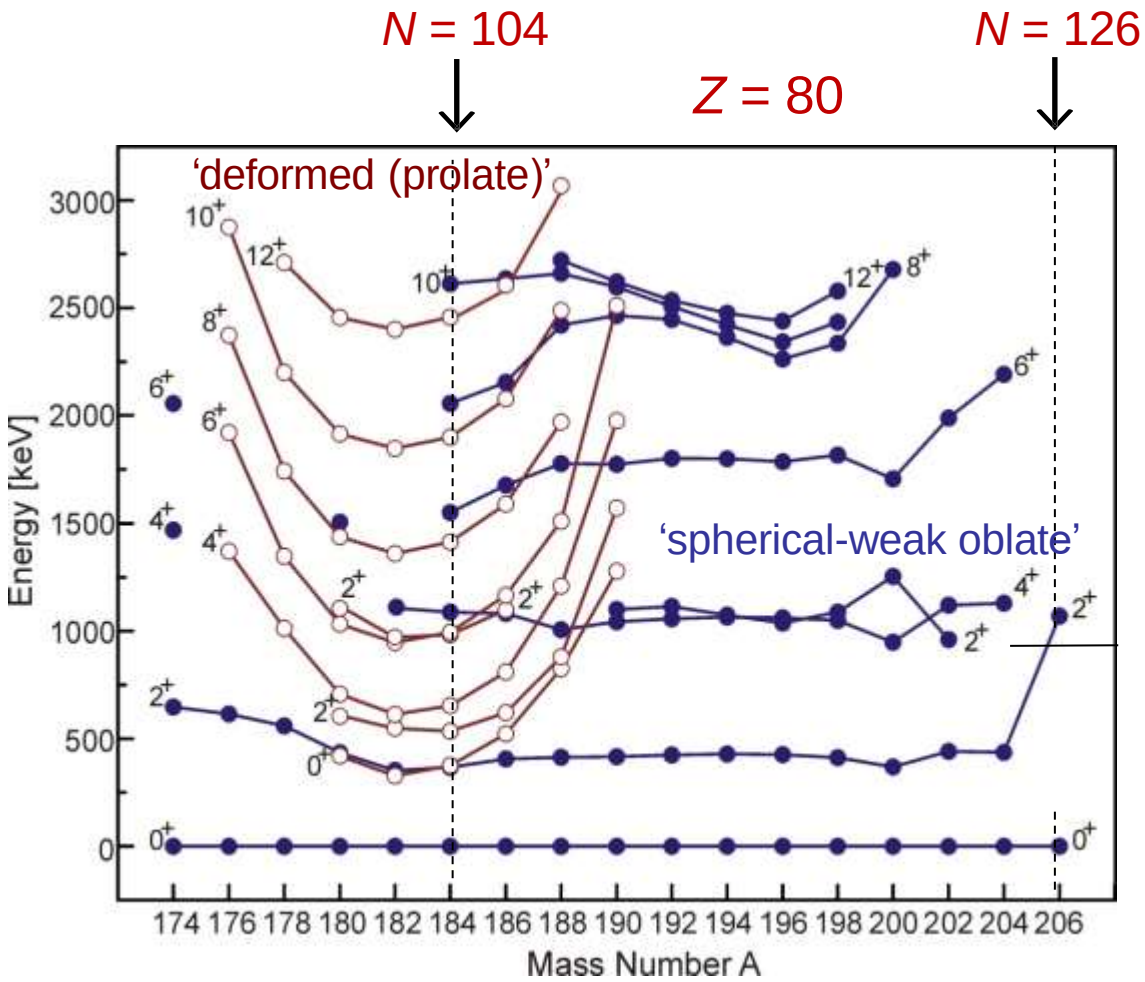
A.M. Hurst et al., PRL 98, 072501 (2007).

# Physics case for $^{182\text{-}188}$Hg

PRL 112, 162701 (2014) PHYSICAL REVIEW LETTERS week ending 25 APRIL 2014

**Shape Coexistence in the Neutron-Deficient Even-Even $^{182-188}$Hg Isotopes Studied via Coulomb Excitation**

N. Bree,[1] K. Wrzosek-Lipska,[1,2,*] A. Petts,[3] A. Andreyev,[1,4] B. Bastin,[1,5] M. Bender,[6,7] A. Blazhev,[8] B. Bruyneel,[8]

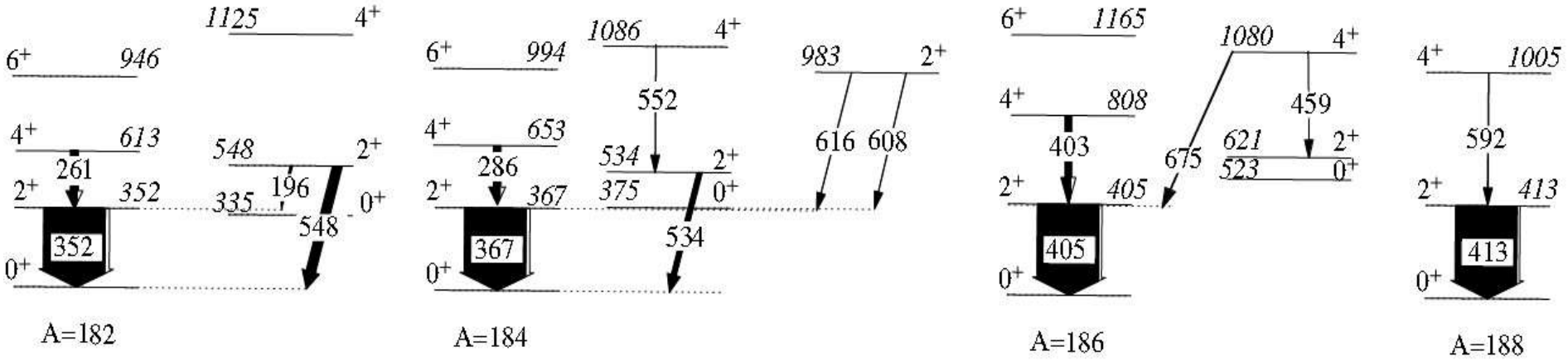


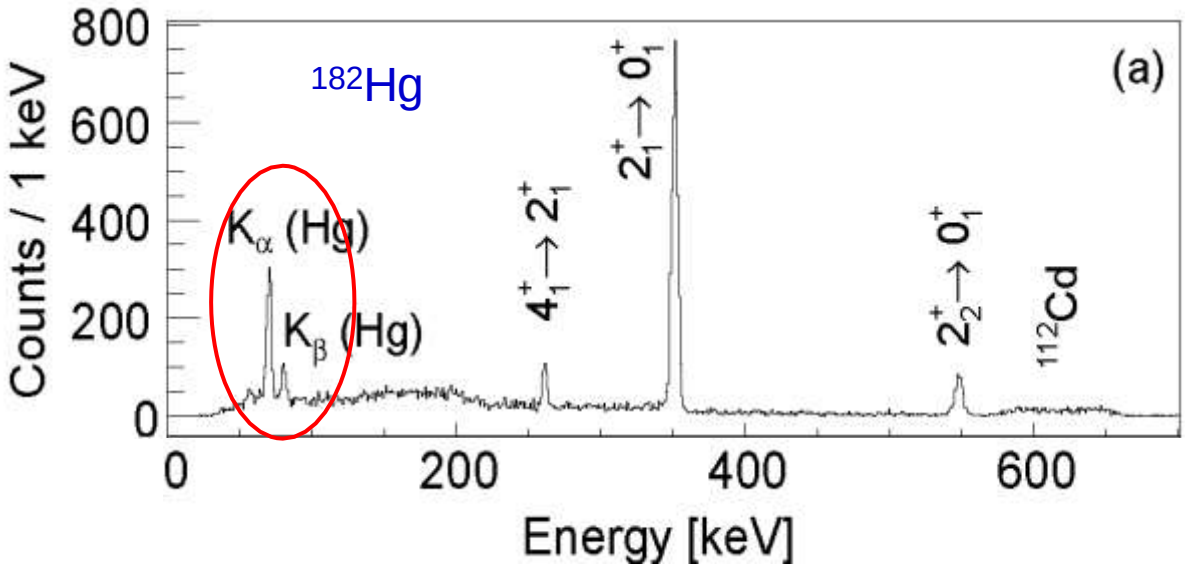

Constant in *oblate* ground state band

*Prolate* excited band reaches minimum around $A$ = 182, 184

With shell closures at $N$ = 82 and $N$ = 126, highest interaction is expected at $N$ = ~104

# IS742 Coulex of $^{182\text{-}188}$Hg at ISOLDE




## Analysis requirements

→ Conversion coefficients

→ Branching ratios

→ Lifetimes ☺

# Lifetime measurements

T. Grahn *et al.*, PRC 80, 014324 (2009).

M. Scheck *et al.*, PRC 81, 014310 (2010).

| $E_i$ [keV] | $E_f$ [keV] | $E_\gamma$ [keV] | $J_i^\pi$ | $J_f^\pi$ | $I_{\gamma,\mathrm{rel}}$ | $\tau$ [ps] | $B(E2)$ [W.u.] | $\lvert Q_t\rvert$ [e b] | $\lvert D_t\rvert$ [$10^{-3}$ e $b^{1/2}$] | $\lvert\beta_2^t\rvert$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 351.8 | 0 | 351.8 | $2^+$ | $0^+$ | 100 | 42.1(23) | 55(3) | 4.1(2) | | 0.15(1) |
| 613.2 | 351.8 | 261.4 | $4^+$ | $2^+$ | 100 | 37.1(11) | 253.1(75) | 7.4(2) | | 0.26(1) |
| 946.3 | 613.2 | 333.1 | $6^+$ | $4^+$ | 100 | 9.1(9) | 331(33) | 8.0(8) | | 0.29(3) |
| 1360.3 | 946.3 | 413.7 | $8^+$ | $6^+$ | 100 | 2.8(3) | 375(40) | 8.4(9) | | 0.30(3) |
| 1847.7 | 1360.3 | 487.4 | $10^+$ | $8^+$ | 100 | 1.44(32) | 327(73) | 7.7(11) | | 0.28(6) |

L. P. Gaffney *et al.*, PRC 89, 024307 (2014).

| | $I^\pi$ ($\hbar$) | $E_\gamma$ (keV) | b.f. | $\tau_{\mathrm{av}}$ (ps) | $\tau_{\mathrm{prev}}$ (ps) | $B(E2)\downarrow$ (W.u.) | $\lvert Q_t\rvert$ ($e$ b) |
|---|---|---|---|---|---|---|---|
| $^{184}$Hg | $2_1^+$ | 366.8 | 1 | 35.7(15) | 30(7) | 52(2) | 4.04(8) |
| | $4_1^+$ | 287.0 | 0.959(4) | 30.2(10) | 32.8(34) | 191(6) | 6.46(11) |
| | $6_1^+$ | 340.1 | 1 | 8.7(4) | 8.1(31) | 308(15) | 7.81(19) |
| | $8_1^+$ | 418.3 | 1 | 3.19(14) | $2.9^{+1.1}_{-1.6}$ | 309(13) | 7.65(17) |
| | $9_3$ | 329.1 | 0.65(16) | 12.1(8) | | 169(40) | 5.6(7) |
| $^{186}$Hg | $2_1^+$ | 405.3 | 1 | 24(3) | 26(4) | 47(6) | 3.9(2) |
| | $4_1^+$ | 402.7 | 0.93(2) | 5.6(20) | 13(4) | 200(70) | 6.6(12) |
| | $6_1^+$ | 356.8 | 1 | 9.1(4) | 7(3) | 231(10) | 6.82(15) |
| | $8_1^+$ | 424.2 | 1 | 4.5(3) | $\approx 4$ | 202(14) | 6.2(2) |
| | $10_1^+$ | 488.9 | 1 | 1.9(2) | | 238(25) | 6.7(4) |

Recoil Distance Doppler Shift

Doppler-Shift Attenuation Method

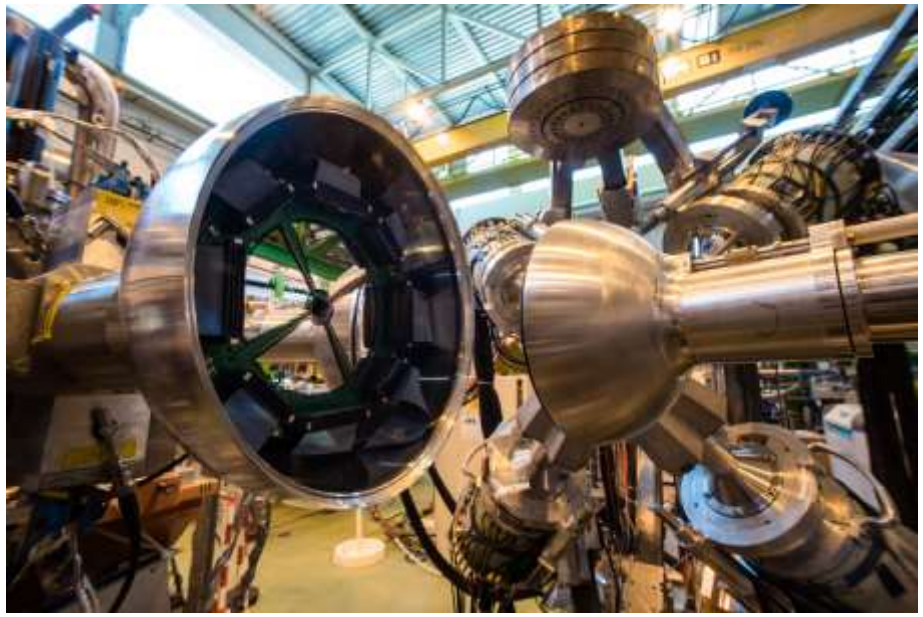
Some states are accessible in Coulex with sufficiently long lifetimes

Accurate lifetimes are a vital input to the analysis of Coulomb excitation!

# HISTARS planned developments

1. Upgrade of the reaction particle detectors to provide good timing and high-rate capabilities

Improvement of count-rate capabilities for a wide range of reactions studies



2. Addition of a fast scintillator array at low Doppler-shift angles to measure lifetimes of nuclear excited states

Possible synergies with other devices

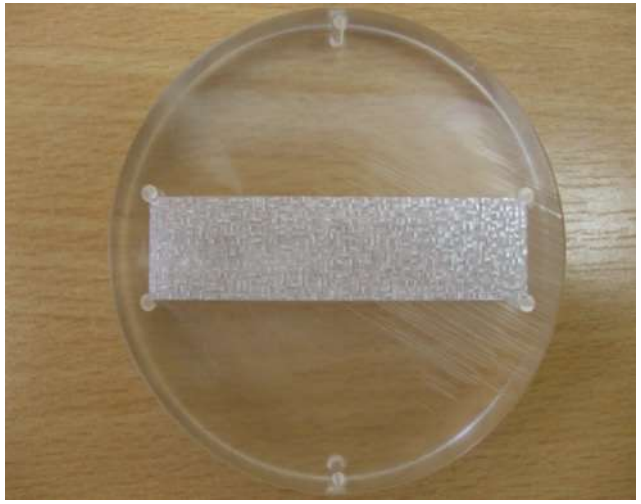
# 1. Particle detection with fast response

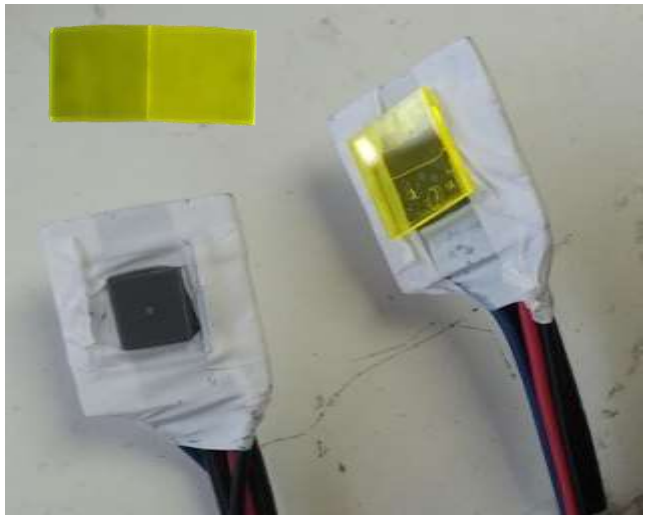
Plastic scintillators
Scintillating fibers
Inorganic crystals:
GAGG(Ce),
YSO(Ce),
Fast LGSO, …

## Fiber device used at ILL

Position resolution 3-mm
Fast start signal for timing

G. Simpson *et al.*





DOI: 10.1002/mp.16333

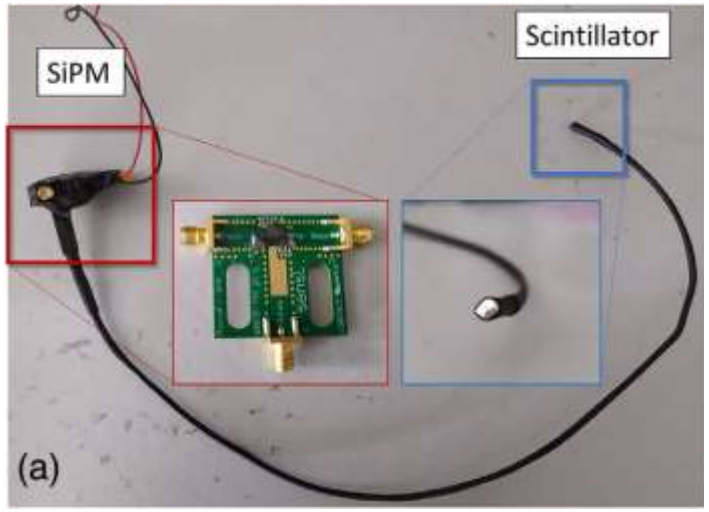
TECHNICAL NOTE

MEDICAL PHYSICS

**Technical note: Measurement of the bunch structure of a clinical proton beam using a SiPM coupled to a plastic scintillator with an optical fiber**

Miguel García Díez[1,2] | Andrea Espinosa Rodriguez[1,2] | Victor Sánchez Tembleque[1,2] | Daniel Sánchez Parcerisa[1,2] | Victor Valladolid Onecha[1,2] | Juan A. Vera Sanchez[3] | Alejandro Mazal[3] | Luis Mario Fraile[1,2] | Jose Manuel Udias[1,2]

M. García-Díez, J.M. Udías *et al.*



# 2. Fast scintillator array

## $LaBr_3(Ce)$

- Alternatives such as $CeBr_3$, co-doped $LaBr_3(Ce)$
- Doping, size, shape

Best values of FWHM time resolution for $LaBr_3(Ce)$ crystals geometries, truncated cone and tapered, at $^{60}Co$ energies and $^{22}Na$ (511 keV). The zero crossing value (Z) is set at 2.0 mV and the CFD threshold at −508 mV.

| Geometry | External Delay (ns) | HV (V) | FWHM $^{60}Co$ (ps) | FWHM $^{22}Na$ (ps) |
|---|---|---|---|---|
| Tapered | 1.5 | −1300 | 111 ± 3 | 160 ± 3 |
| Truncated cone | 1.7 | −1200 | 110 ± 3 | 158 ± 3 |
| 1 in. cylinder | 1.5 | −1300 | 98 ± 2 | 148 ± 2 |

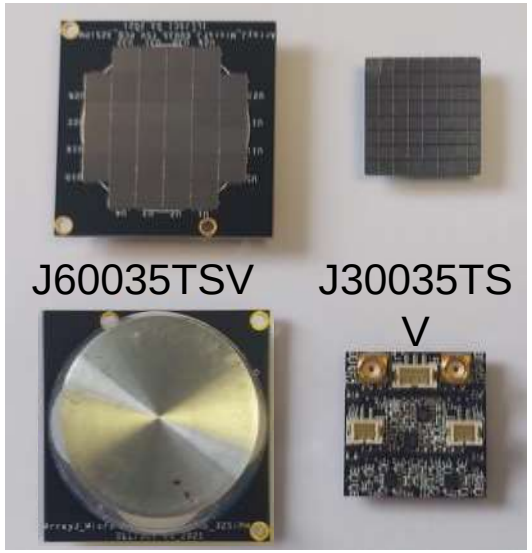
V. Vedia *et al.*, NIM A 795 (2015) 144

## Photosensors

- PMT: selection + development
- SiPMs

J.R. Murias, S. Gaitán,
M. Caballero, J.M. Udías, *et al.*

S. Pascu *et al.*, NIM A1070 (2025) 170001




## **Digitizing** algorithms

V. Sánchez-Tembleque *et al.*, NIM A 927 (2019) 54

Nuclear Inst. and Methods in Physics Research, A 927 (2019) 54–62
Contents lists available at ScienceDirect
Nuclear Inst. and Methods in Physics Research, A
journal homepage: www.elsevier.com/locate/nima

Optimizing time-pickup algorithms in radiation detectors with a genetic algorithm

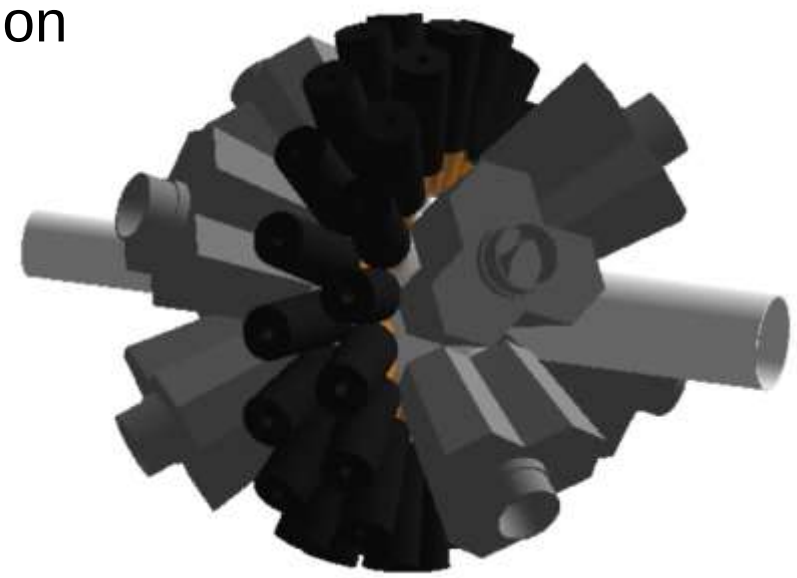
V. Sanchez-Tembleque [a,*], V. Vedia [a], L.M. Fraile [a,b], S. Ritt [c], J.M. Udias [a,b]
[a] Grupo de Física Nuclear and IPARCOS, Universidad Complutense de Madrid, CEI Moncloa, Madrid, Spain
[b] Instituto de Investigación Sanitaria del Hospital Clínico San Carlos (IdISSC), Madrid, Spain
[c] Paul Scherrer Institute, Villigen PSI, Switzerland

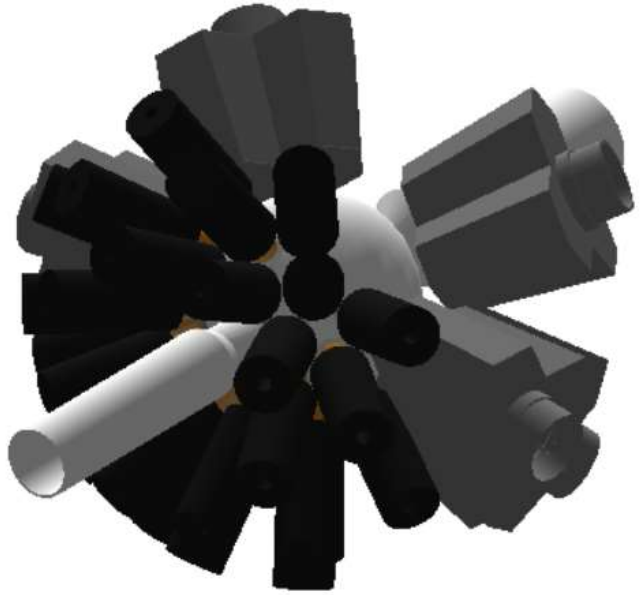
| Algorithm | $^{22}Na$ | $^{60}Co$ |
|---|---|---|
| CFD + TAC [4] | 226 ± 4 ps | 156 ± 4 ps |
| DLED | 216 ± 1 ps | 154 ± 1 ps |
| RDLED | 222 ± 1 ps | 159 ± 1 ps |
| CR filter + RDLED | 210 ± 1 ps | 143 ± 1 ps |
| D-CFD | 208 ± 1 ps | 143 ± 1 ps |
| General filter + RDLED | 194 ± 1 ps | 136 ± 1 ps |

# Geant4 simulations

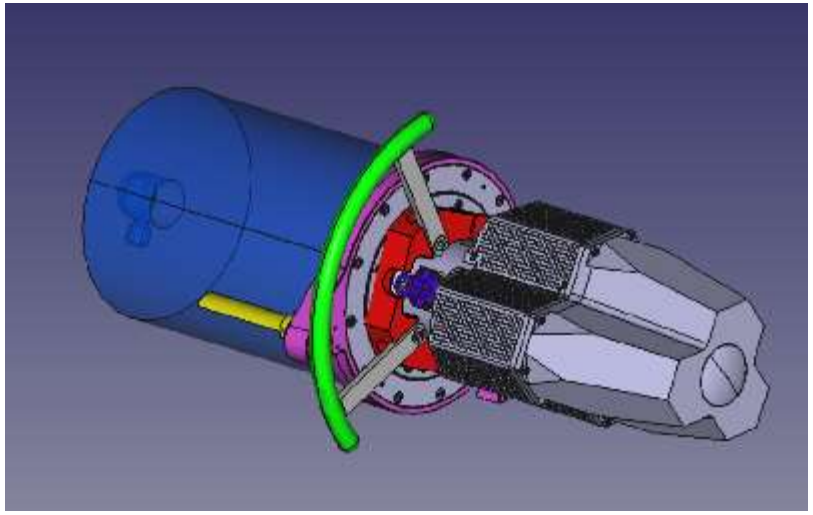
Two configurations under investigation

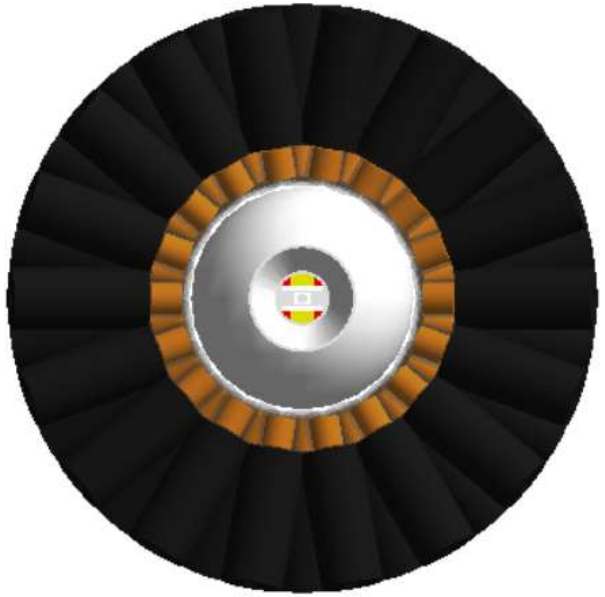
- **Central** geometry ~90° :
  36 $LaBr_3$(Ce) at 10 cm
  8 Miniball clusters at 13 cm
- **Backward** geometry ~140° :
  24 $LaBr_3$(Ce) at 10 cm
  6 Miniball clusters at 12 cm



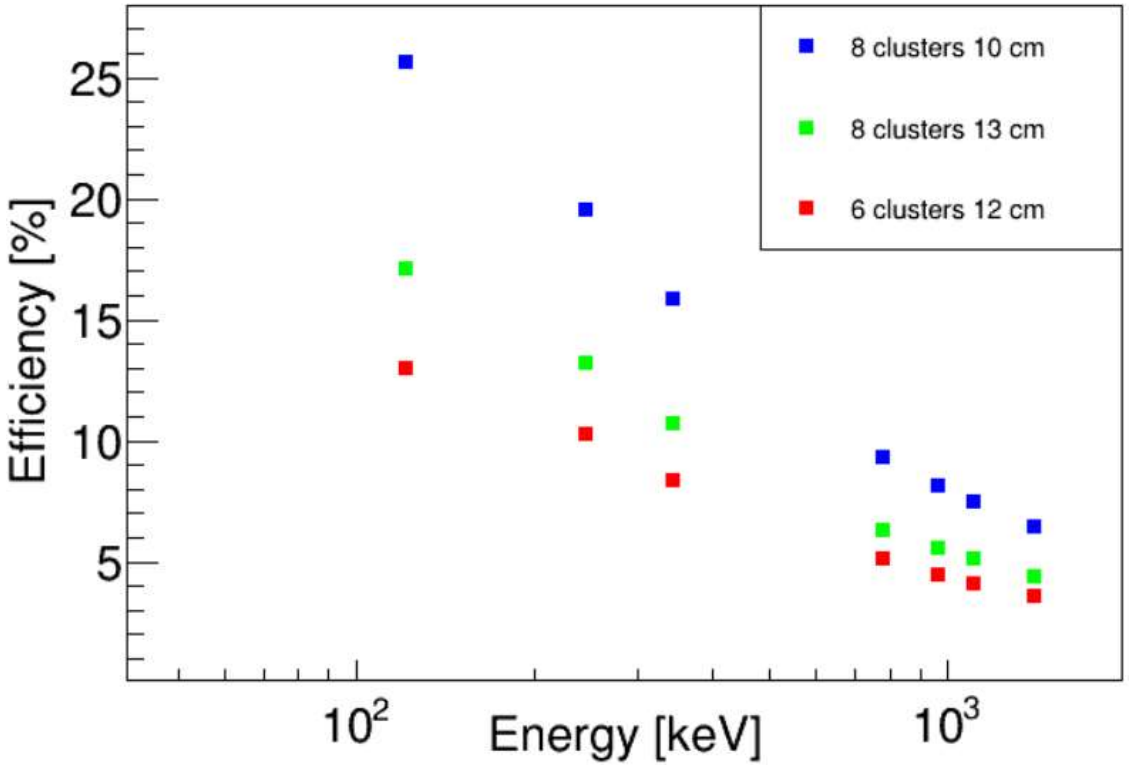


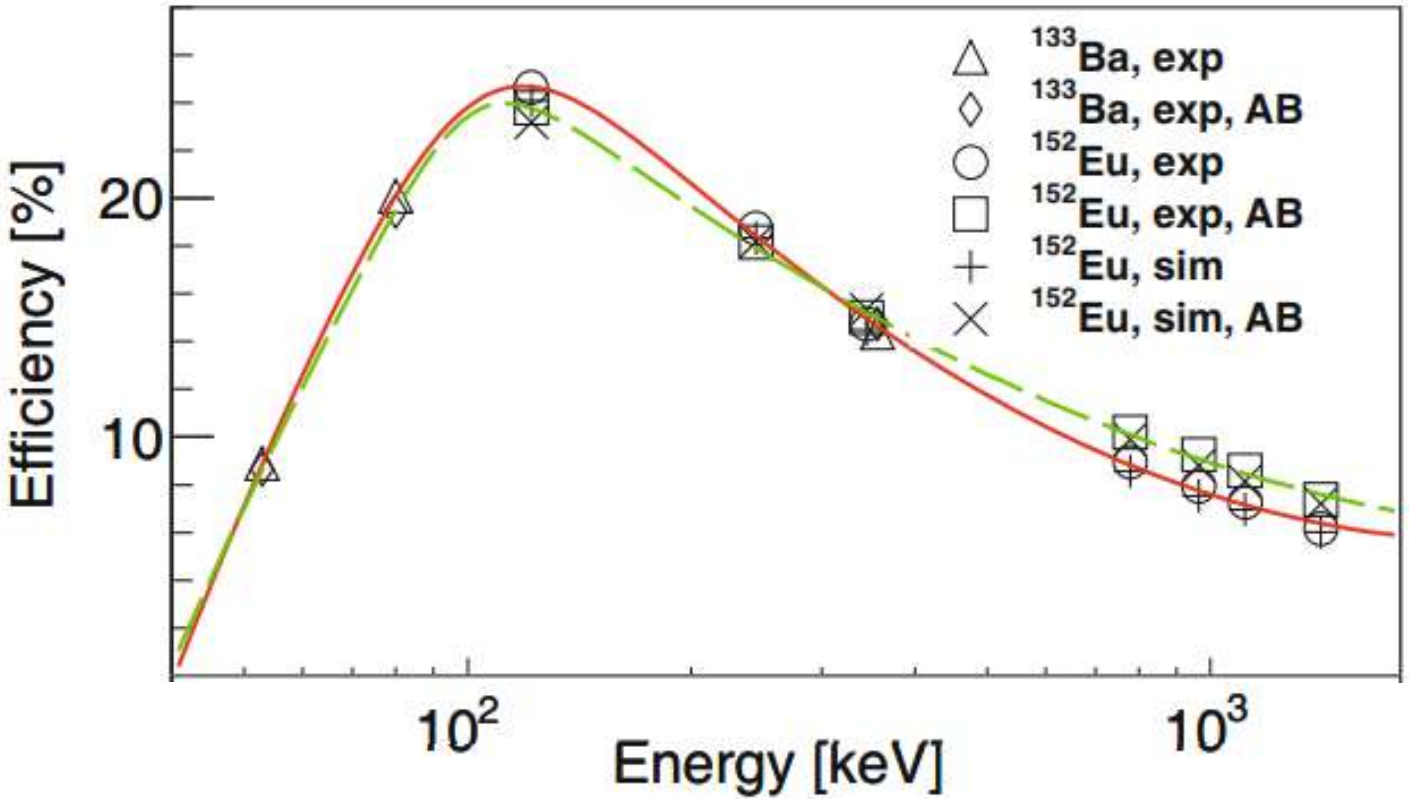
New tapered casing to be implemented!





# Efficiency of Miniball clusters



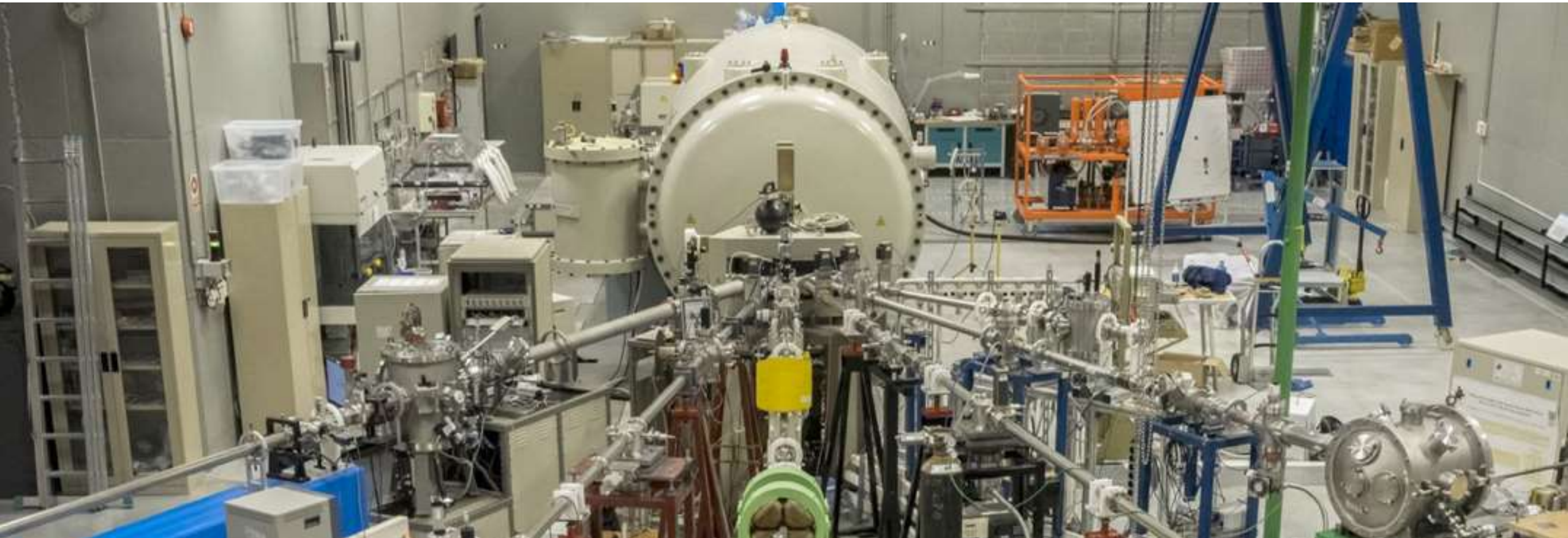




N. Warr *et al.,* EPJ A (2013) 49: 40

# Stable beam tests at CMAM

To test particle-gamma coincidence capabilities with fast scintillators using the 5-MV tandem accelerator in Madrid

Presentation by Miriam Caballero tomorrow ☺



# LOI284 at HIE-ISOLDE

Instrument concept

More realistic conditions

→ HIE-ISOLDE bunching structure

→ Mechanical integration

→ DAQ

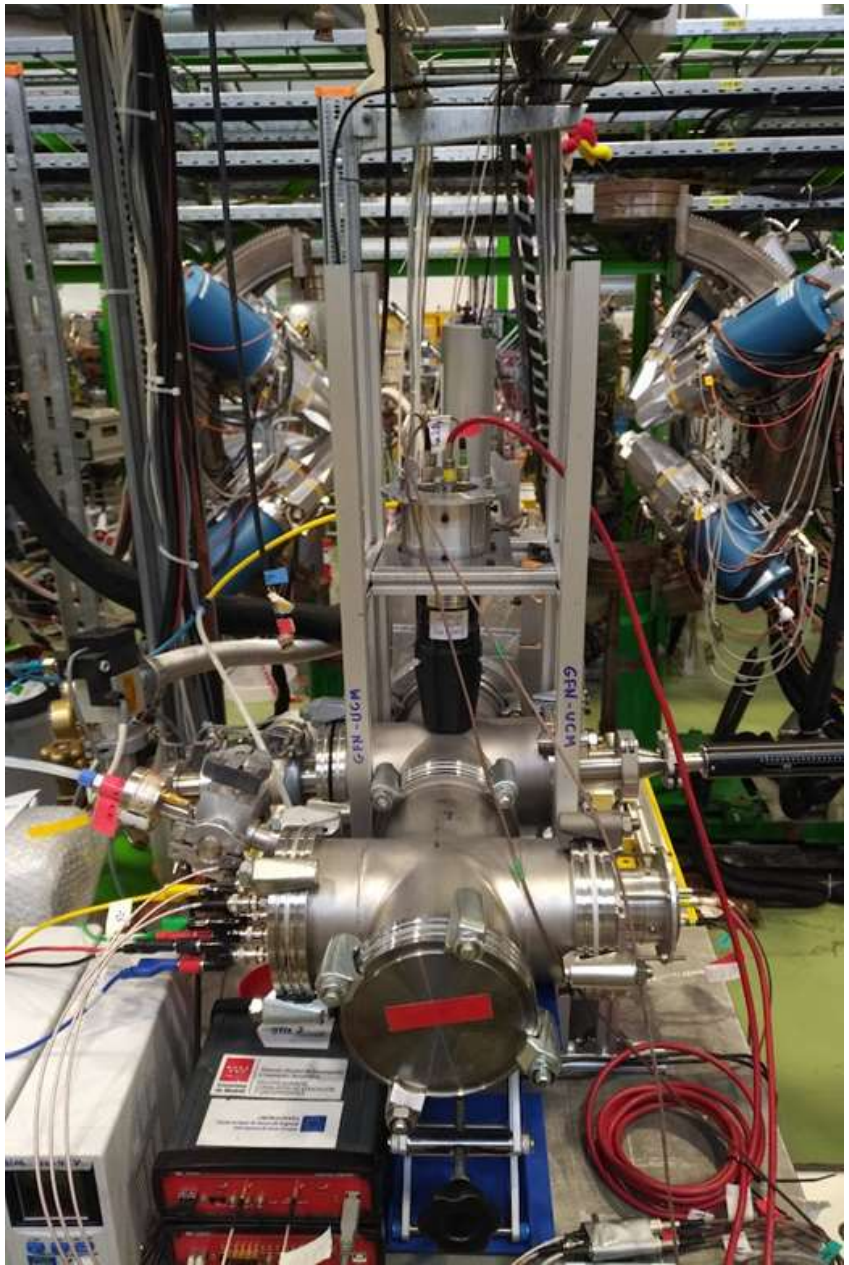
→ …

Cross-check simultaneous measurement of excitation and lifetimes

→ Lifetimes from 200 ps to 2 ns are well suited

→ Uncertainty of some previous measurements could be improved with fast scintillators

Stable beams proposed for initial tests, then RIB



# Work packages and timeline

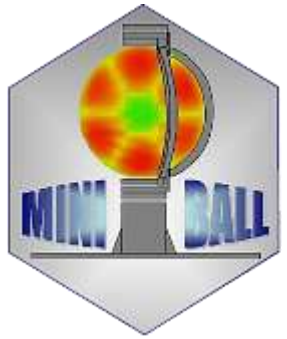
| HISTARS (ISOLDE/CERN) | | Year 1 | | | | Year 2 | | | | Year 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| **WP1: Physics goals** | | | | | | | | | | | | | |
| Identification of physics cases | | | | | | | | | | | | | |
| ***Milestone 1.1*** | Benchmark cases, letter of Intent | | | **M1** | | | | | | | | | |
| **WP2: Definition of the HISTARS fast-timing gamma array** | | | | | | | | | | | | | |
| Simulations and selection of external detectors | | | | | | | | | | | | | |
| ***Milestone 2.1*** | External HISTARS fast-timing array | | | **M2** | | | | | | | | | |
| **WP3: Test and selection of optimal ultra-fast scintillators** | | | | | | | | | | | | | |
| Test and selection of fast particle detectors | | | | | | | | | | | | | |
| ***Milestone 3.1*** | Selection of fast particle detectors | | | | | **M3** | | | | | | | |
| **WP4: Mechanical design and integration of gamma scintillators** | | | | | | | | | | | | | |
| Design and construction of the mechanical structure | | | | | | | | | | | | | |
| ***Milestone 4.1*** | Installation of mechanical support | | | | | | **M4** | | | | | | |
| **WP5: External fast-timing array** | | | | | | | | | | | | | |
| Purchasing, mounting, test and integration | | | | | | | | | | | | | |
| ***Milestone 5.1*** | Installation of gamma array | | | | | | | **M5** | | | | | |
| **WP6: Internal detection array** | | | | | | | | | | | | | |
| Purchasing, mounting, test and integration | | | | | | | | | | | | | |
| ***Milestone 6.1*** | Installation of particle array | | | | | | | | | **M6** | | | |
| **WP7: Offline setup** | | | | | | | | | | | | | |
| Mounting, integration, electronics and DAQ, tests | | | | | | | | | | | | | |
| ***Milestone 7.1*** | Working HISTARS prototype | | | | | | | | | | | **M7** | |
| **WP8: Commissioning** | | | | | | | | | | | | | |
| Commissioning with radioactive beam | | | | | | | | | | | | | |
| ***Milestone 8.1*** | HISTARS ready for experiments | | | | | | | | | | | | **M8** |

**Spanish institutes involved in these developments:**

- Grupo de Física Nuclear, IPARCOS Universidad Complutense, Madrid (L.M. Fraile)
- IEM-CSIC, Madrid (O. Tengblad)
- IFIC, CSIC-UV, Valencia (E. Nácher)

# THANK YOU!



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