Isolde Tape Station and future at SPES
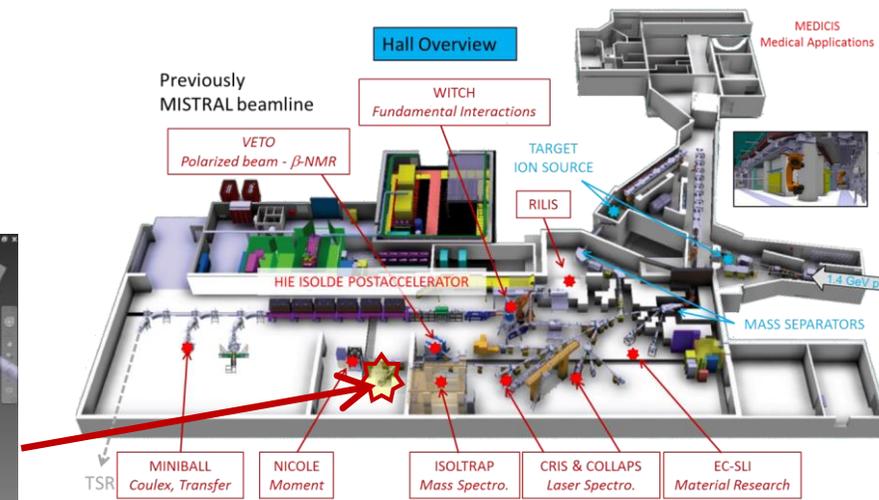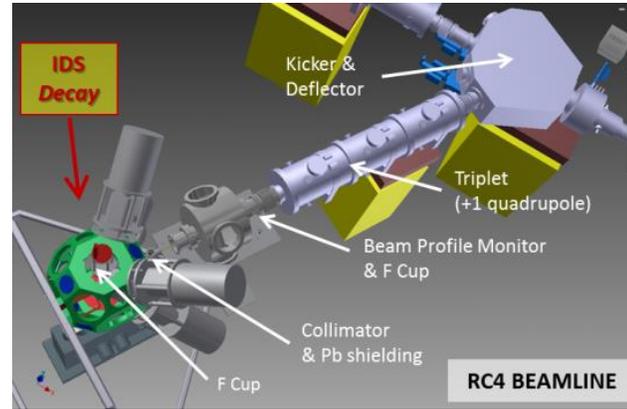G.Benzoni (INFN-Mi)

25/09/2025

G.Benzoni

The ISOLDE Decay station

- Permanent setup at the low-energy branch of ISOLDE

- **Physics programme**
  - Nuclear structure physics (80%)
  - Nuclear astrophysics (10%)
  - Nuclear industry and medicine (5%)
  - Solid state physics (5%)

>100 researchers from 20 institutions

- Belgium (KU Leuven)
- Denmark (Aarhus University)
- Finland (University of Jyväskylä)
- Germany (Institut für Kernphysik – Universität zu Köln)
- Italy (Università degli Studi e INFN Milano)
- Poland (Faculty of Physics, University of Warsaw)
- Romania (IFIN-HH Bucharest)
- South Africa (iThemba LABS; University of the Western Cape)
- Spain (IEM CSIC Madrid; IFIC-CSIC Valencia; UCM Madrid)
- Sweden (Lund University)
- Switzerland (CERN - ISOLDE)
- UK (STFC Daresbury Laboratory; University of Liverpool; University of Surrey; University of York, Edinburg)
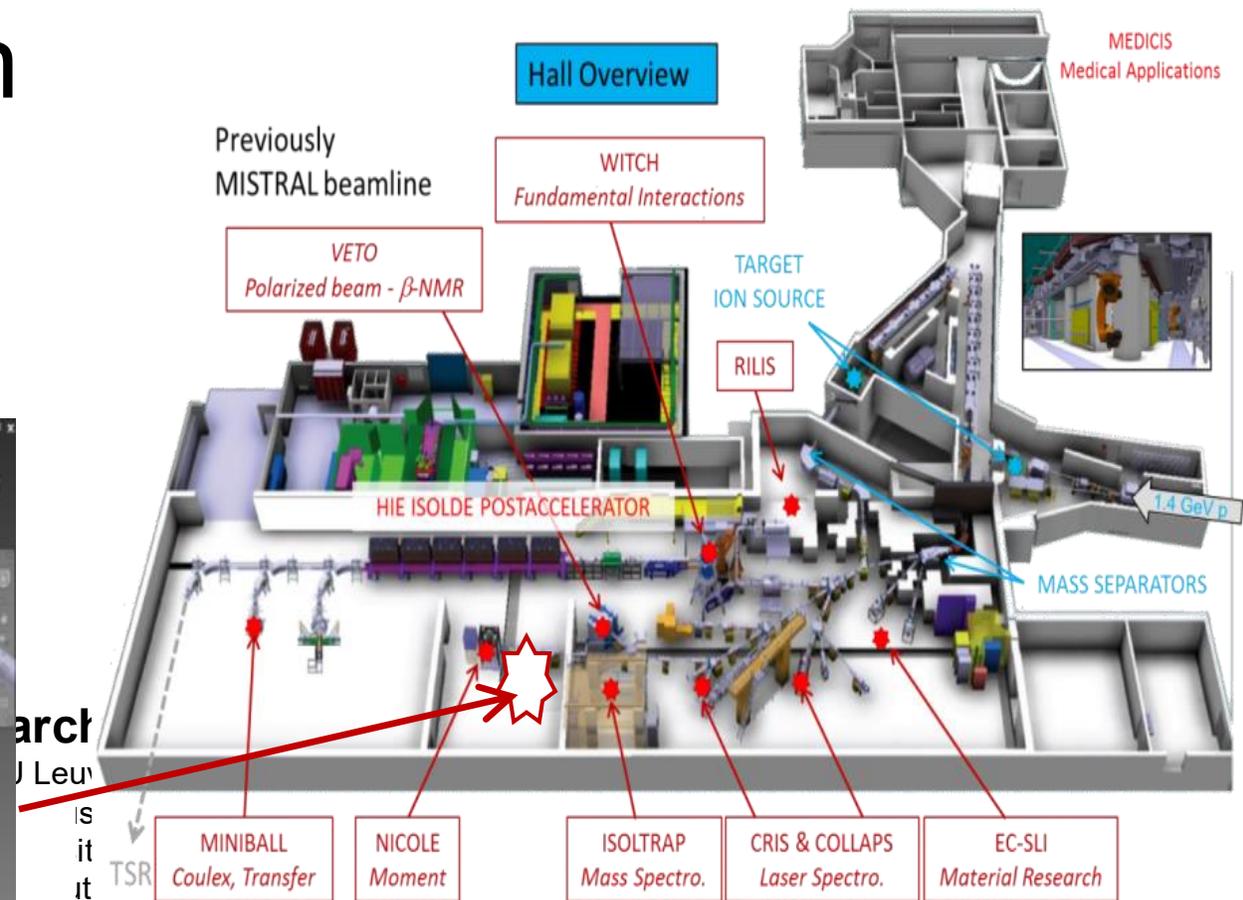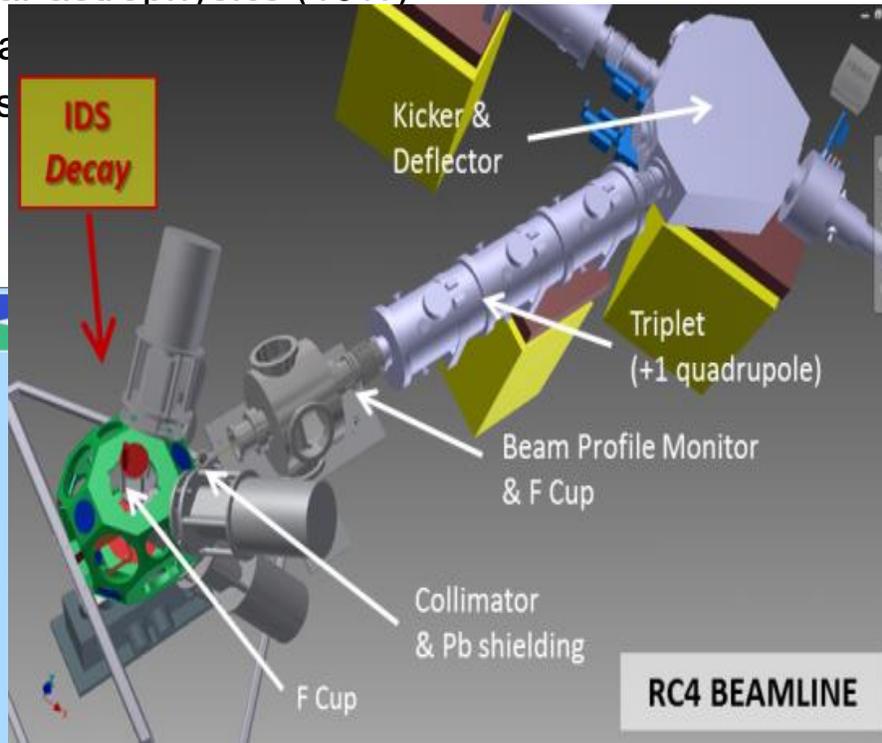- USA (University of Tennessee)

IDS is supported by 20 institutes across the world, and used by many more globally

The ISOLDE Decay station

- Permanent setup at the low-energy branch of ISOLDE

- **Physics programme**
  - Nuclear structure physics (80%)
  - Nuclear astrophysics (10%)
  - Nuclea...
  - Solid s...

IDS Decay

Kicker & Deflector

Triplet (+1 quadrupole)

Beam Profile Monitor & F Cup

Collimator & Pb shielding

F Cup

RC4 BEAMLINE

Hall Overview

Previously MISTRAL beamline

MEDICIS Medical Applications

WITCH Fundamental Interactions

VETO Polarized beam - β-NMR

TARGET ION SOURCE

RILIS

HIE ISOLDE POSTACCELERATOR

1.4 GeV p

MASS SEPARATORS

TSR

MINIBALL Coulex, Transfer

NICOLE Moment

ISOLTRAP Mass Spectro.

CRIS & COLLAPS Laser Spectro.

EC-SLI Material Research

...arch...
...U Leuv...
...s...
...it...
...t...
- ... degli Studi e INFN Milano)
- ... of Physics, University of Warsaw)
- ...FIN-HH Bucharest)
- ... (iThemba LABS; University of the Western Cape)
- ...CSIC Madrid; IFIC-CSIC Valencia; UCM Madrid)
- ...nd University)
- ...Switzerland (CERN - ISOLDE)
- UK (STFC Daresbury Laboratory; University of Liverpool; University of Surrey; University of York, Edinburg)
- USA (University of Tennessee)

IDS is supported by 20 institutes across the world, and used by many more globally

3

12 HPGe clovers detectors (as of Sep. 2024)
- 4 crystals / clover
- 20% relative eff. / crystal
- 2 thin-carbon window detectors (~10 keV)

8 clovers with addback
≈23% eff @ 200 keV
≈7% eff @ 1 MeV
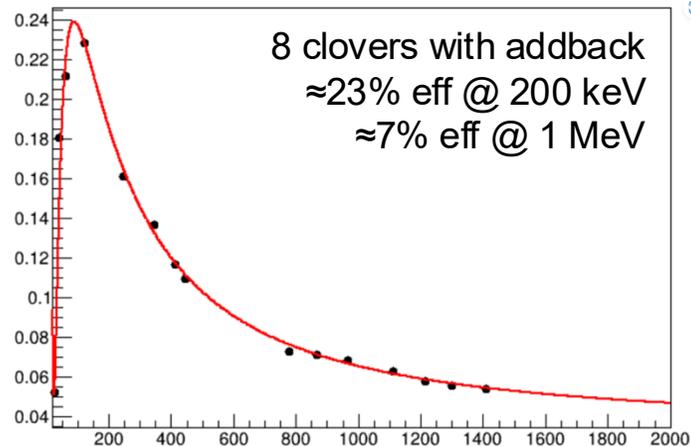
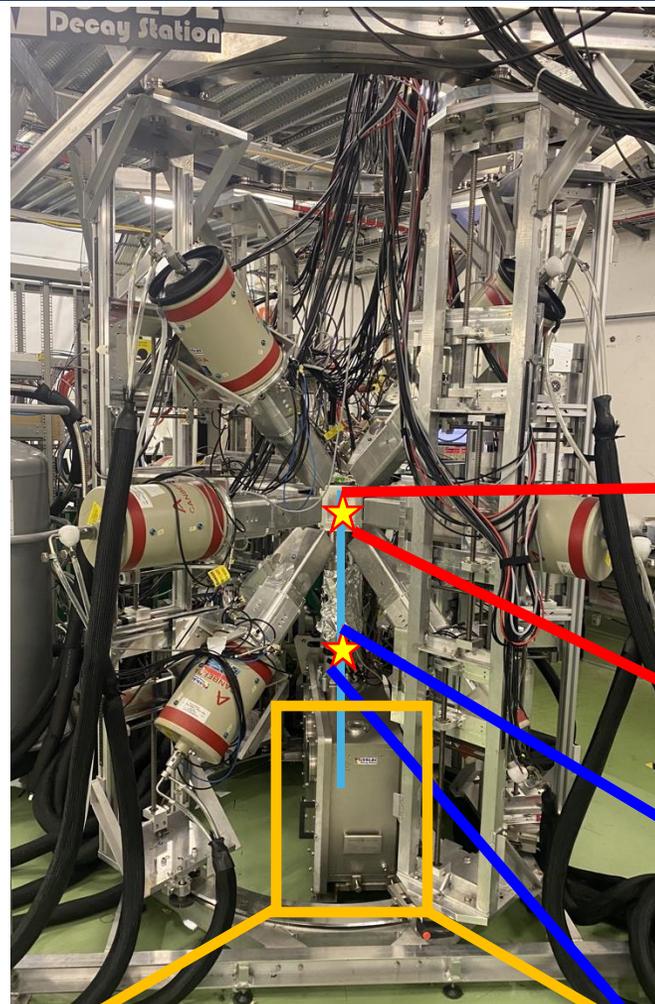**Flexible + dynamic support structure (2023)**
- Detectors mounted on vertical gantries, 3 clovers per gantry, gantries mounted on circular rails
- Can move detectors radially + vertically, tilt vertically, rotate on axes

Digital XIA pixie-16 acquisition
- 16 channels per module
- 12-16 bit ADC
- 100, 250 and 500 MHz modules
- 208 channels/crate

Movable tape system
- Reel-to-reel aluminsed mylar tape (~2.5 km)
- Fully automated system
- Integrated with ISOLDE beam logic, RILIS laser system, and our DAQ
- **Primary "implantation" position** For main aims of experiments
- **Secondary "decay" position** Free "bonus" experiment, long-lived activity
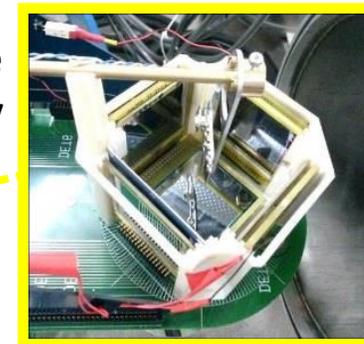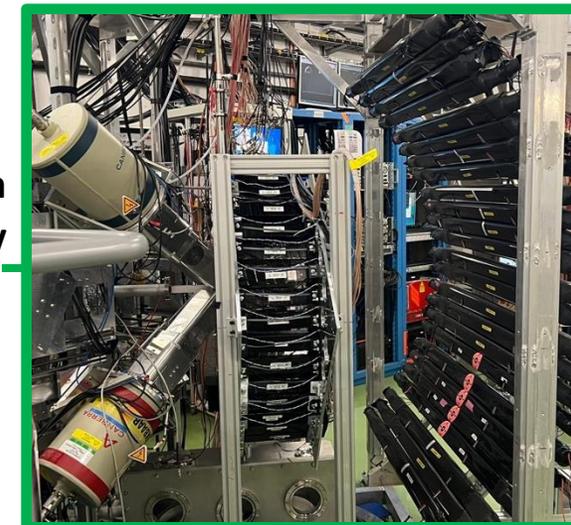
Ancillary systems
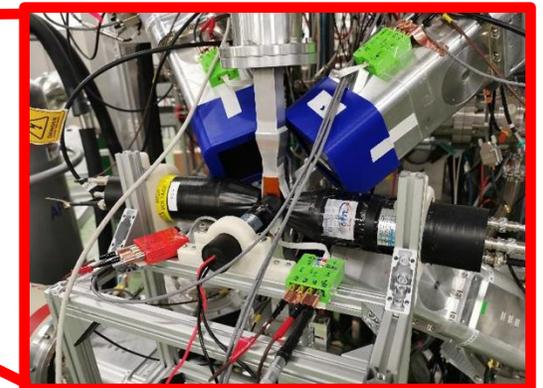
High β-γ efficiency

Fast-timing

Conversion electrons
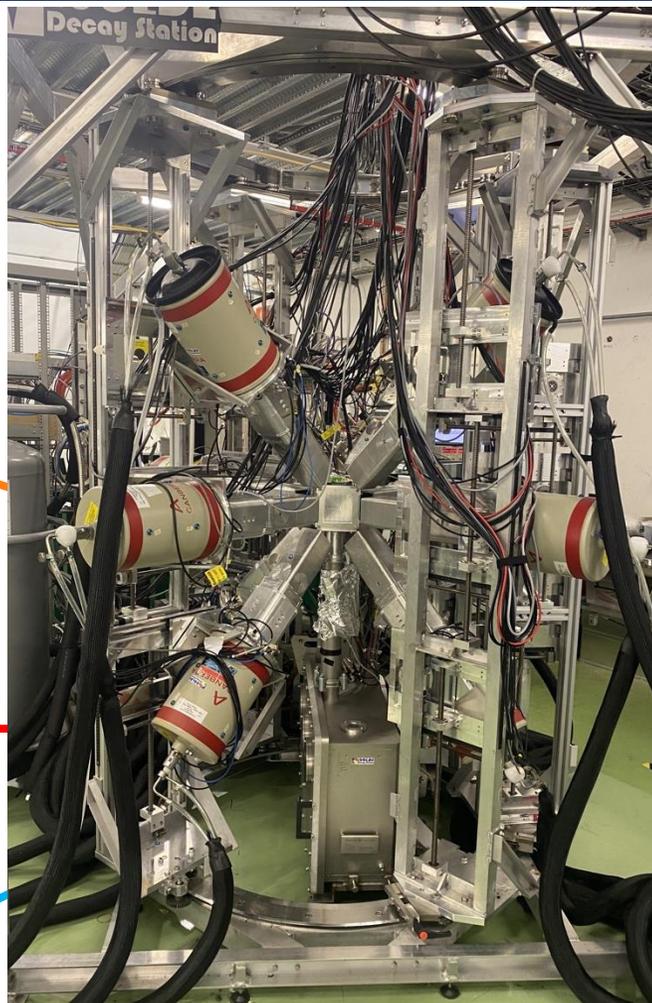
Charged-particle Spectroscopy

Neutron Spectroscopy

Plastic scints. (β tagging)

TD-PAC – Coming "soon"

- System "specialised" to needs of particular experiment
- Easily interchangeable, and compatible with each other
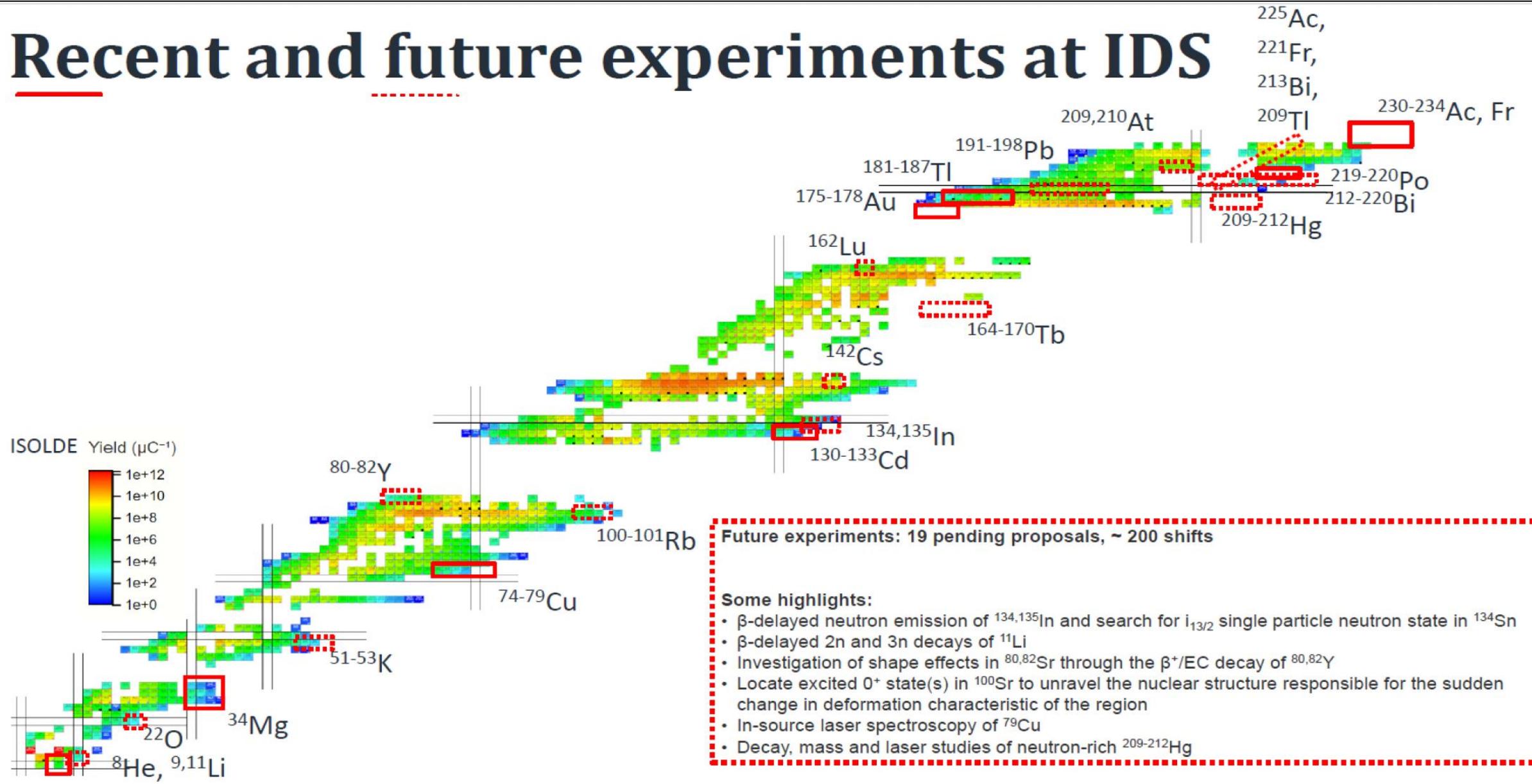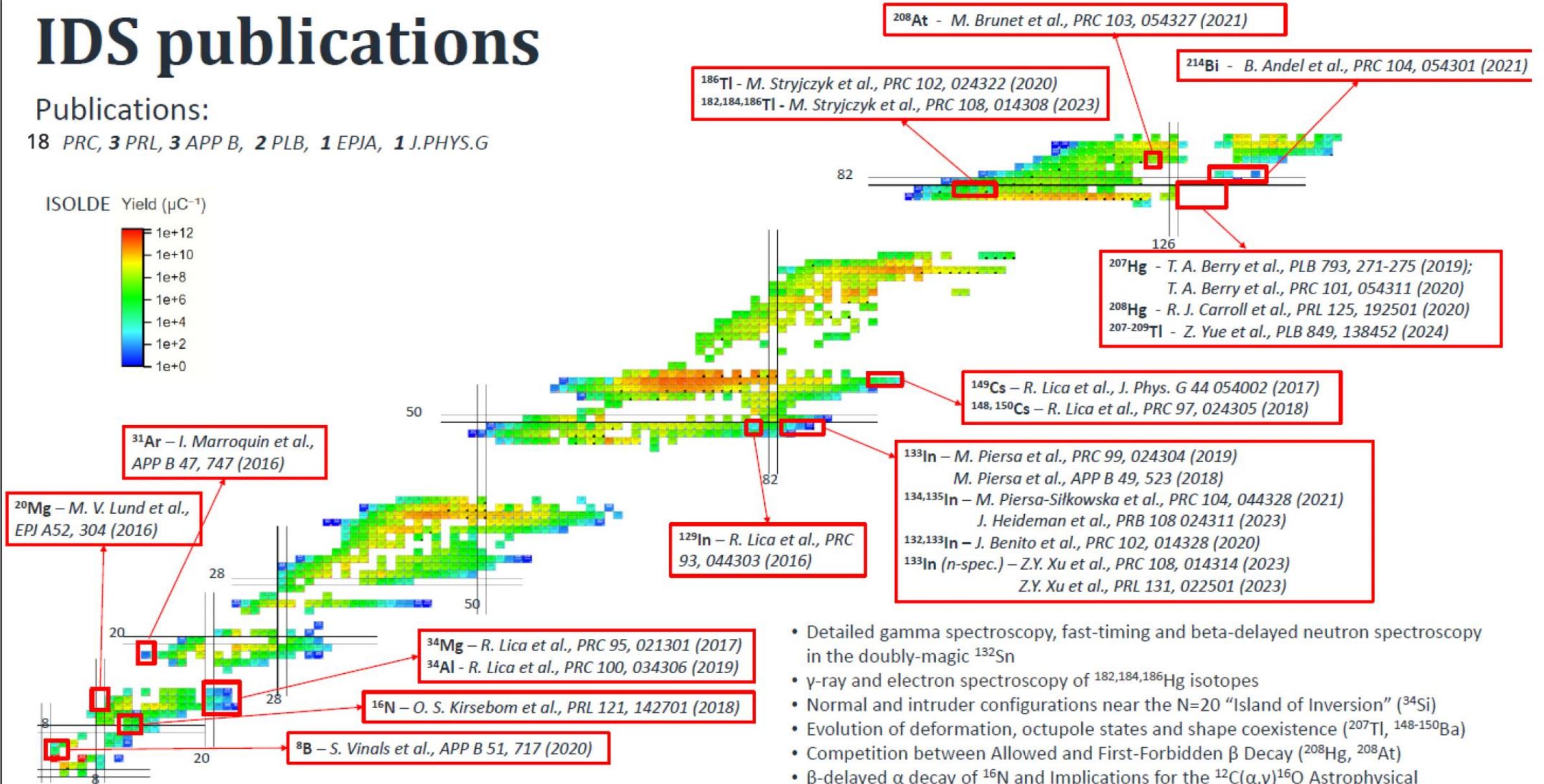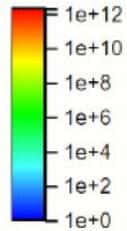
Recent and future experiments at IDS

ISOLDE Yield (μC⁻¹)

Future experiments: 19 pending proposals, ~ 200 shifts

Some highlights:
- β-delayed neutron emission of ^{134,135}In and search for $i_{13/2}$ single particle neutron state in ^{134}Sn
- β-delayed 2n and 3n decays of ^{11}Li
- Investigation of shape effects in ^{80,82}Sr through the β^+/EC decay of ^{80,82}Y
- Locate excited 0^+ state(s) in ^{100}Sr to unravel the nuclear structure responsible for the sudden change in deformation characteristic of the region
- In-source laser spectroscopy of ^{79}Cu
- Decay, mass and laser studies of neutron-rich $^{209-212}$Hg

Chart source: https://isoyields2.web.cern.ch/IsoldeYieldChart.aspx

IDS publications

Publications:

18 *PRC*, **3** *PRL*, **3** *APP B*, **2** *PLB*, **1** *EPJA*, **1** *J.PHYS.G*

ISOLDE Yield (μC^{-1})

- 1e+12
- 1e+10
- 1e+8
- 1e+6
- 1e+4
- 1e+2
- 1e+0

208At - M. Brunet et al., PRC 103, 054327 (2021)

214Bi - B. Andel et al., PRC 104, 054301 (2021)

186Tl - M. Stryjczyk et al., PRC 102, 024322 (2020)
182,184,186Tl - M. Stryjczyk et al., PRC 108, 014308 (2023)

207Hg - T. A. Berry et al., PLB 793, 271-275 (2019);
        T. A. Berry et al., PRC 101, 054311 (2020)
208Hg - R. J. Carroll et al., PRL 125, 192501 (2020)
207-209Tl - Z. Yue et al., PLB 849, 138452 (2024)

149Cs – R. Lica et al., J. Phys. G 44 054002 (2017)
148, 150Cs – R. Lica et al., PRC 97, 024305 (2018)

31Ar – I. Marroquin et al., APP B 47, 747 (2016)

20Mg – M. V. Lund et al., EPJ A52, 304 (2016)

133In – M. Piersa et al., PRC 99, 024304 (2019)
        M. Piersa et al., APP B 49, 523 (2018)
134,135In – M. Piersa-Siłkowska et al., PRC 104, 044328 (2021)
        J. Heideman et al., PRB 108 024311 (2023)
132,133In – J. Benito et al., PRC 102, 014328 (2020)
133In (n-spec.) – Z.Y. Xu et al., PRC 108, 014314 (2023)
        Z.Y. Xu et al., PRL 131, 022501 (2023)

129In – R. Lica et al., PRC 93, 044303 (2016)

34Mg – R. Lica et al., PRC 95, 021301 (2017)
34Al - R. Lica et al., PRC 100, 034306 (2019)

16N – O. S. Kirsebom et al., PRL 121, 142701 (2018)

8B – S. Vinals et al., APP B 51, 717 (2020)

- Detailed gamma spectroscopy, fast-timing and beta-delayed neutron spectroscopy in the doubly-magic ^{132}Sn
- γ-ray and electron spectroscopy of ^{182,184,186}Hg isotopes
- Normal and intruder configurations near the N=20 "Island of Inversion" (^{34}Si)
- Evolution of deformation, octupole states and shape coexistence (^{207}Tl, $^{148-150}$Ba)
- Competition between Allowed and First-Forbidden β Decay (^{208}Hg, ^{208}At)
- β-delayed α decay of ^{16}N and Implications for the ^{12}C(α,γ)^{16}O Astrophysical Reaction Rate

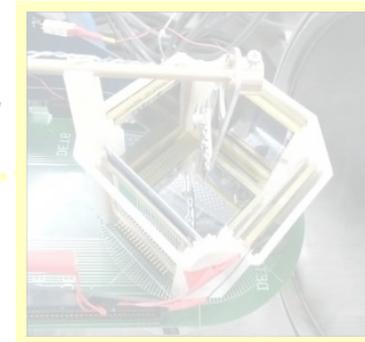Chart source: https://isoyields2.web.cern.ch/IsoldeYieldChart.aspx
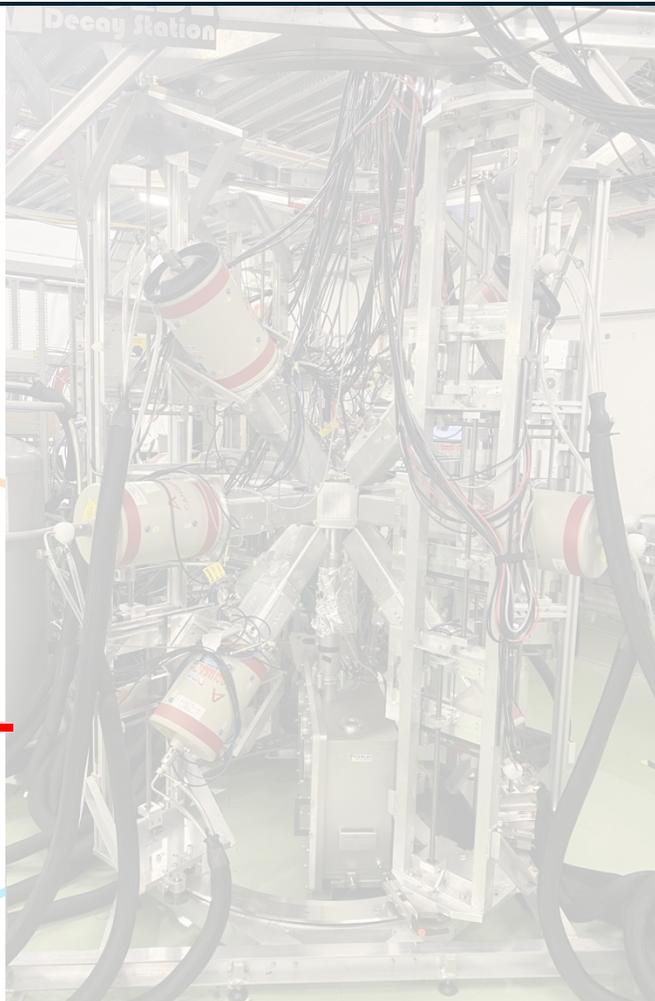
Ancillary systems

High β-γ efficiency

Charged-particle Spectroscopy
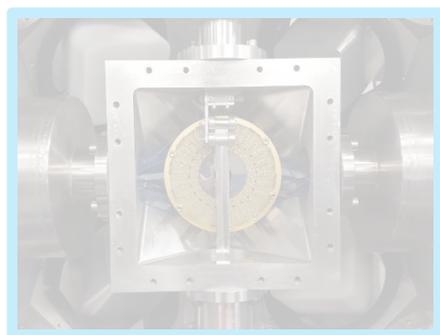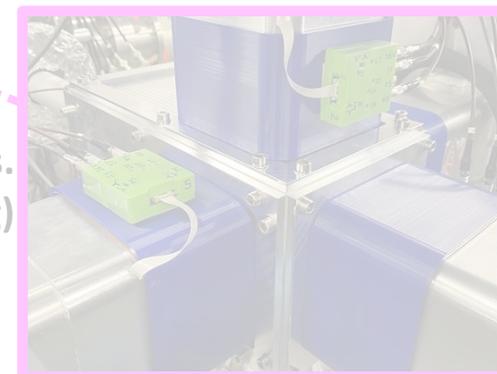
Fast-timing

Neutron Spectroscopy
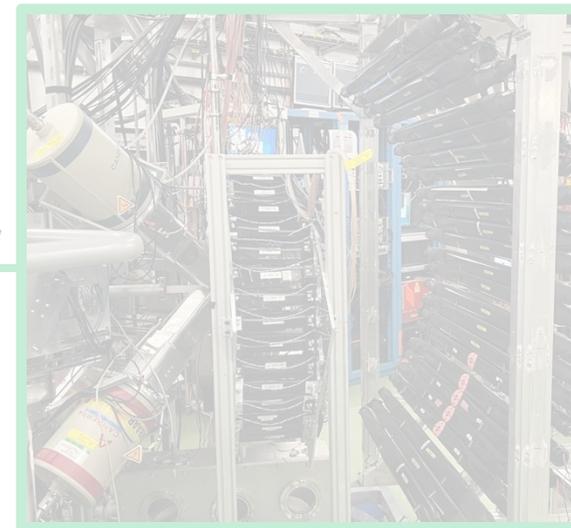
Conversion electrons

TD-PAC – Coming "soon"

- System "specialised" to needs of particular experiment
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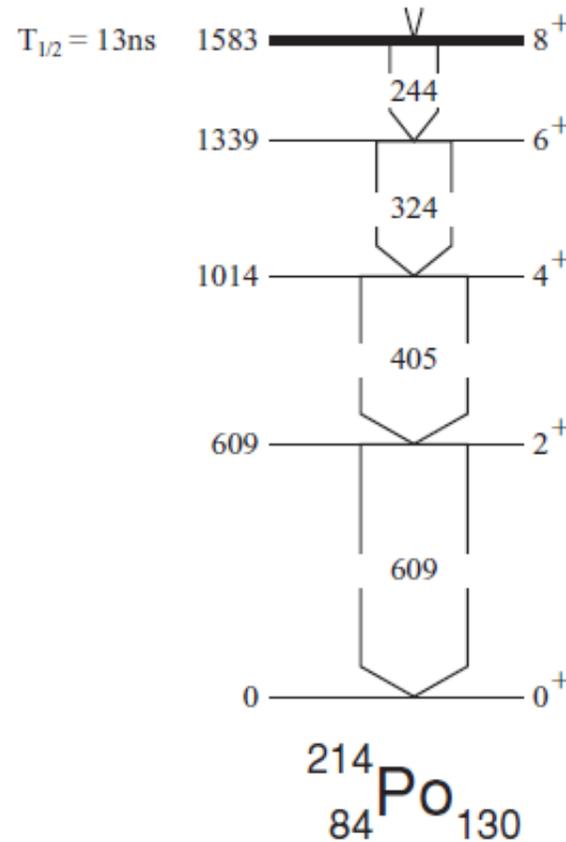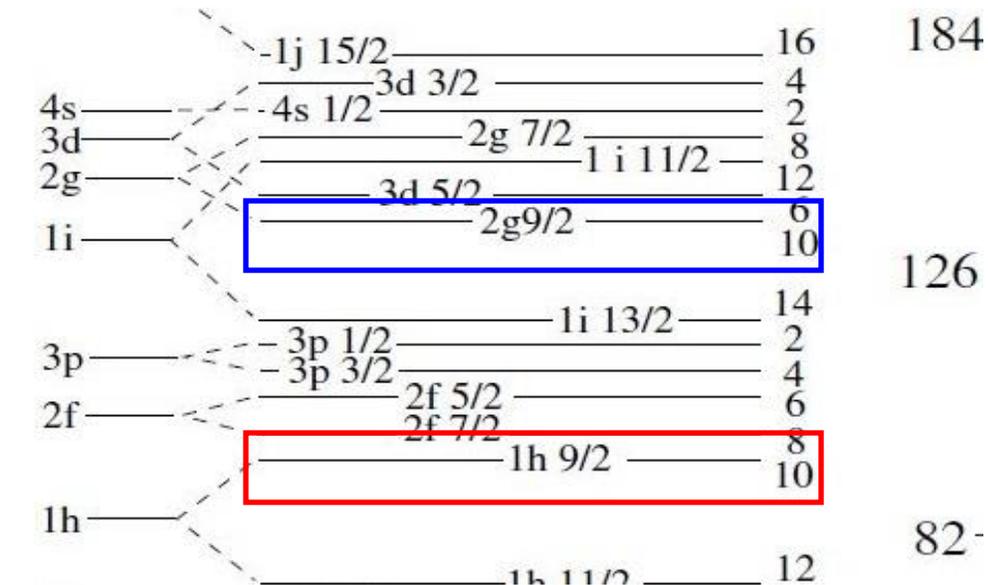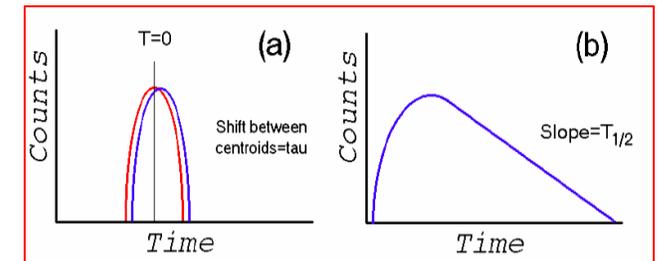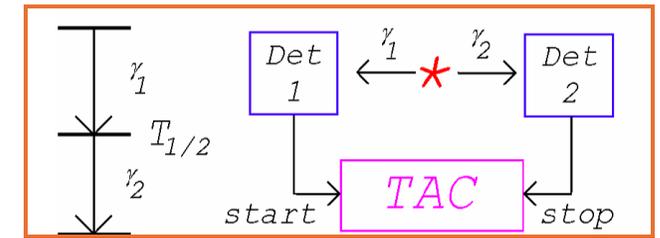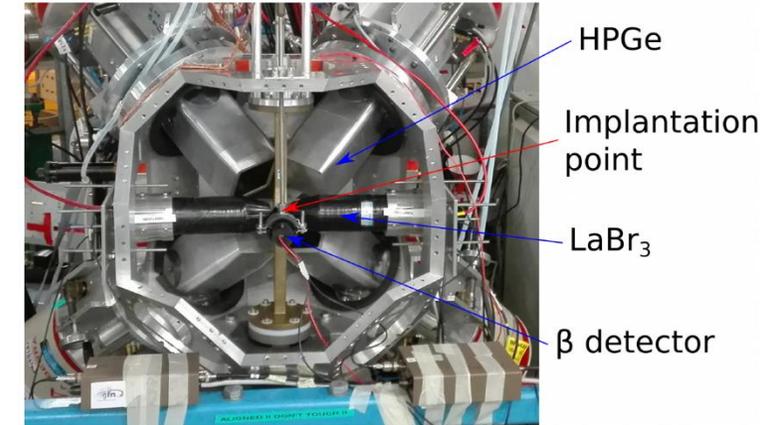
Plastic scints. (β tagging)

IS650: The nature of Yrast states in ^{214,216,218}Po

Spokespersons: R. Lica and A. N. Andreyev

- Two protons outside of Pb core – excellent testing ground for shell model calcs.
- Two protons in $\pi h_{9/2}$ and neutrons fill $\nu g_{9/2}$
- Expect seniority scheme Yrast structure up to $J^\pi = 8^+$

Astier and Porquet, PRC **83**, 014311 (2011)

Ranges:
Centroid shift : **10 ps - 100 ps**
Slope method: **50 ps - 50 ns** (or longer)
[H. Mach et al. NIM A 280, 49 (1989)]

IS650: The nature of Yrast states in ^{214,216,218}Po

R. Lica *et al.,* PRL **134** 052502 (2025)

- Lifetimes measured and B(E2)s extracted for Yrast states up to 8$^+$.
- Compared to shell model calcs. Using KPHE and H208 interactions.
- Good agreement – improved with weakening of pairing strength (-m).
- Seniority structure eroded with increasing neutron no.
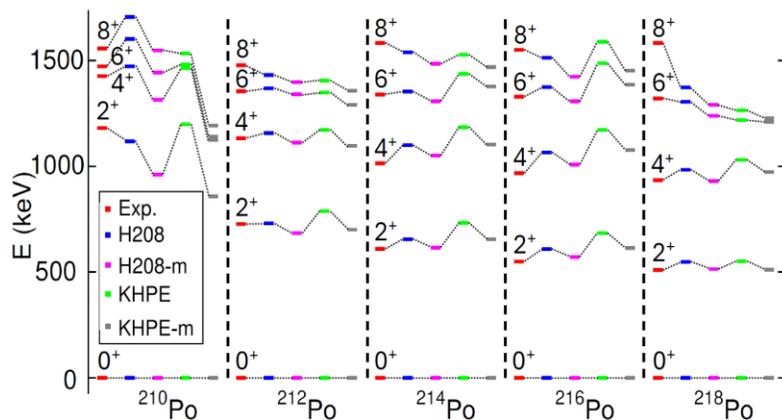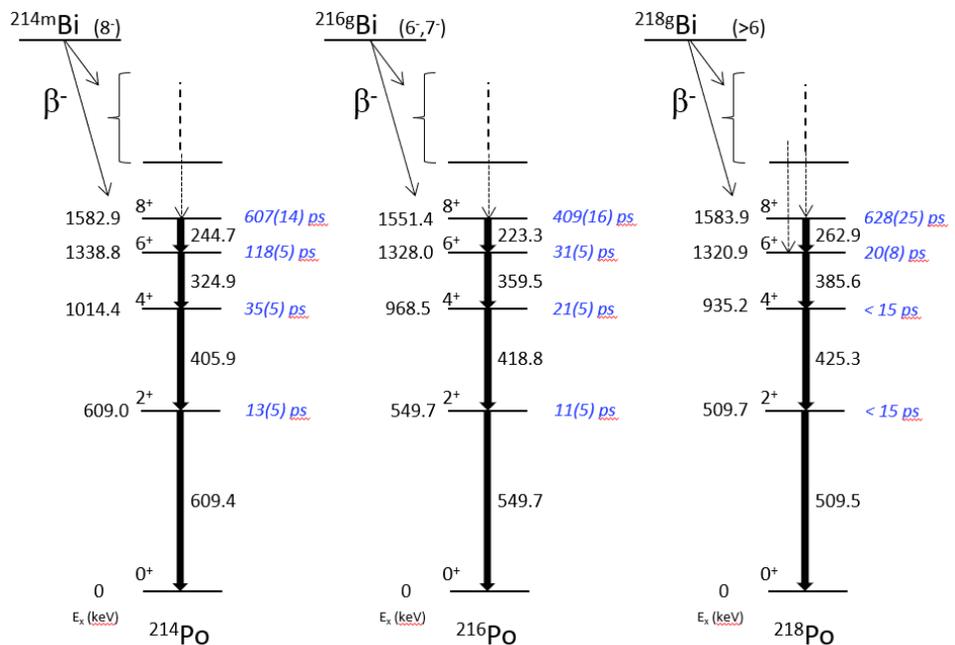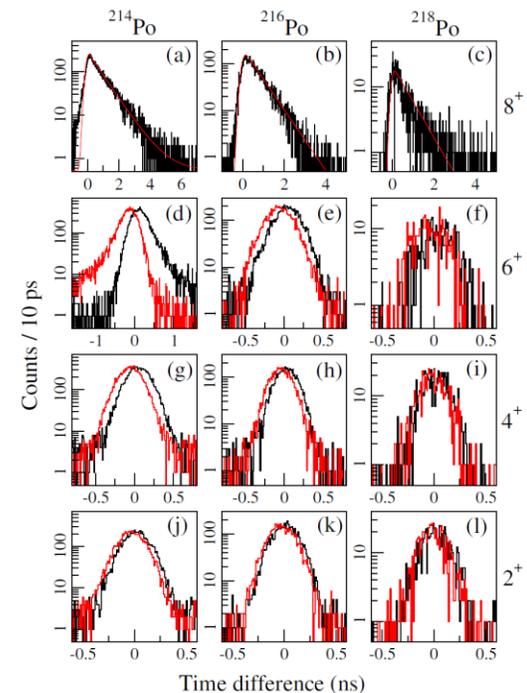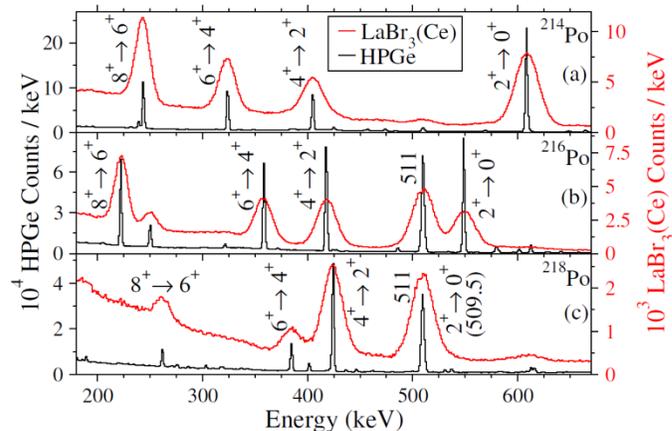
KHPE: Warburton and Brown, PRC **43**, 602 (1991)
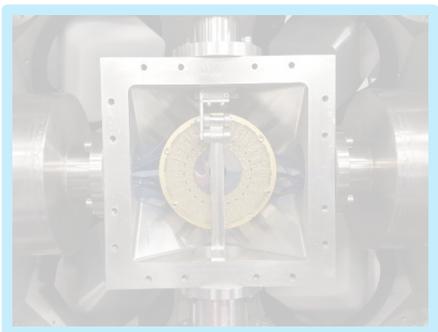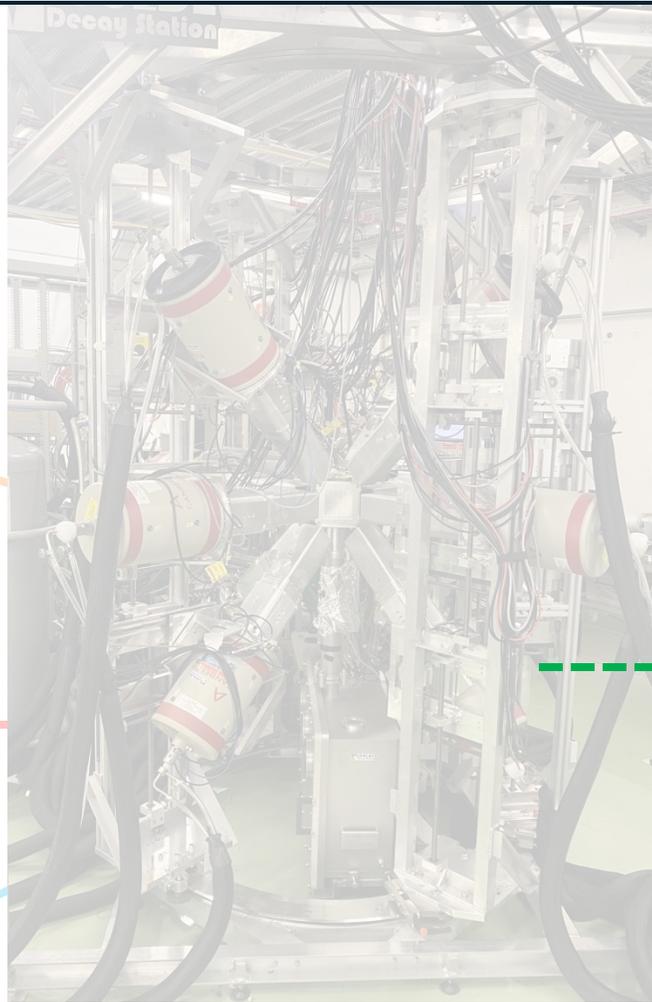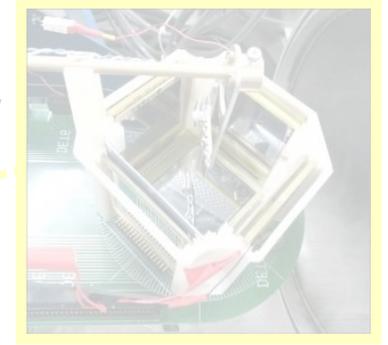H208: Naïdja, PRC **103**, 054303 (2021)
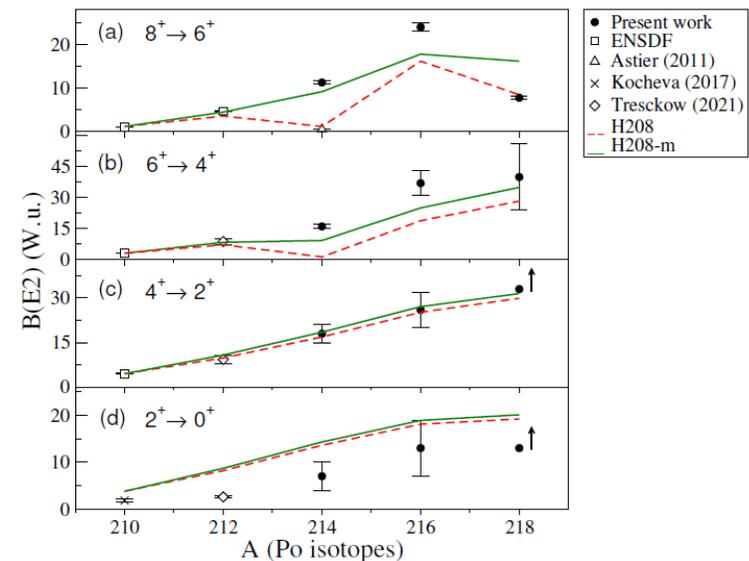
Ancillary systems

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Charged-particle Spectroscopy

Fast-timing
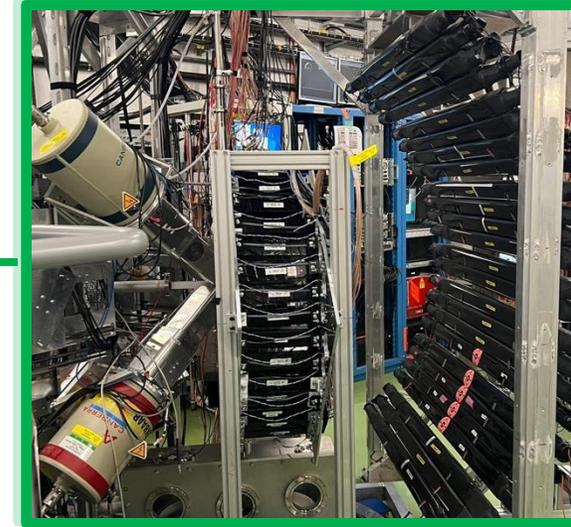
Neutron Spectroscopy

Conversion electrons

TD-PAC – Coming "soon"

- System "specialised" to needs of particular experiment
- Easily interchangeable, and compatible with each other

Plastic scints. (β tagging)

Selective Gamow-Teller transformations populate highly exited states in daughter nucleus.

Particle emission from C.N. modeled with Hauser-Feshbach formalism, depends only on spins, parities and E*...

N=34 Z=19

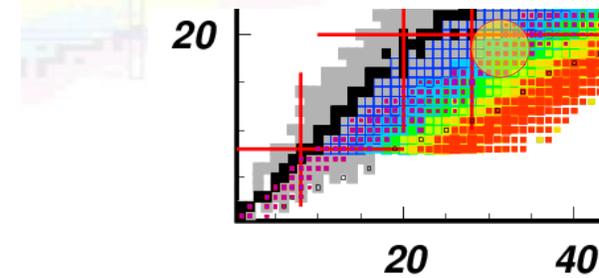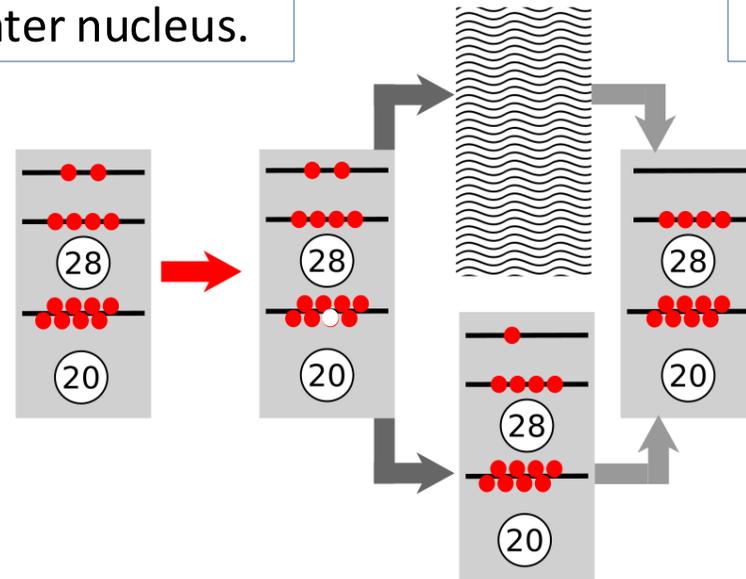... direct neutron emission, may depend also on details of nuclear structure.

Decays near doubly magic-nuclei candidates for the testing universality of the C.N. hypothesis.

"Evidence of nonstatistical neutron emission following β-decay near doubly magic 132Sn"
J. Heideman et al. (IDS Collaboration) Phys. Rev. C 108, 024311(2023)
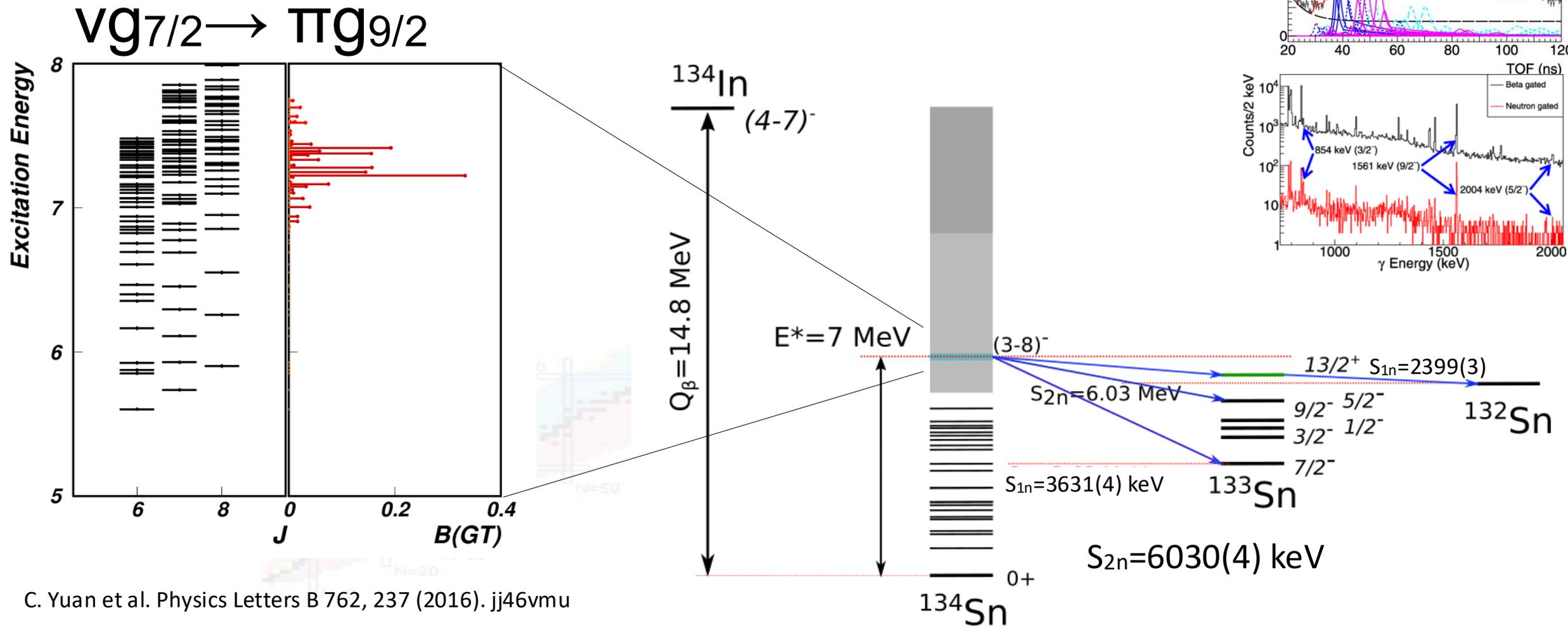**Z. Y. Xu et al. Phys. Rev. Lett. 133, 042501 (2024)**

$$\nu g_{7/2} \rightarrow \pi g_{9/2}$$

C. Yuan et al. Physics Letters B 762, 237 (2016). jj46vmu

$S_{2n}=6030(4)$ keV

S$_{1n}$=2399(3)

S$_{2n}$=6.03 MeV

S$_{1n}$=3631(4) keV

Q$_\beta$=14.8 MeV

E*=7 MeV

Grzywacz for IS662 coll.

13

β2n spectroscopy of ^{134}In and search for $i_{13/2}$ in ^{133}In
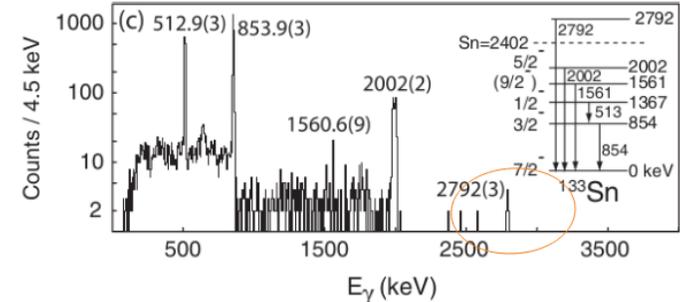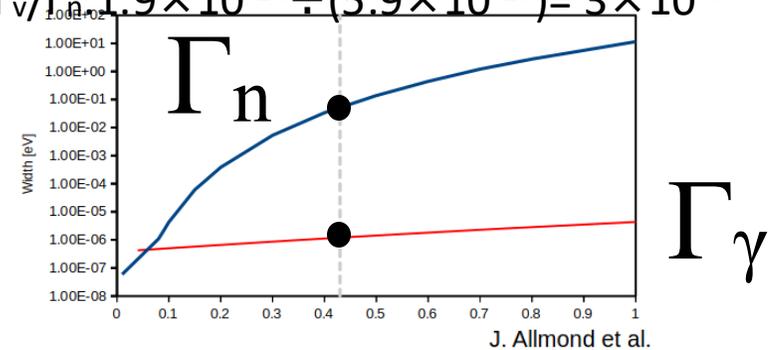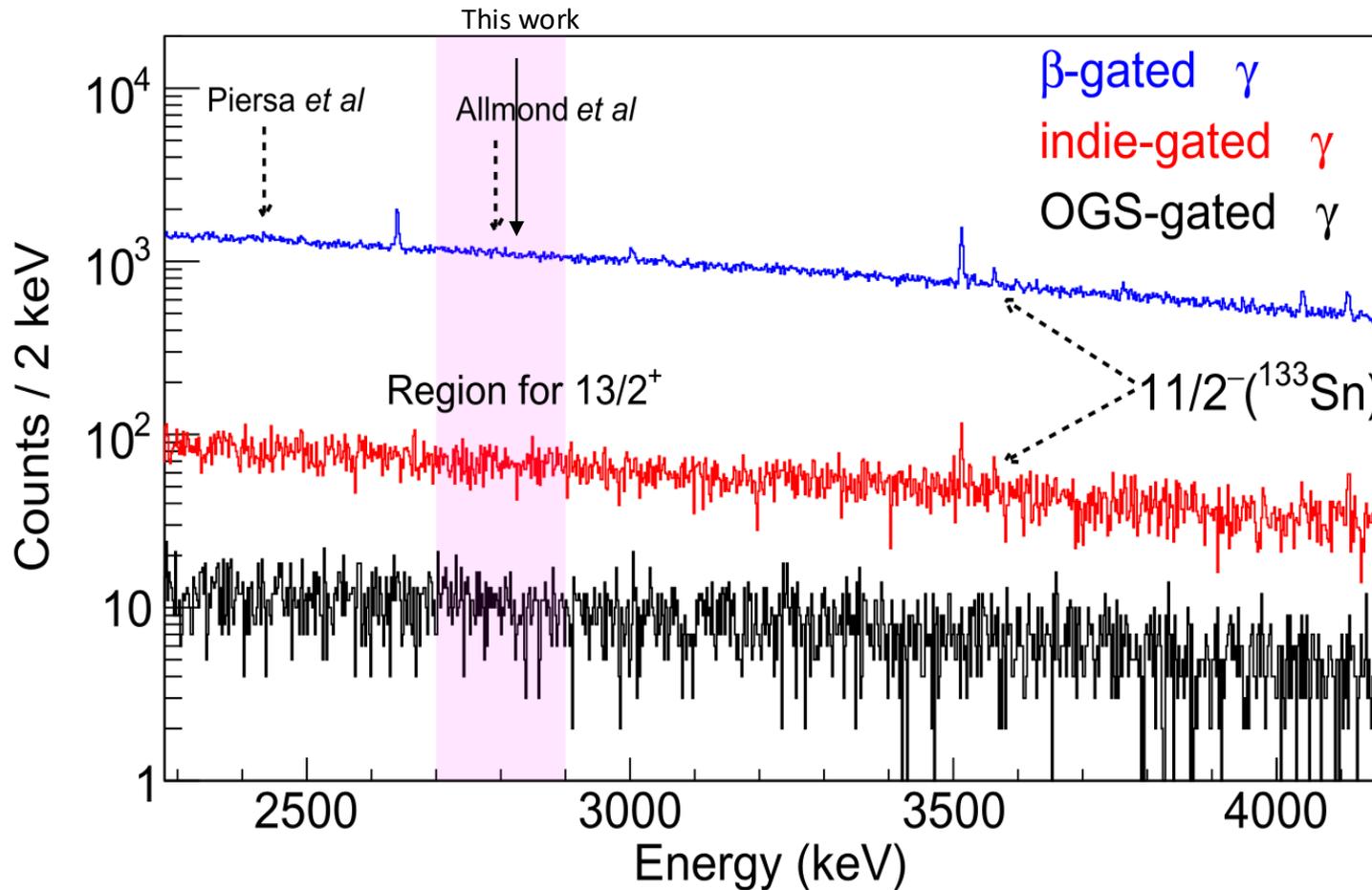
Unbound $i_{13/2}$ resonance (L=6) at 2830(10) keV
0.430 MeV above S_n in ^{133}Sn
(Consistent with B. Kay result from (d,p))

Γ_n= 0.03 eV (Woods-Saxon potential)
τ=6.58x10^{-16}/0.03 = 1.9×10^{-14} s

$T_{1/2\_w}$(E3)=8.5×10^{-10} s Γ= 7.7x10^{-7} eV
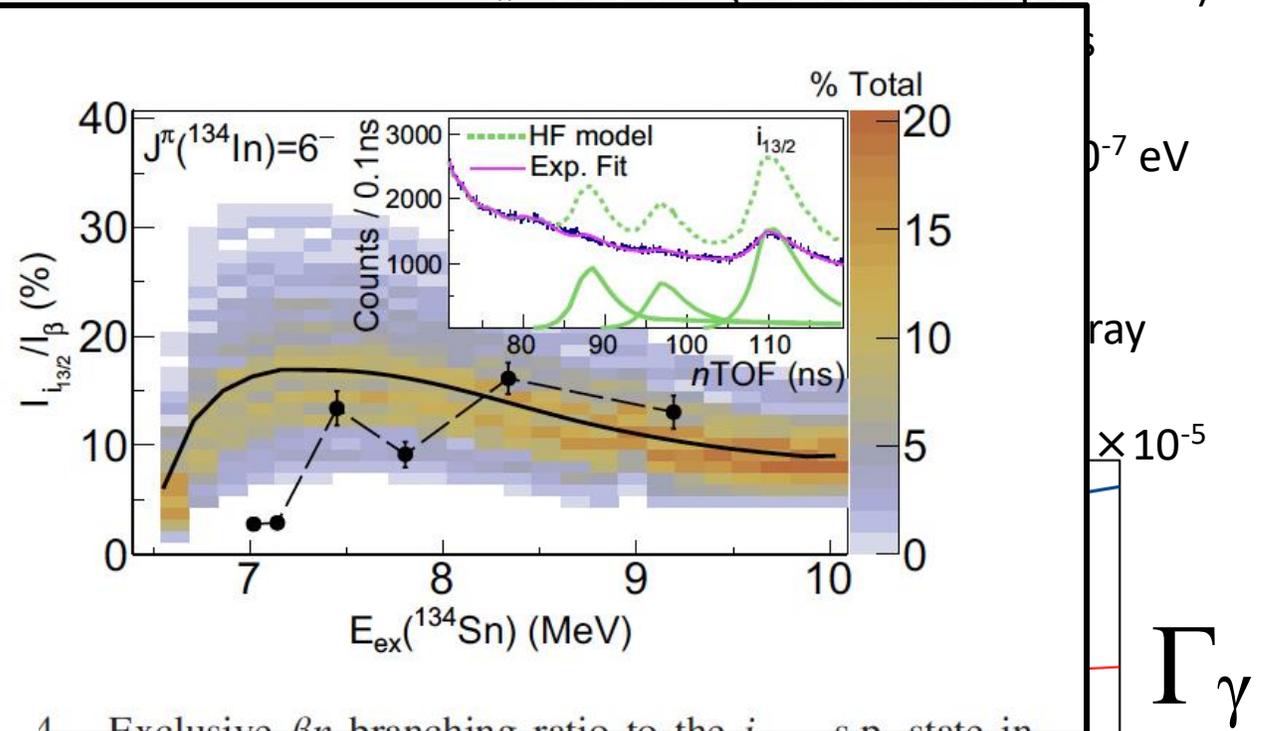τ=ln(2)*$T_{1/2\_w}$=5.89×10^{-10}s

Negligible chance to observe γ-ray

Γ_v/Γ_n=1.9×10^{-14} ÷ (5.9×10^{-10})= 3×10^{-5}

This work

Piersa et al   Allmond et al

β-gated γ
indie-gated γ
OGS-gated γ

Region for 13/2$^+$

11/2$^-$(^{133}Sn)

Γ_n Γ_γ

J. Allmond et al.

14

Unbound $i_{13/2}$ resonance (L=6) at 2830(10) keV
0.430 MeV above S_n in ^{133}Sn
(Consistent with B. Kay result from (d,p))

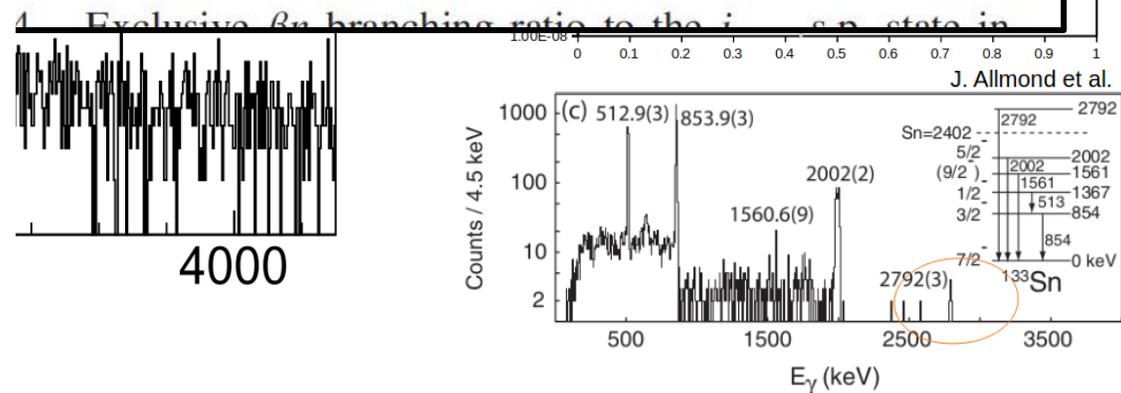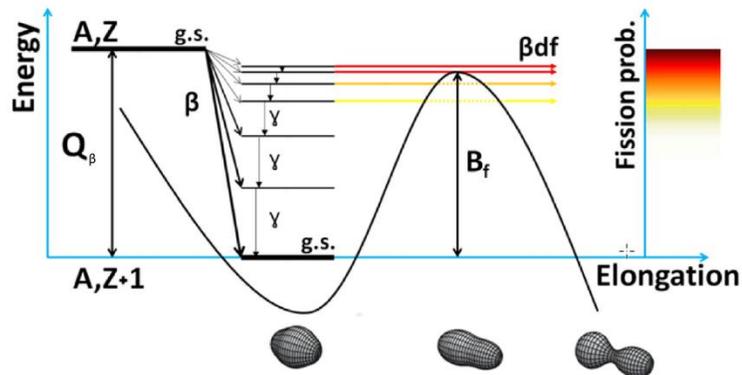Γ_n= 0.03 eV   (Woods-Saxon potential)

This work

Piersa et al

Allmond et al

Region for 13/2$^+$

PHYSICAL REVIEW LETTERS VOL..XX, 000000 (XXXX)

10^{-7} eV

ray

$\times 10^{-5}$

Γ_γ

J. Allmond et al.
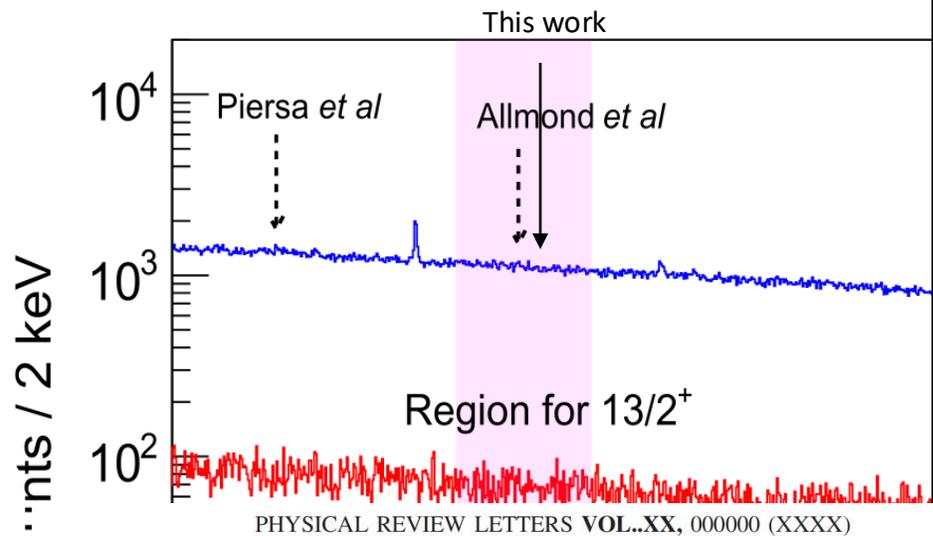
P. Dyszel,[1] R. Grzywacz,[1] Z. Y. Xu,[1] N. Kitamura,[2] M. Karny,[3] A. Korgul,[3] M. Madurga,[1] S. Neupane,[4]
A. Algora,[5] A. N. Andreyev,[6] M. Araszkiewicz,[3,7] R. A. Bark,[8] J. Benito,[9] N. Bernier,[9] M. J. G. Borge,[10]
M. Caballero,[9] P. Chuchala,[3] T. E. Cocolios,[11] C. Costache,[12] J. G. Cubiss,[6,13] H. DeWitte,[11] J. E. Escher,[4]
D. Fernandez-Ruiz,[10] A. Fijalkowska,[3] L. M. Fraile,[9] H. O. U. Fynbo,[14] J. Gouge,[1] J. L. Herraiz,[9] A. Illana,[9]
P. M. Jones,[8] D. S. Judson,[15] P. Kamińska,[3] T. Kawano,[16] K. Kolos,[4] M. Labiche,[17] R. Licǎ,[12] M. Llanos-Expósito,[9]
G. G. DeLorenzo,[9] N. Marginean,[12] I. Michelon,[18] C. Mihai,[12] E. Nácher,[5] C. Neacsu,[12] J. S. Nielsen,[14] B. Olaizola,[10]
J. N. Orce,[19] C. A. A. Page,[6] R. D. Page,[15] J. Pakarinen,[20,21] A. Perea,[10] M. Piersa-Siłkowska,[1,9,22] Zs. Podolyák,[23]
J. S. Prieto,[10] M. Rajabali,[24] J. Shaw,[11] K. Solak,[3] M. Stryjczyk,[25,20] O. Tengblad,[10] P. G. T. Vicente,[9] N. Warr,[26]
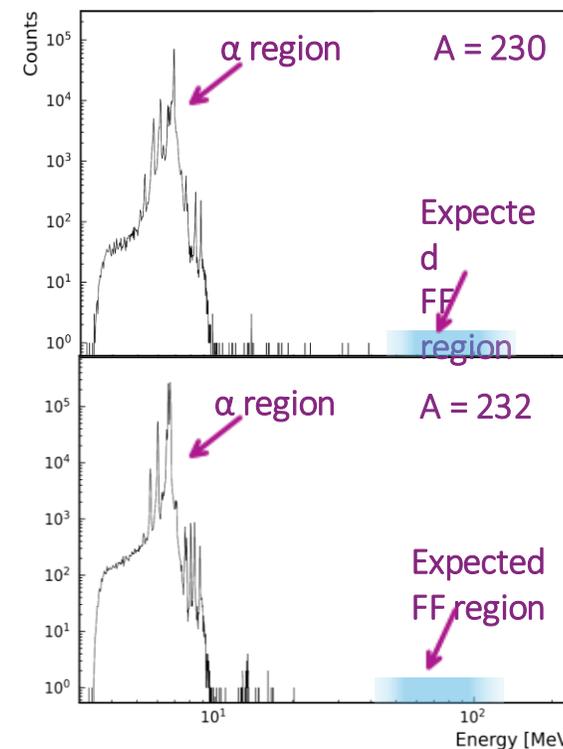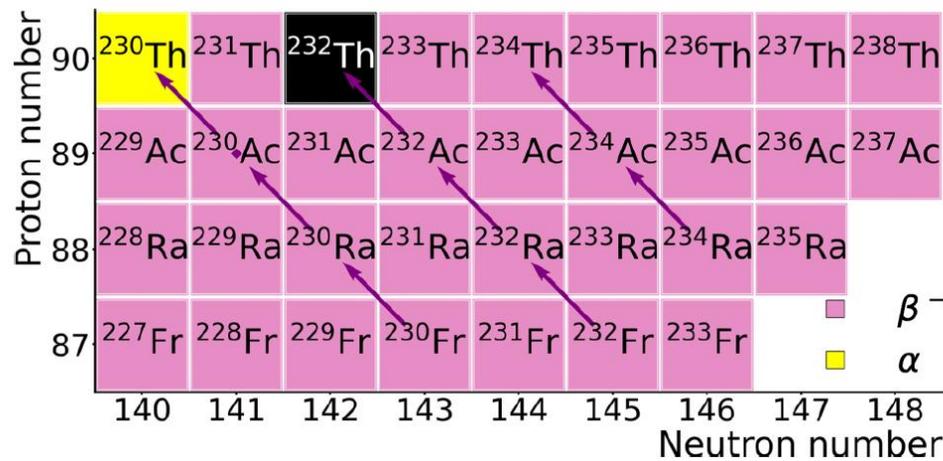J. Wilson,[6] Z. Yue,[6] and S. Zajda[3]

(IDS Collaboration)

$J^\pi(^{134}$In)=6$^-$

HF model
Exp. Fit

$i_{13/2}$

% Total

4 Exclusive βn branching ratio to the $i_{13/2}$ s.p. state in

(c) 512.9(3) | 853.9(3)

Sn=2402

2002(2)

1560.6(9)

2792(3)

^{133}Sn

LOI216: βDF of ^{230,232,234}Ac

- Probability of βDF
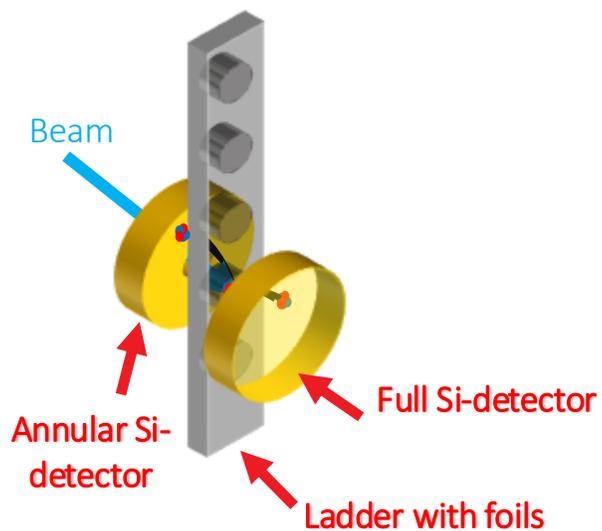
- $P_{\beta DF} = \dfrac{N_{\beta DF}}{N_{\beta}}$

Results
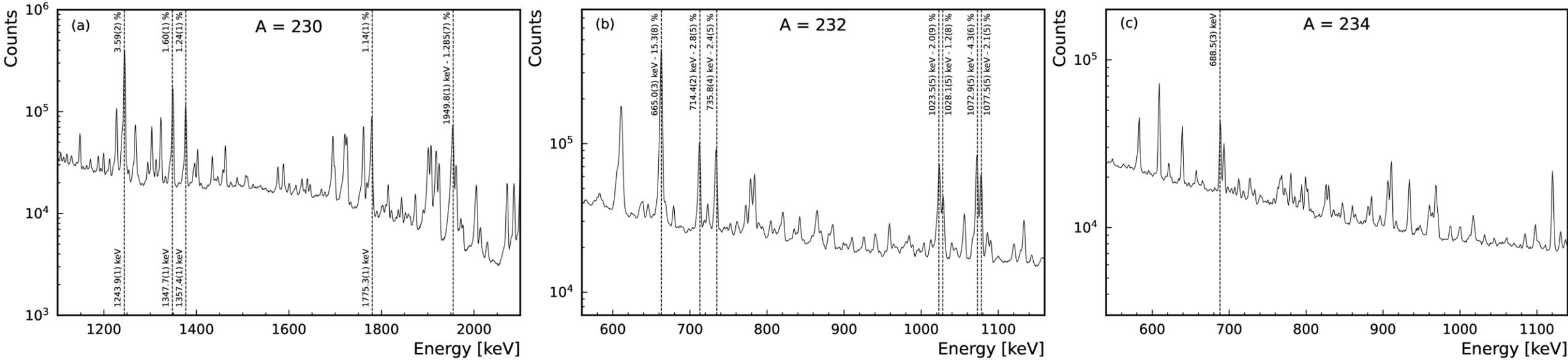
(a) A = 230
Counts vs Energy [keV]
3.59(2) %
1.60(1) %
1.24(1) %
1.14(1) %
1949.8(1) keV - 1.285(7) %
1243.9(1) keV
1347.7(1) keV
1357.4(1) keV
1775.3(1) keV

(b) A = 232
665.0(3) keV - 15.3(8) %
714.4(2) keV - 2.8(5) %
735.8(4) keV - 2.4(5) %
1023.5(5) keV - 2.0(9) %
1028.1(5) keV - 1.2(8) %
1072.9(5) keV - 4.3(6) %
1077.5(5) keV - 2.1(5) %

(c) A = 234
688.5(3) keV

$$P_{\beta DF}= \frac{1.84^{*}}{\frac{N_{\gamma}}{I_{\gamma}\cdot\varepsilon_{\gamma}}\cdot\varepsilon_{FF}}$$

$$T_{1/2p,\beta DF}= \frac{T_{1/2}}{P_{\beta DF}}$$

* 1.84 is the upper limit of Poisson's distribution of 0 observed events with a confidence level of 84% [10]

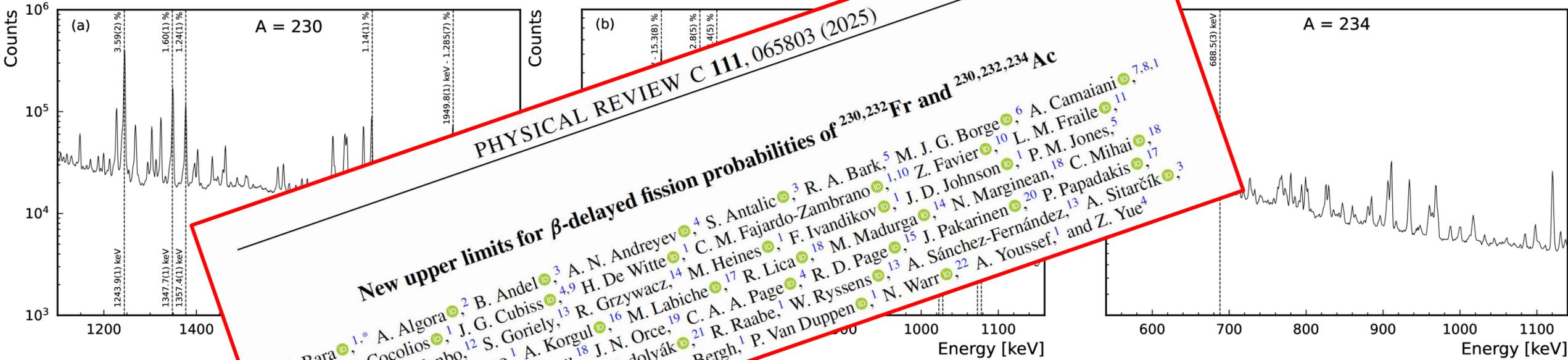| Isotope	N_{β}	$P_{\beta DF}$			$T_{1/2p,\beta DF}$
		Lit.		This work [11]	
^{230}Fr	$1.4(1)\cdot10^{8}$	$< 3\cdot10^{-6}$	[9]	$< 3.5\cdot10^{-8}$	$> 5.8\cdot10^{8}$
^{232}Fr	$4.3(10)\cdot10^{7}$	$< 2\cdot10^{-6}$	[9]	$< 1.3\cdot10^{-7}$	$> 4.2\cdot10^{7}$
^{230}Ac	$1.02(4)\cdot10^{10}$	$1.19(40)\cdot10^{-8}$	[6]	$< 4.7\cdot10^{-10}$	$> 2.8\cdot10^{11}$
^{232}Ac	$1.50(8)\cdot10^{9}$	$< 10^{-6}$	[9]	$< 3.2\cdot10^{-9}$	$> 4.4\cdot10^{10}$
^{234}Ac	$8.4(29)\cdot10^{6}$	/		$< 4.9\cdot10^{-6}$	$> 9.0\cdot10^{6}$

[6] Y. Shuanggui et al., Eur. Phy. J. A 10, 1-3 (2001).
[9] K. A. Mezilev et al., Zeitschrift für Physik A Atomic Nuclei 337, 109 (1990).
[10] K.-H. Schmidt et al., Z. Phys. A – Atoms and Nuclei 316, 19-26 (1984).
[11] S. Bara et al., Phys. Rev. C, 111, 065803 (2025)

Results

$$P_{\beta DF}= \frac{1.8...}{\frac{N_\gamma}{I_\gamma \cdot \varepsilon_\gamma} \cdot \varepsilon...}$$

$$T_{1/2p,\beta DF}= \frac{T_{1/2}}{P_{\beta DF}}$$

* 1.84 is the upper limit of Poisson's distribution of 0
observed events with a confidence level of 84% [10]

PHYSICAL REVIEW C 111, 065803 (2025)

New upper limits for β-delayed fission probabilities of ^{230,232}Fr and ^{230,232,234}Ac

S. Bara,[1,*] A. Algora,[2] B. Andel,[3] A. N. Andreyev,[4] S. Antalic,[3] R. A. Bark,[5] M. J. G. Borge,[6] A. Camaiani,[7,8,1]
T. E. Cocolios,[1] J. G. Cubiss,[4,9] H. De Witte,[1] C. M. Fajardo-Zambrano,[1,10] Z. Favier,[10] L. M. Fraile,[11]
H. O. U. Fynbo,[12] S. Goriely,[13] R. Grzywacz,[14] M. Heines,[1] F. Ivandikov,[1] J. D. Johnson,[1] P. M. Jones,[5]
D. S. Judson,[15] J. Klimo,[1] A. Korgul,[16] M. Labiche,[17] R. Lica,[18] M. Madurga,[14] N. Marginean,[20] P. Papadakis,[17] C. Mihai,[18]
J. Mišt,[3] E. Nácher,[2] C. Neacsu,[18] J. N. Orce,[19] C. A. A. Page,[4] R. D. Page,[15] J. Pakarinen,[13] A. Sitarčík,[3]
A. Perea,[6] M. Piersa-Siłkowska,[11] V. Van Den Bergh,[1] R. Raabe,[1] W. Ryssens,[1] N. Warr,[22] A. Youssef,[4] and Z. Yue[4]
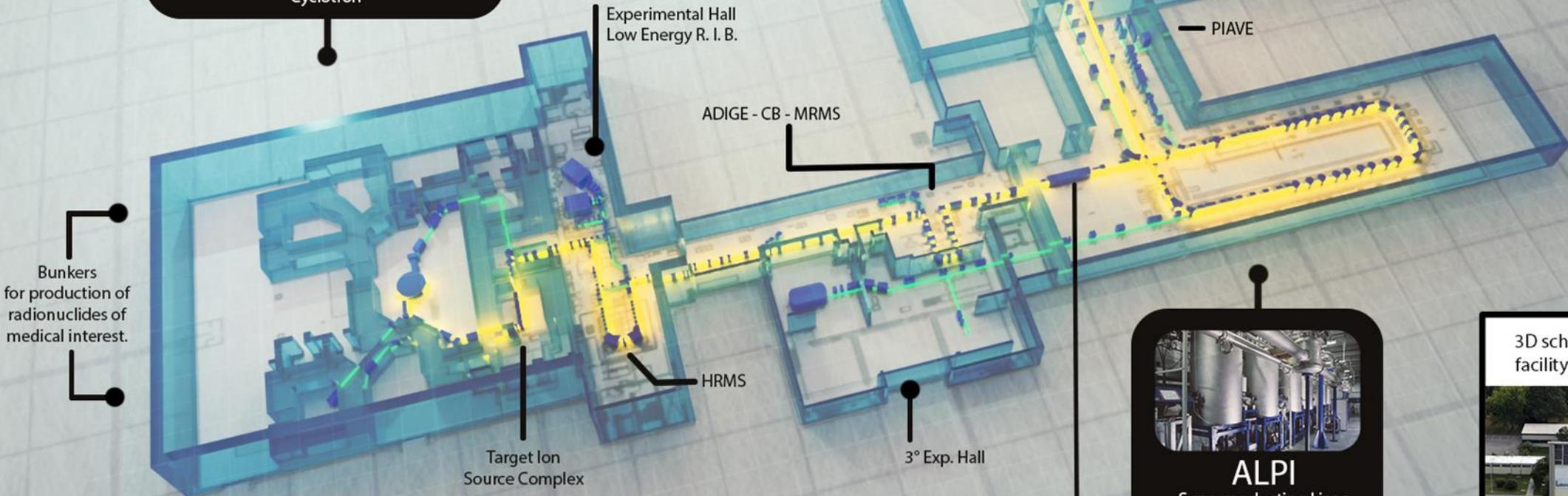O. Tengblad,[6] J. M. Udías,

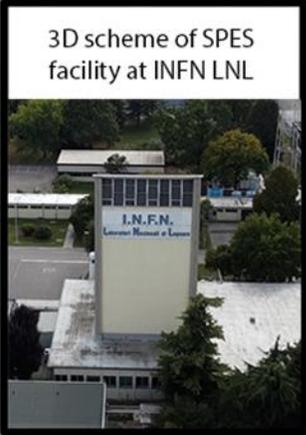| Isotope	N_β	$P_{\beta DF}$			$T_{1/2p, \beta DF}$
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[10] K.-H. Schmidt et al., Z. Phys. A – Atoms and Nuclei 316, 19-26 (1984).
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IDS++

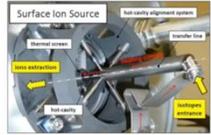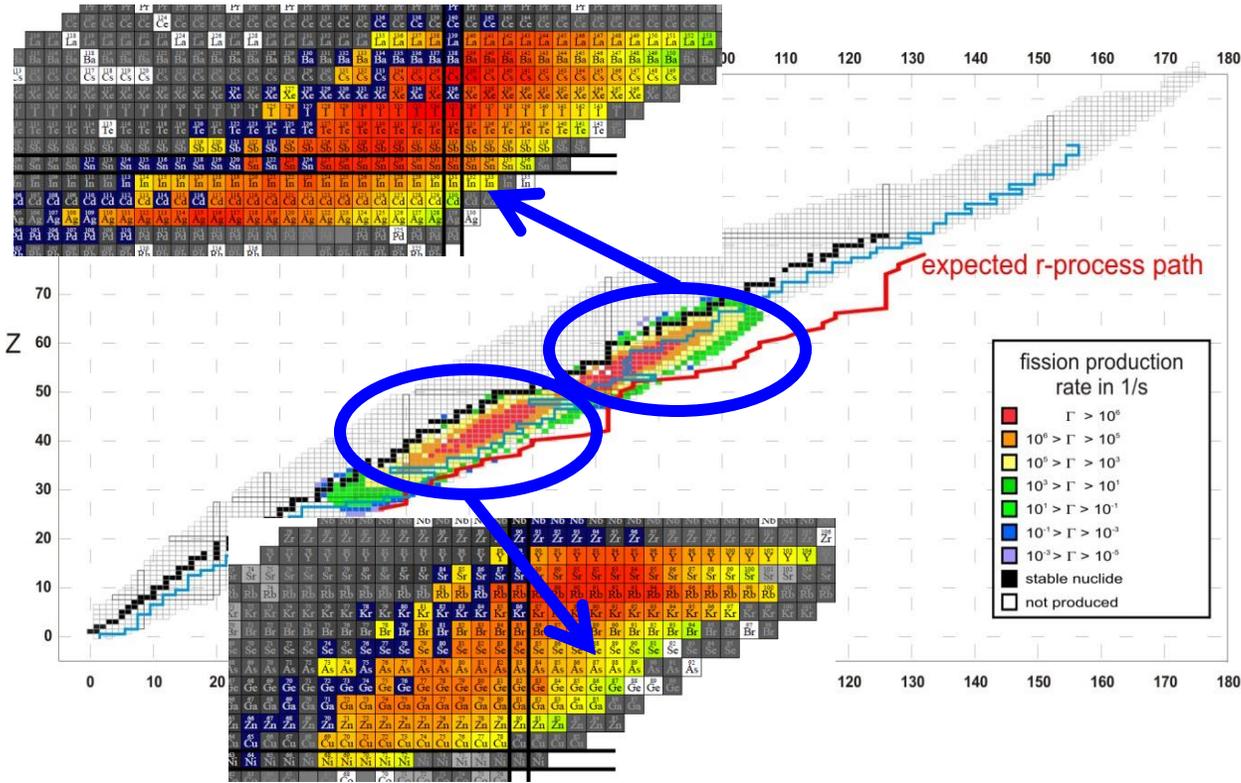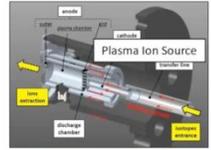## New conversion e- setups

New SPEDE chamber

SLICES (LN$_2$ cooled)
[Marchini *et al.*, NIM A **1020**, 165860 (2021)]

Fully digital fast-timing setup – increase #detectors

500 MHz pixie
FWHM = 360 ps

Analogue: ~150 ps

Collaborate with ion-source and laser teams

R. Heinke *et al.*, *Hyperfine Interactions* **238**, 6 (2017)

Full neutron setup: INDiE + NEXT + OGS

Two NEXT arrays, 24 total modules

3D scheme of SPES facility at INFN LNL

Neutron-rich fission products
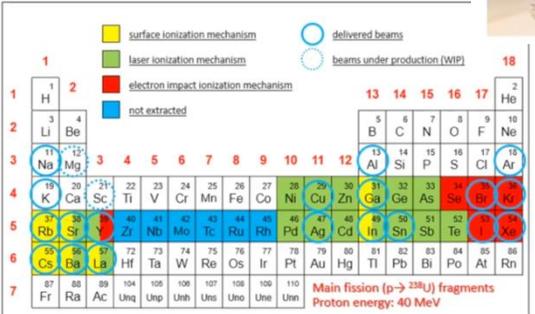
Several extraction schemes
Complementing with new
materials SiC, ZrGe, TiC

- Phase 1: Operation of the SPES cyclotron April 2024 and first experiment May 2024
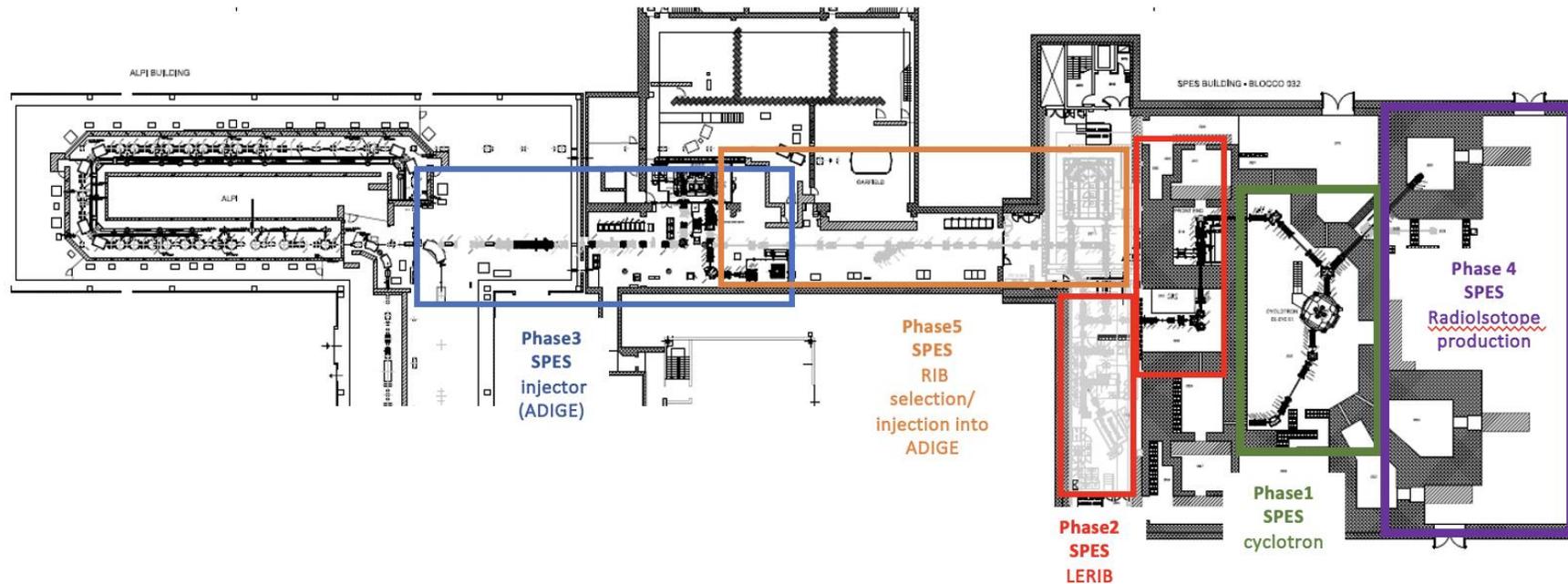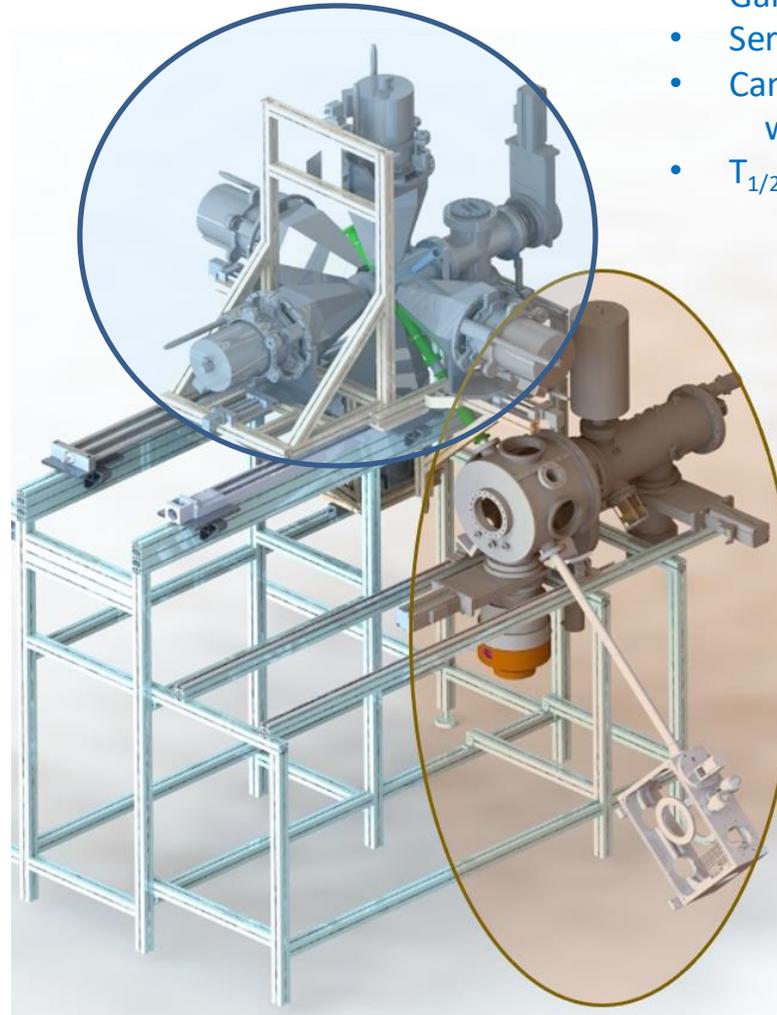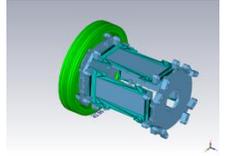- **Phase 2: Commissioning of the ISOL low-energy radioactive beams: 2024 – spring 2025**
- Phase 3: Complete the ADIGE new injector and RFQ for ALPI (SPES post-accelerator)
- Phase 4: Radioisotope production facility
- Phase 5: Commissioning of post-accelerated radioactive beams (SiC target)

b-DS +SLICES in A13 @SPES

- beta tagging by EJ212 array SiPM readout
- Gamma detection using 5 GTC+AC
- Served by tape to remove bg.
- Can be complemented
    w/scintillator detectors (LaBr3(Ce))
- $T_{1/2}$, decay scheme, P_n via g discrimination

A. Saltarelli [a b], G. Benzoni [c] ✉, E.R. Gamba [d c e], C. Boiano [c], C. Cialdai [f], A. Goasduff [g], N. Marchini [f], A. Nannini [f], M. Ottanelli [f], M. Perri [a b f], M. Rocchini [f], N. Toniolo [g]

- Second position SLICES array for E0 and CE
- Large area (~ 3900 mm^2) Si(Li) detector 6.8 mm thick segmented in 32 sectors
- Magnetic Transport System
- Plastic Scintillator + HPGe

N. Marchini et al. PRC 105, 054304 (2021)
N.Marchini et al. NIMA 1020, 165860 (2021)

INFN
Milano
Istituto Nazionale di Fisica Nucleare
Sezione di Milano

b-DS +SLICES in A13 @SPES

Position of the ^{207}Bi source:
— Outside the chamber
— Inside the chamber

Normalized counts vs Integrated charge (a.u.)

511 keV

1779 keV ^{28}Si 2^+

HPGe singles
HPGe coinc

t1/2=2.25 min

Counts / 1 keV vs E_γ (keV)

- beta tagging by EJ212 array SiPM readout
- Gamma detection using 5 GTC+AC
- Served by tape to remove bg.
- Can be complemented
  w/scintillator detectors (LaBr3(Ce))
- $T_{1/2}$, decay scheme, P_n via g discrimination

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 1082, Part 2, February 2026, 170927

Full Length Article

Installation of a β-decay station at SPES

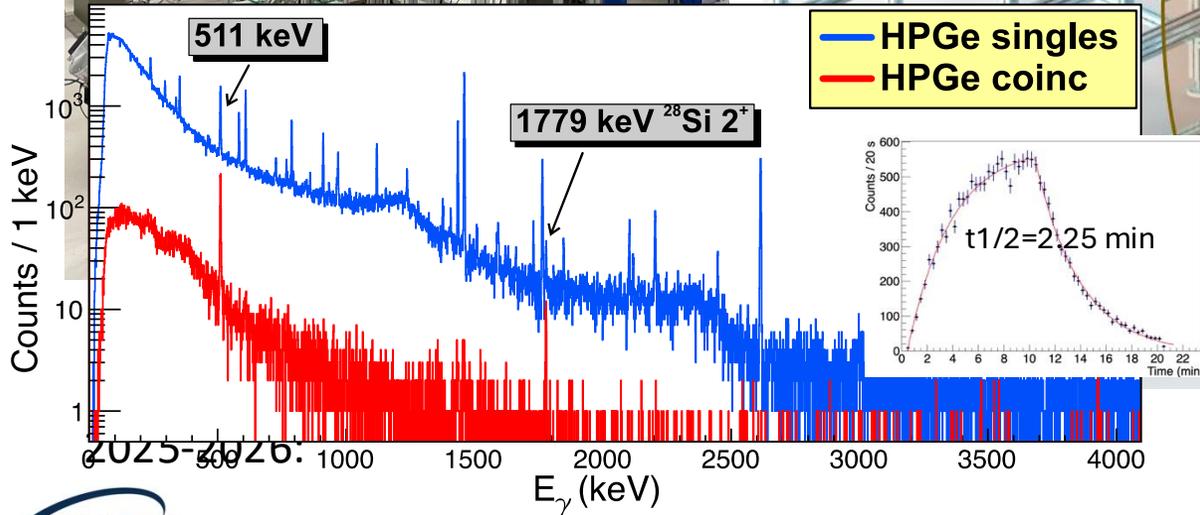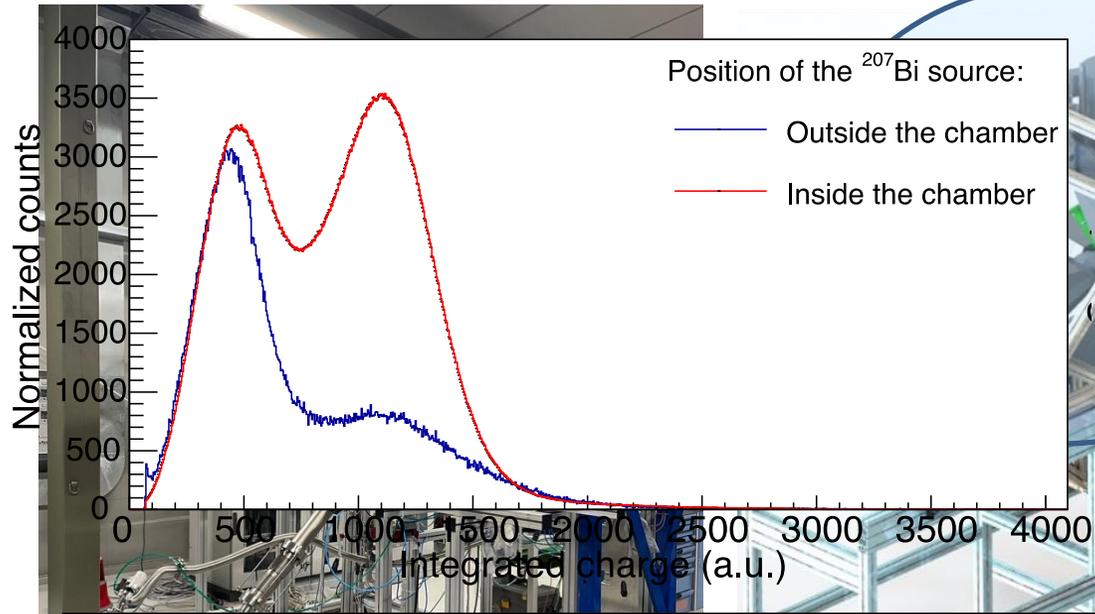A. Saltarelli [a b], G. Benzoni [c] ✉ 🖂, E.R. Gamba [d c e], C. Boiano [c], C. Cialdai [f], A. Goasduff [g], N. Marchini [f], A. Nannini [f], M. Ottanelli [f], M. Perri [a b f], M. Rocchini [f], N. Toniolo [g]

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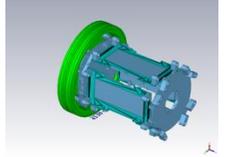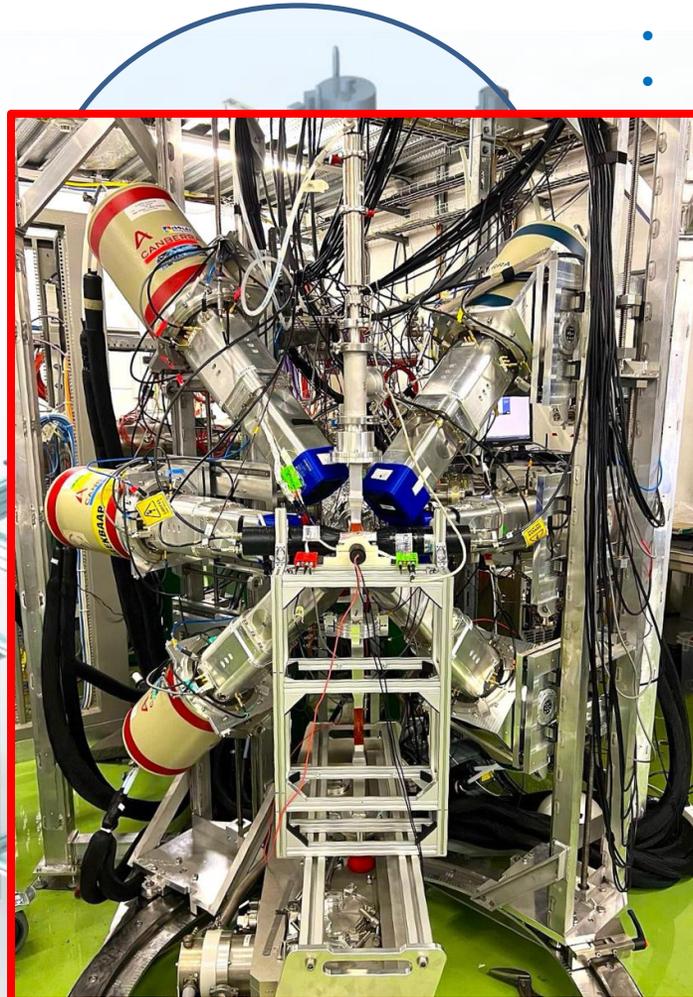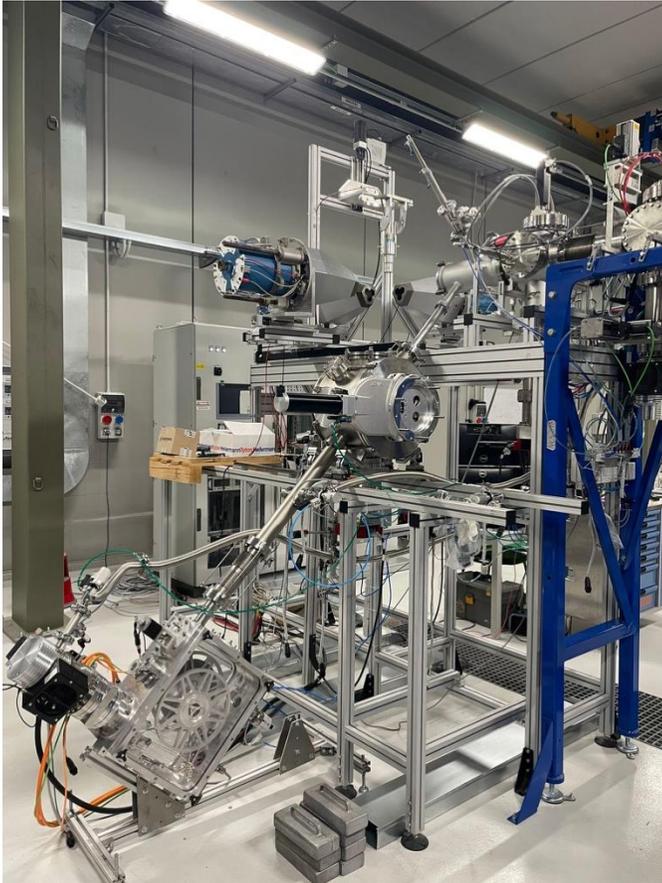- Magnetic Transport System
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N. Marchini et al. PRC 105, 054304 (2021)
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2025-2026:

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Sezione di Milano

b-DS +SLICES in A13 @SPES

- beta tagging by EJ212 array SiPM readout
- Gamma detection using 5 GTC+AC

Proposal for the Installation of the SLICES Spectrometer at the IDS

SLICES@IDS

- We propose SLICES at ISOLDE as an ancillary device for the IDS

- SLICES is highly complementary, and not in competition, to SPEDE in terms of electron energies that can be detected

- Physics case: *E0 measurements and shape coexistence in mid-mass nuclei* (here, the energy of the electrons is often in the MeV energy range)

- First recognition with James and Razvan last August, two possibilities for the installation:
  - Below the beam line, on the irradiation side
  - At the beam line level, behind the irradiation side

- This proposal has already been discussed within the INFN GAMMA experiment (nuclear spectroscopy groups of Camerino, Firenze, LNL, Milano and Padova), who supports the idea

- If agreed, we propose to work on this during LS3

IDS Collaboration Meeting   Marco Rocchini   8

Decay spectroscopy is a powerful tool to shed light into nuclear structure and new phenomena
Simple but ingeniously combined set-ups allow to investigate rare phenomena
IDS is paving the way thanks to ISOLDE know-how on beam production and delivery
AND dedication of young people

Soon to come on board are b-DS @ SPES and DESIR facility @ GANIL
Competitor to fragmentation facilities

THANK YOU