UK Nuclear Physics Update (2023)

- **UK Nuclear Physics Science includes research into:**
  - Nuclear Structure, Nuclear Reactions & Nuclear Astrophysics
  - Hadronic Physics
  - Nuclear Theory
  - Applications and Societal Benefits through instrument development and nuclear data application.
  - Also Involvement in some Network grants (UKNDN ; Early Diagnosis Network ; NuSEC Network)

‘Core’ UKRI funding comes via STFC (tensioned vs Particle Physics and Astronomy.

Paddy Regan: p.regan@surrey.ac.uk Paddy.regan@npl.co.uk

UK Nuclear Physics Update (2023)

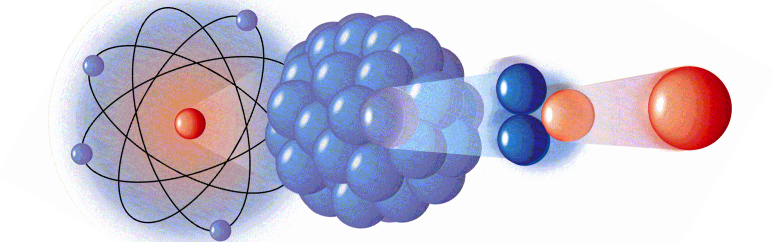
- **UK Nuclear Physics Science include experimental input investment, instrumentation and manpower for:**

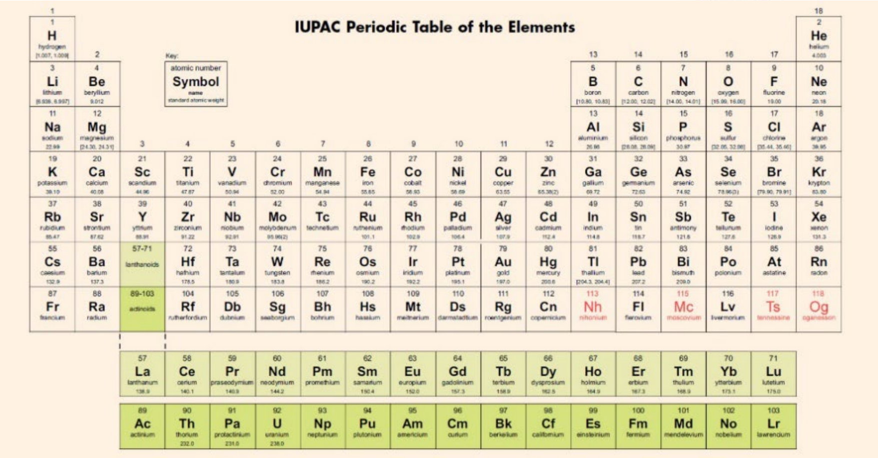
  - Nuclear Structure, Nuclear Reactions & Nuclear Astrophysics
    - Radioactive Ion Beam Facilities: FAIR (Germany) ; CERN-ISOLDE (Switzerland); RIBF-RIKEN (Japan) ; TRIUMF (Vancouver, Canada); GANIL (France).
    - Stable beam facilities inc. Argonne National Lab (USA); Jyvaskyla (Finland) ; Legnaro (Italy); Gran Sasso (Italy), others…

  - Hadronic Physics
    - (nucleon / parton distributions – including J-LAB (Virginia, USA)
    - Hot, dense nuclear matter) - including ALICE (CERN)

Some 'Big' Physics Questions?

1) What are the fundamental building block of matter ?
2) How can you see 'inside' an atomic nucleus / nucleons?
3) Where & when were the stable elements formed?
4) How do we measure very long / short radioactive decays?
5) What are some of the applications of nuclear science?

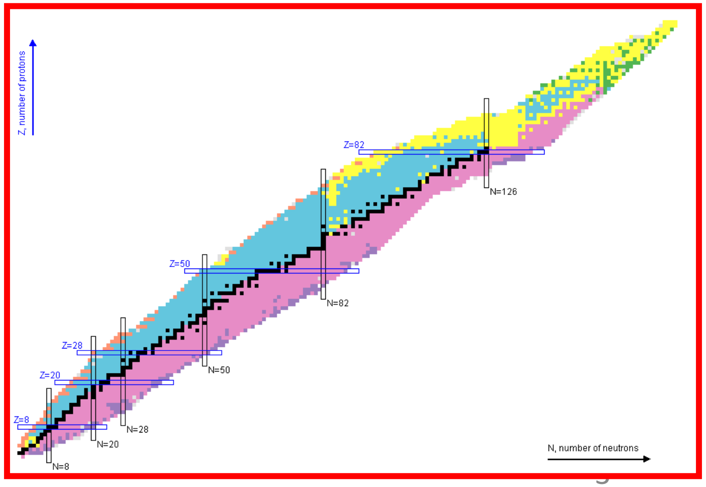




IUPAC Periodic Table of the Elements

Key:
atomic number
Symbol
name
standard atomic weight

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H hydrogen																	2 He helium
3 Li lithium	4 Be beryllium											5 B boron	6 C carbon	7 N nitrogen	8 O oxygen	9 F fluorine	10 Ne neon
11 Na sodium	12 Mg magnesium											13 Al aluminium	14 Si silicon	15 P phosphorus	16 S sulfur	17 Cl chlorine	18 Ar argon
19 K potassium	20 Ca calcium	21 Sc scandium	22 Ti titanium	23 V vanadium	24 Cr chromium	25 Mn manganese	26 Fe iron	27 Co cobalt	28 Ni nickel	29 Cu copper	30 Zn zinc	31 Ga gallium	32 Ge germanium	33 As arsenic	34 Se selenium	35 Br bromine	36 Kr krypton
37 Rb rubidium	38 Sr strontium	39 Y yttrium	40 Zr zirconium	41 Nb niobium	42 Mo molybdenum	43 Tc technetium	44 Ru ruthenium	45 Rh rhodium	46 Pd palladium	47 Ag silver	48 Cd cadmium	49 In indium	50 Sn tin	51 Sb antimony	52 Te tellurium	53 I iodine	54 Xe xenon
55 Cs caesium	56 Ba barium	57-71 lanthanoids	72 Hf hafnium	73 Ta tantalum	74 W tungsten	75 Re rhenium	76 Os osmium	77 Ir iridium	78 Pt platinum	79 Au gold	80 Hg mercury	81 Tl thallium	82 Pb lead	83 Bi bismuth	84 Po polonium	85 At astatine	86 Rn radon
87 Fr francium	88 Ra radium	89-103 actinoids	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Nh nihonium	114 Fl flerovium	115 Mc moscovium	116 Lv livermorium	117 Ts tennessine	118 Og oganesson
		57 La lanthanum	58 Ce cerium	59 Pr praseodymium	60 Nd neodymium	61 Pm promethium	62 Sm samarium	63 Eu europium	64 Gd gadolinium	65 Tb terbium	66 Dy dysprosium	67 Ho holmium	68 Er erbium	69 Tm thulium	70 Yb ytterbium	71 Lu lutetium	
		89 Ac actinium	90 Th thorium	91 Pa protactinium	92 U uranium	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium	



Size of the UK community

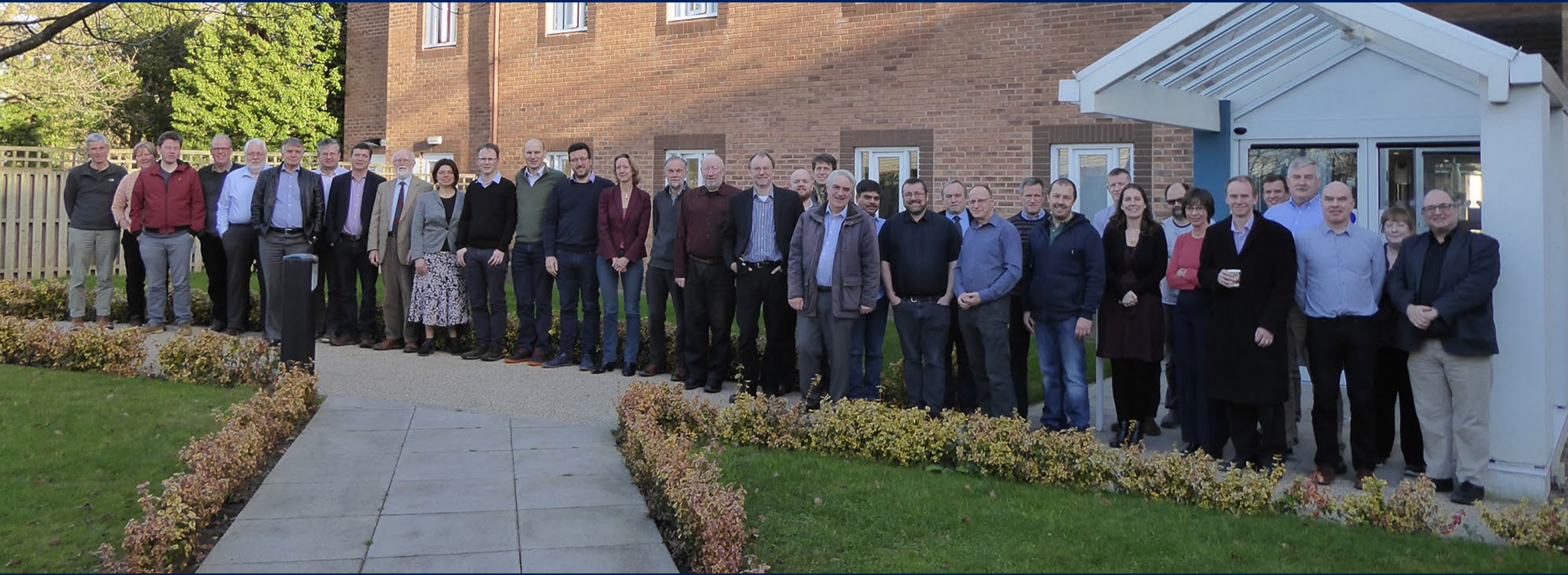
- There are ~70 academics / faculty staff @ 12 institutions carrying out nuclear physics research
  - Includes appointments via STFC ERF, UKRI-FLF, Roy. Soc Fel.
  - Almost all are University-based researchers

- ~90 PhD Research students across the community
  - ~40 - 50 funded by STFC quota plus a few iCASE etc.

- Nucl. Phys. Advisory Panel - Chair J. Dobczewski (York)
- Nucl. Phys. Grant Panel - Chair K. Flanagan (Manchester).

* UK Nucl. Phys. Community annually (10-11 Jan 2023 in IoP London)

* IoP Nucl. Phy. Conf. held each April (U. York, April 2023)



Nuclear Physics Community Meeting Jan 2022

Members of STFC - Nuclear Physics Avisory Panel (NPAP)

Jacek Dobaczewski (chair)	University of York
Rachel Montgomery	University of Glasgow
Philippos Papadakis	STFC
Pascal Reiter	University of Edinburgh
David Sharp	University of Manchester
Paul Stevenson	University of Surrey

Engaging with:

Science Board Liaison: David Ireland, University of Glasgow

PPAP Chair: Matthew Needham, University of Edinburgh

PAAP Chair: Sergey Burdin, University of Liverpool

The Nuclear Physics Strategy document

- Scope and range of Physics
- Current projects
- Future projects
- Other issues
- 10 year horizon

- Last one published 2019
- Update one due out later this year (2023).

The Physics of Nuclei
Nuclear Matter and
Nucleosynthesis

Report of the Nuclear Physics Advisory Panel

22 April 2016

https://stfc.ukri.org/about-us/how-we-are-governed/advisory-boards-panels-committees/nuclear-physics-advisory-panel/

2017 NuPECC Long Range plan. Chapter 6. APPLICATIONS AND SOCIETAL BENEFITS (renewal due out 2024 with lots of UK input)

NuPECC

NuPECC
Long Range Plan 2017
Perspectives
in Nuclear Physics

European Science Foundation

- Energy production: fission, fission.
- Health applications
  - therapy; imaging; radioisotope production; theranostics, etc.
- Radioprotection / health physics.
- Environmental radioactivity, space applications, climate science.
- Cultural Heritage science.
- Nuclear security; counter terrorism; Nuclear forensics.
- Materials science, nanotechnology.

http://www.esf.org/fileadmin/user_upload/esf/Nupecc-LRP2017.pdf

STFC Nuclear Physics Grants Panel (NPGP)

Nuclear Physics Grants Panel Membership 2023

Name	Institute	Expertise
Professor Kieran Flanagan (Chair)	Manchester	Nuclear Structure
Dr Nara Singh Bondili	UWS	Nuclear Structure
Prof. Jens Jorgen Gaardhoje	Copenhagen	Hadronic Physics
Dr Liam Gaffney – Liverpool	Liverpool	Nuclear Structure
Dr David Hamilton	Glasgow	Hadronic Physics
Professor Morten Hjorth-Jenson	MSU/Oslo	Nuclear Theory
Dr Marc Labiche	Daresbury Lab	Nuclear Structure
Professor Alison Laird	York	Nuclear Astrophysics
Dr Judith McGovern	Manchester	Nuclear Theory
Professor Zsolt Podolyak	Surrey	Nuclear Structure
Prof. Dan Watts	York	Hadronic Physics

Outcome (STFC) Statistics from previous rounds

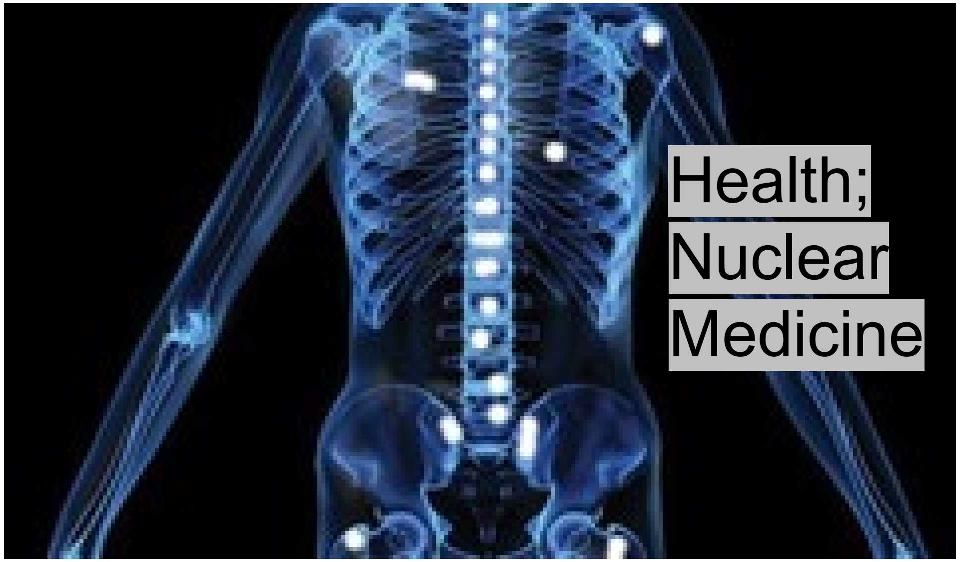
Measure	2011	2014	2017	2020
Number of proposals	8	8	8	8
Number of institutes	10	10	11	12
Number of scientific themes	34	35	35	33
Academics – Number (Requested)	46	52 (58)	53 (65)	45 (66)
Academics - Average FTE	14.5%	11%	9%	6%
Academics – Total FTE per year	**6.3**	**5.6**	**4.5**	**2.8**
PDRA – Number	29	21	27	23
PDRA - Total FTE per year	**18.3**	**16.1**	**18.2**	**19.0**
Core Posts – Number	11	12	9	9
Core Posts - Total FTE per year	**8.3**	**7.9**	**6.8**	**6.5**
Cross Community - Number	13	14	16	12
Cross Community - Total FTE per year	**12.1**	**10.3**	**11.3**	**10.3**
Number of Studentships	**2**	**1**	**3**	**3**
Technician - Total FTE per year	-	**2.1**	**2.9**	**3.9**
Total Number of FTE per year	47.0	43.0	46.7	45.6

TOTAL PDRAs including CORE RAs:
2017: 21.78 FTE / year
2020: 21.4 FTE / year

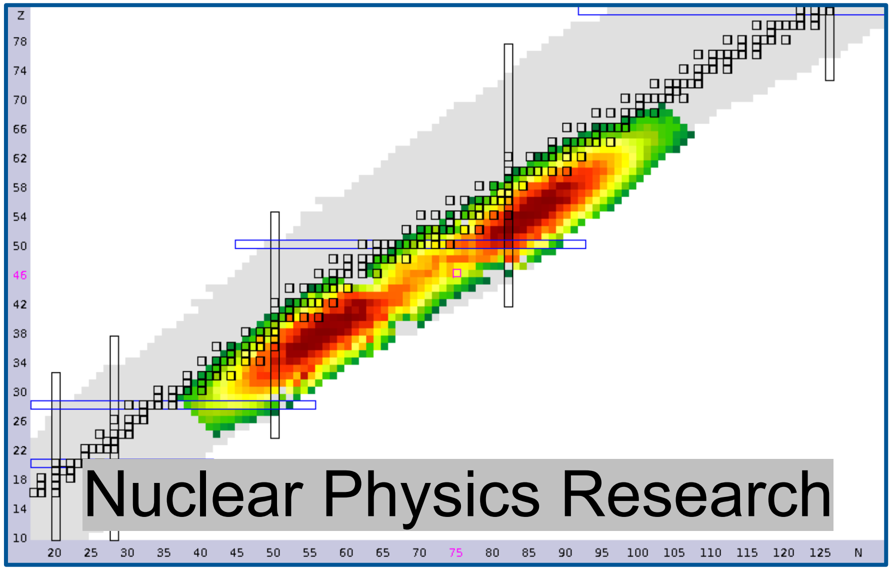
Impact from UK nuclear physics

Nuclear Energy & Decommissioning

Security & Environmental Monitoring

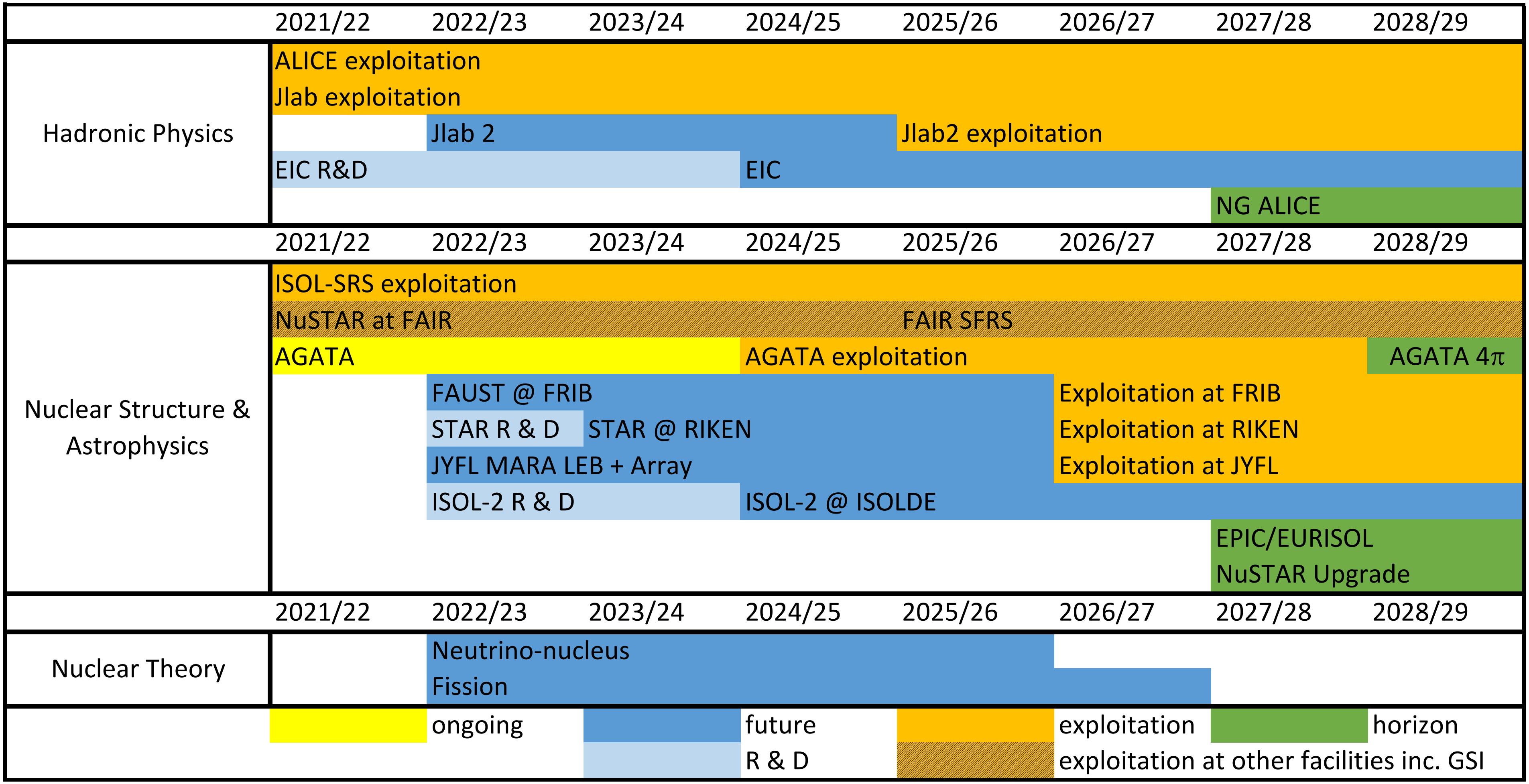


Health; Nuclear Medicine



Nuclear Physics Research

Roadmap for existing projects and future opportunities



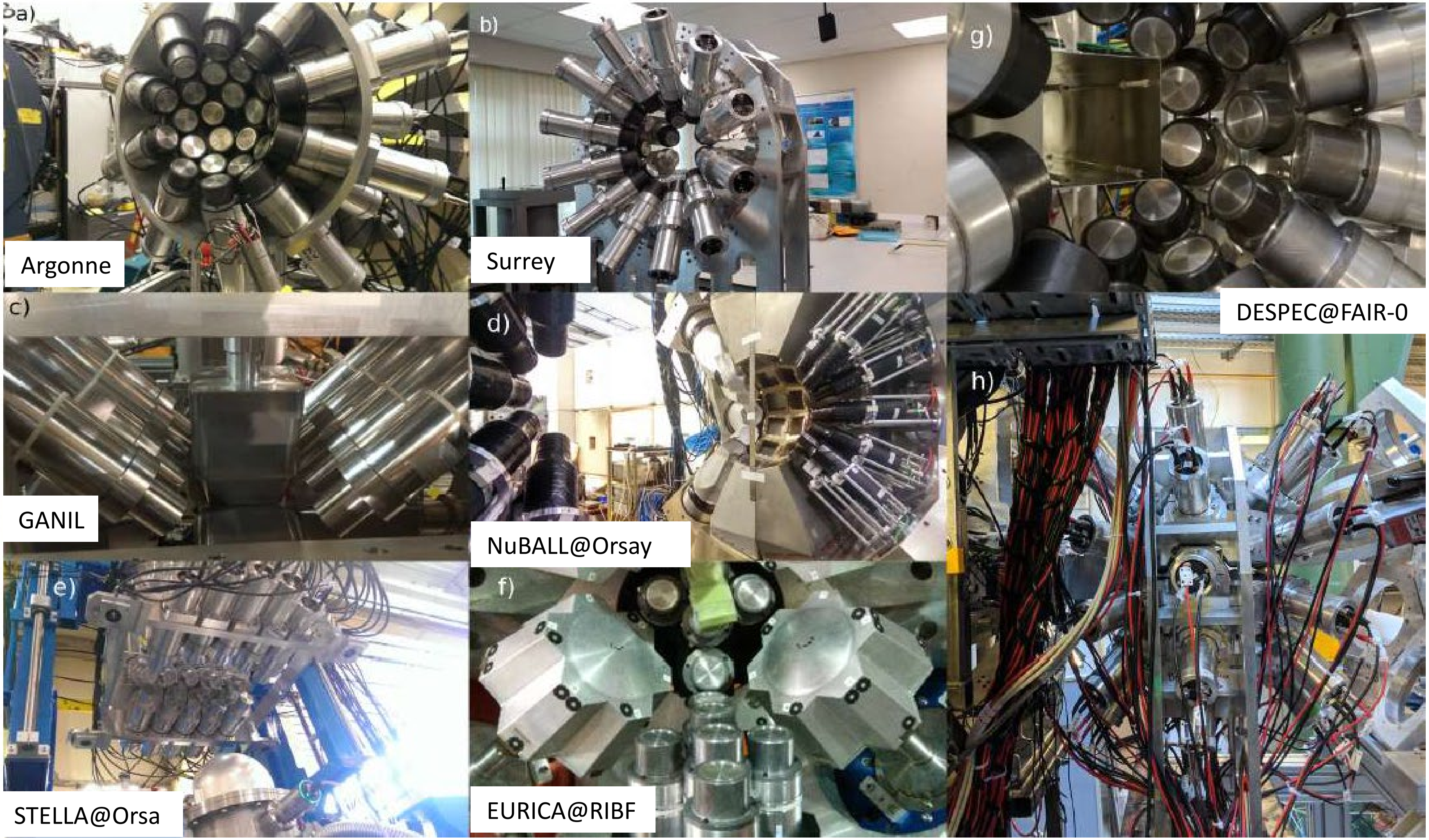
	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29
Hadronic Physics	ALICE exploitation							
	Jlab exploitation							
		Jlab 2			Jlab2 exploitation			
	EIC R&D			EIC				
							NG ALICE	
	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29
Nuclear Structure & Astrophysics	ISOL-SRS exploitation							
	NuSTAR at FAIR				FAIR SFRS			
	AGATA			AGATA exploitation				AGATA 4π
		FAUST @ FRIB				Exploitation at FRIB		
		STAR R & D	STAR @ RIKEN			Exploitation at RIKEN		
		JYFL MARA LEB + Array				Exploitation at JYFL		
		ISOL-2 R & D		ISOL-2 @ ISOLDE				
							EPIC/EURISOL	
							NuSTAR Upgrade	
	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29
Nuclear Theory		Neutrino-nucleus						
		Fission						
	🟨	ongoing	🟦	future	🟧	exploitation	🟩	horizon
			⬜	R & D	▨	exploitation at other facilities inc. GSI		

Examples of 2 STFC / UKRI funded nuclear phsyics detector projects:

1) Current: **FATIMA**

2) Future: **FAUST**

Design build & commission precision instrumentation (e.g. AGATA; J-LAB; ALICE@CERN; NuSTAR@FAIR; ISS@CERN-ISOLDE) and use them for UK 'buy in' at labs around the world… e.g The UK Fast TIMing Array (FATIMA) – 36 $LaBr_3$(Ce) gamma-ray spectrometers.

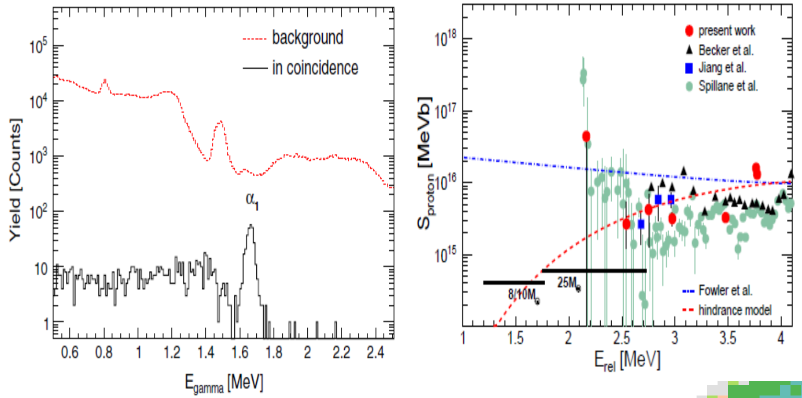


M. Rudigier, Zs. Podolyák, P.H. Regan et al.

Nuclear Inst. and Methods in Physics Research, A 969 (2020) 163967

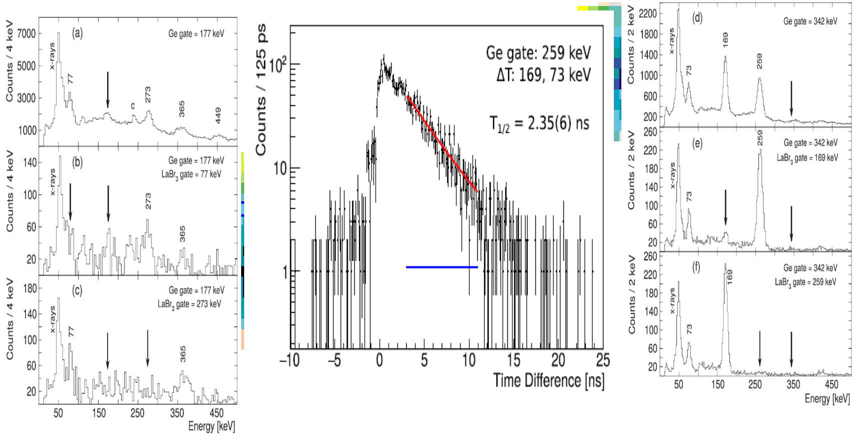
PHYSICAL REVIEW LETTERS **124**, 192701 (2020)

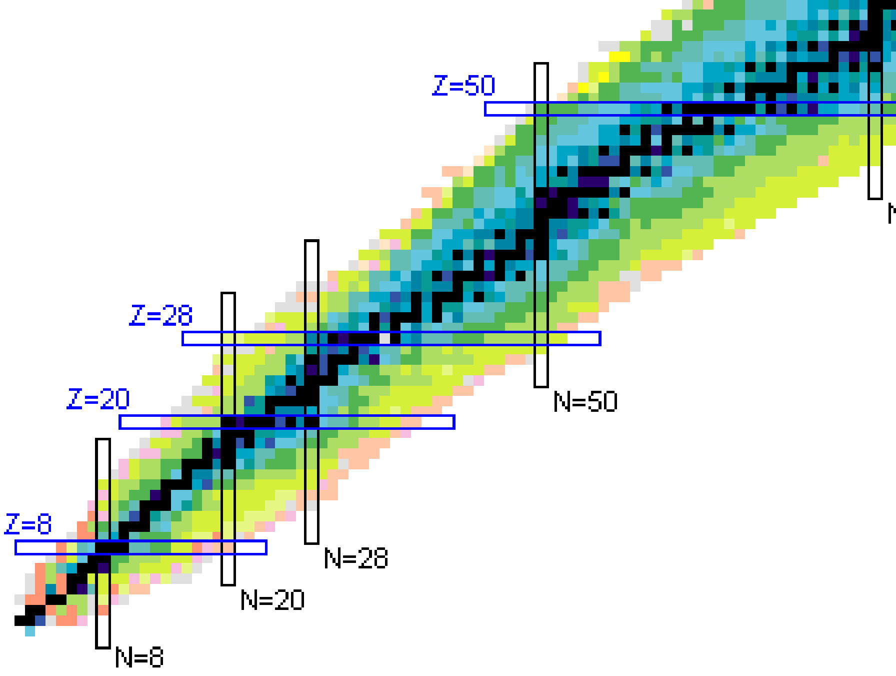
Advances in the Direct Study of Carbon Burning in Massive Stars



PHYSICAL REVIEW C **101**, 024313 (2020)

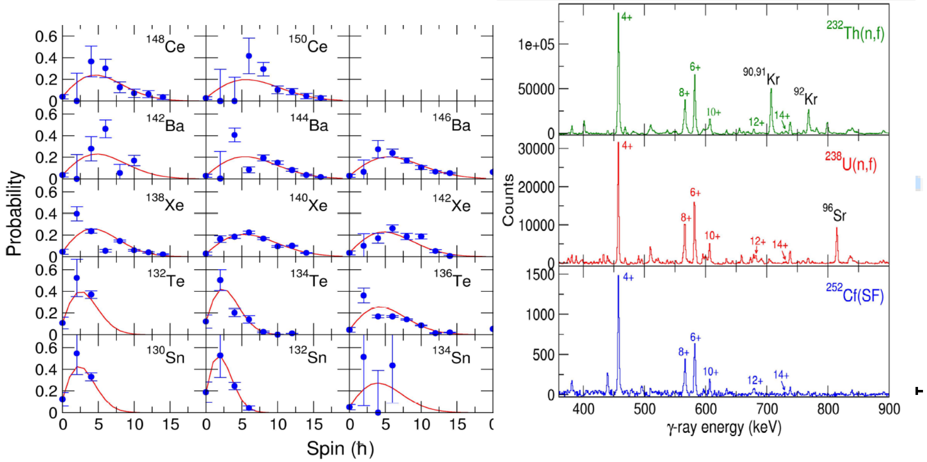
Half-life measurements in ^{164,166}Dy using γ-γ fast-timing spectroscopy with the ν-Ball spectrometer





Article **566** | Nature | Vol 590 | 25 February 2021

Angular momentum generation in nuclear fission



FATIMA contributes to answering some very ‘big nuclear physics’ question

Current setup - FATIMA

- ***FA***st ***TIM***ing ***A***rray of 36 $LaBr_3$(Ce) crystals
- Brighton, Surrey, IFIN-HH, Cologne, Daresbury, Madrid, Manchester…
- 6 IFIN-HH modules at GSI
- Extremely stable VME electronics > 1yr

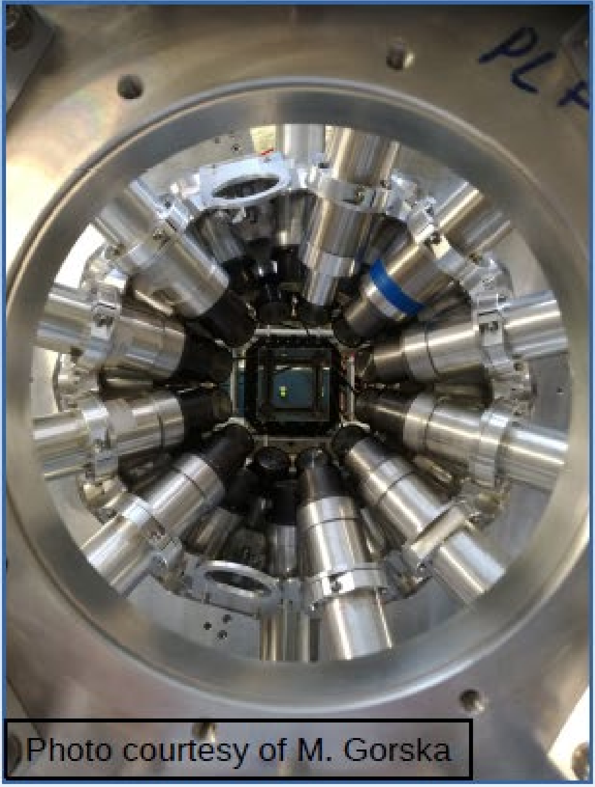
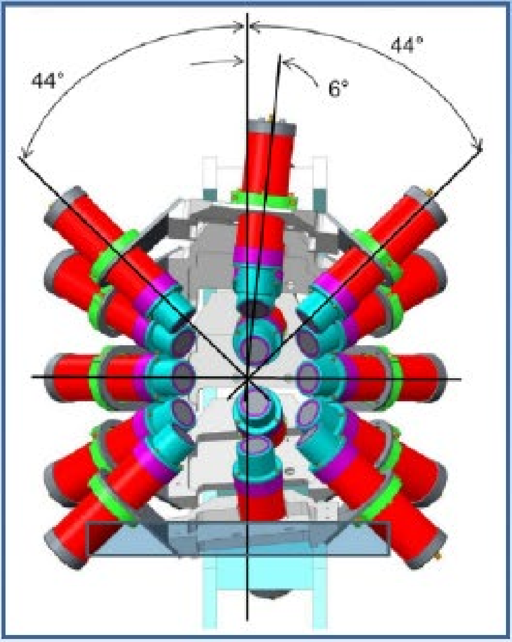
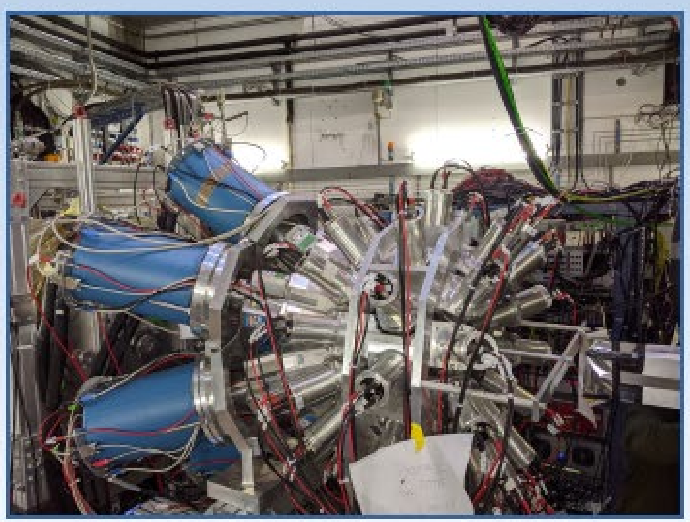
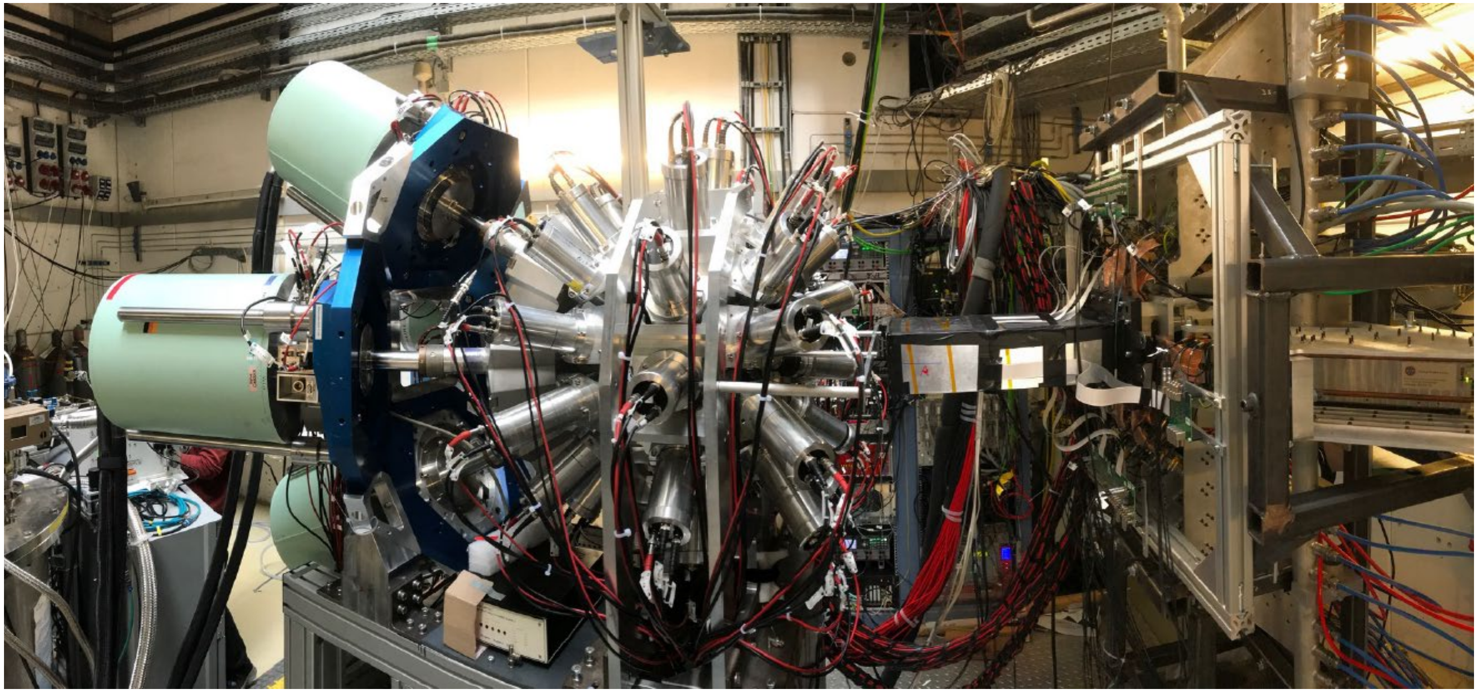


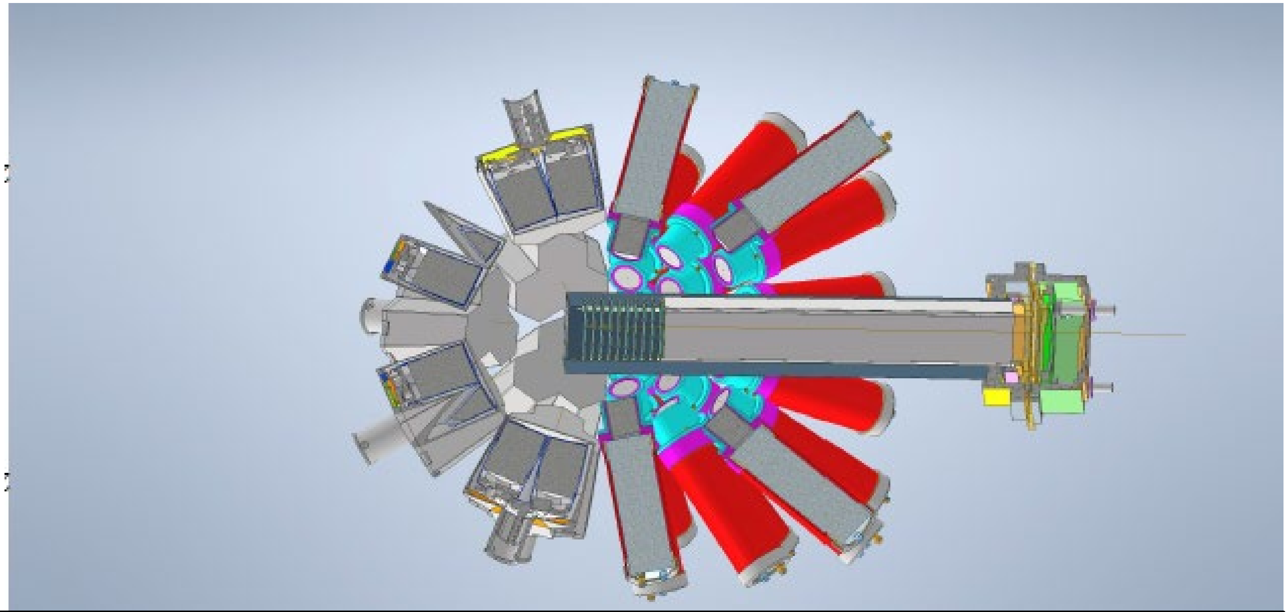
Photo courtesy of M. Gorska



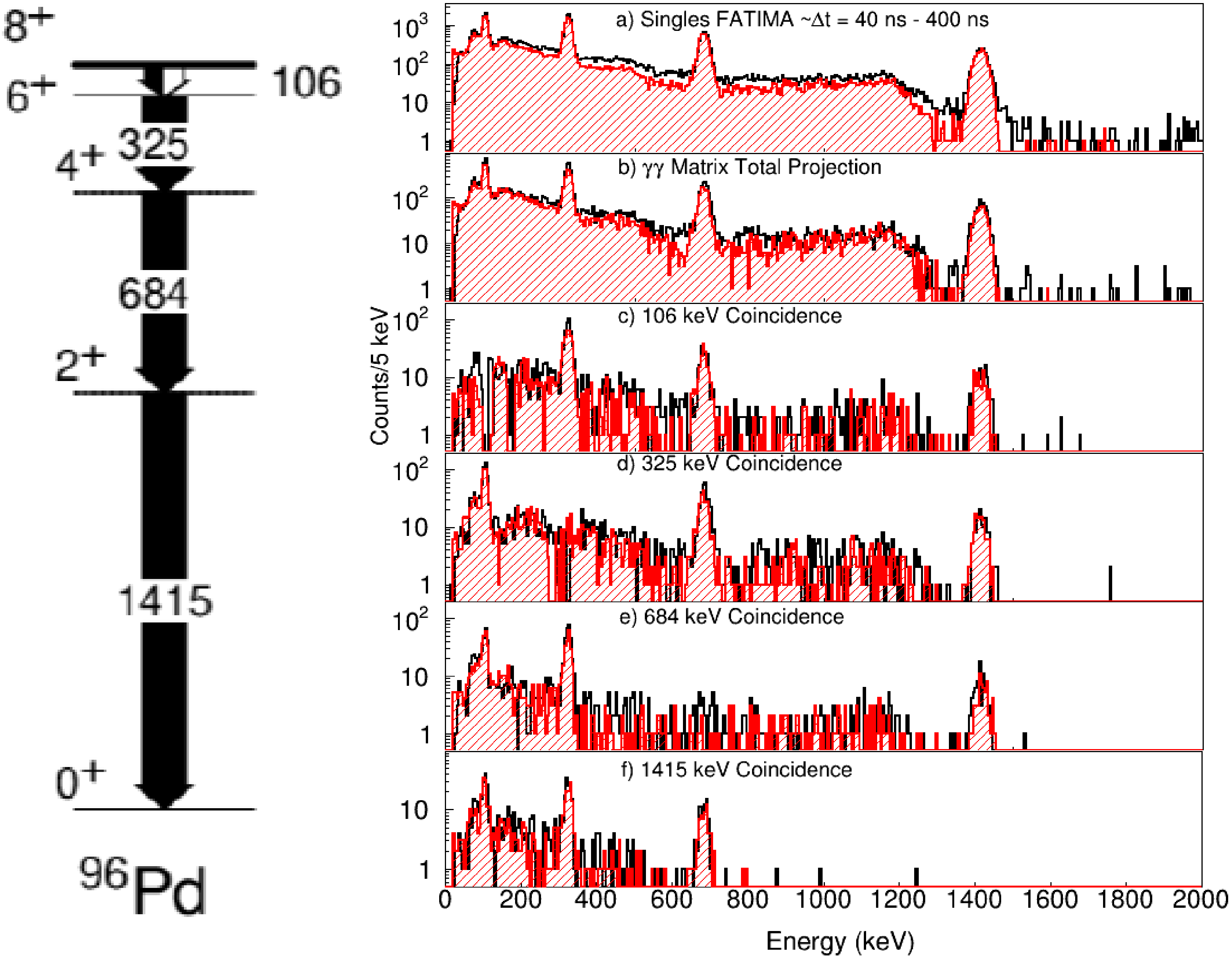


M.Rudigier *et al.*, NIM A 969, 163967 (2020)

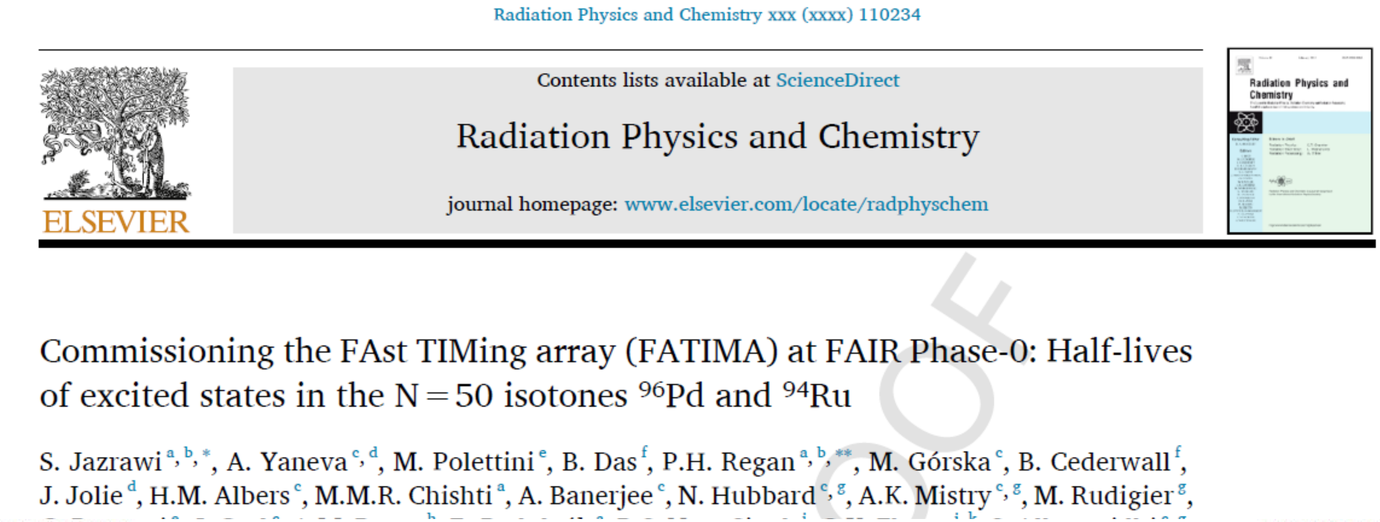




A.K.Mistry, H Albers et al. NIM **A1033** (2022) 166662



GEANT4 simulations for FATIMA (Chishti, Jazrawi et al., Nuclear Instruments and Methods, A in press (Aug 2023)


Radiation Physics and Chemistry xxx (xxxx) 110234

Contents lists available at ScienceDirect

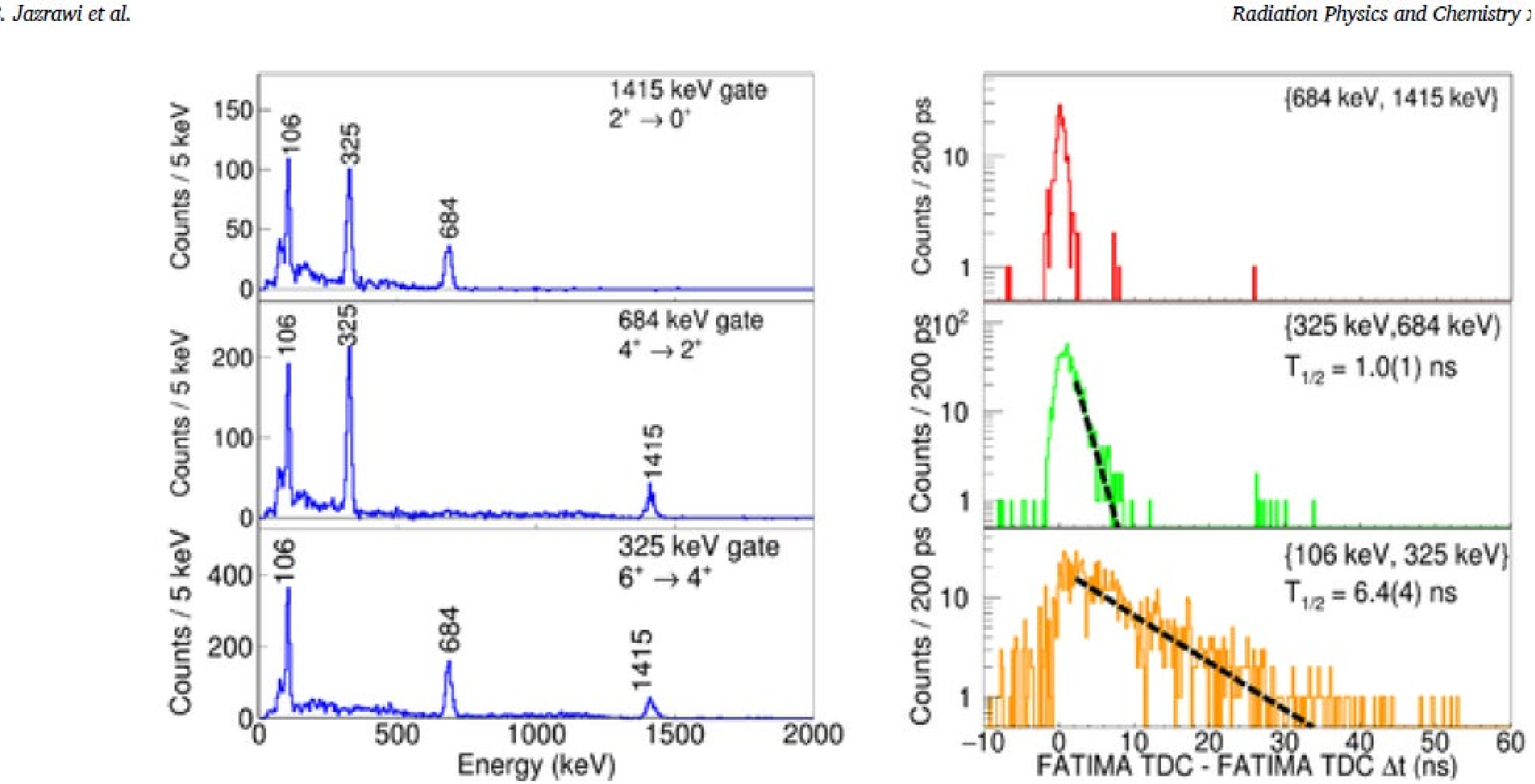
Radiation Physics and Chemistry

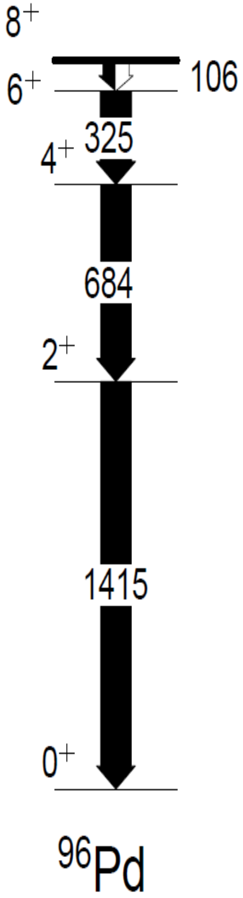
journal homepage: www.elsevier.com/locate/radphyschem

Commissioning the FAst TIMing array (FATIMA) at FAIR Phase-0: Half-lives of excited states in the N = 50 isotones ^{96}Pd and ^{94}Ru

S. Jazrawi[a, b, *], A. Yaneva[c, d], M. Polettini[e], B. Das[f], P.H. Regan[a, b, **], M. Górska[c], B. Cederwall[f], J. Jolie[d], H.M. Albers[c], M.M.R. Chishti[a], A. Banerjee[c], N. Hubbard[c, g], A.K. Mistry[c, g], M. Rudigier[g],

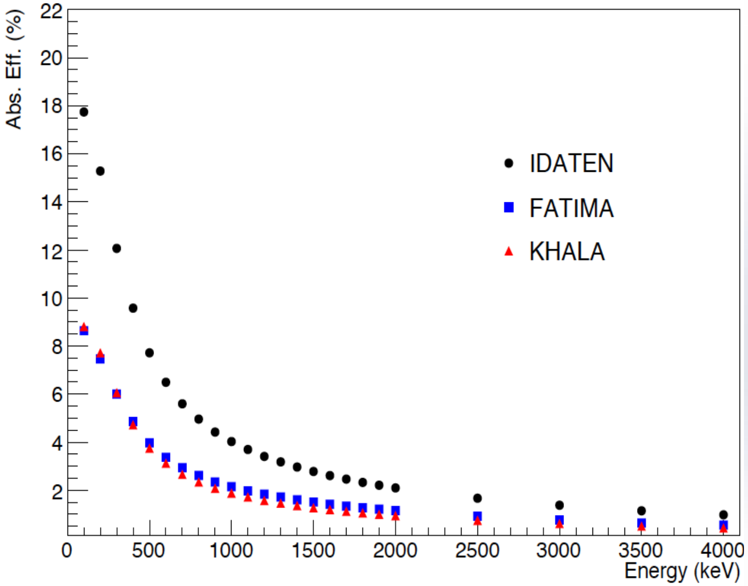
^{96}Pd$_{50}$ $I^{\pi}=8^{+}$ isomer,
H. Mach et al., PR**C95**,
014313 (2017),
$T_{1/2}$ (6^{+}) = 6.3(6) ns
$T_{1/2}$ (4^{+}) = 1.0(1) ns
$T_{1/2}$(2^{+}) < 17 ps

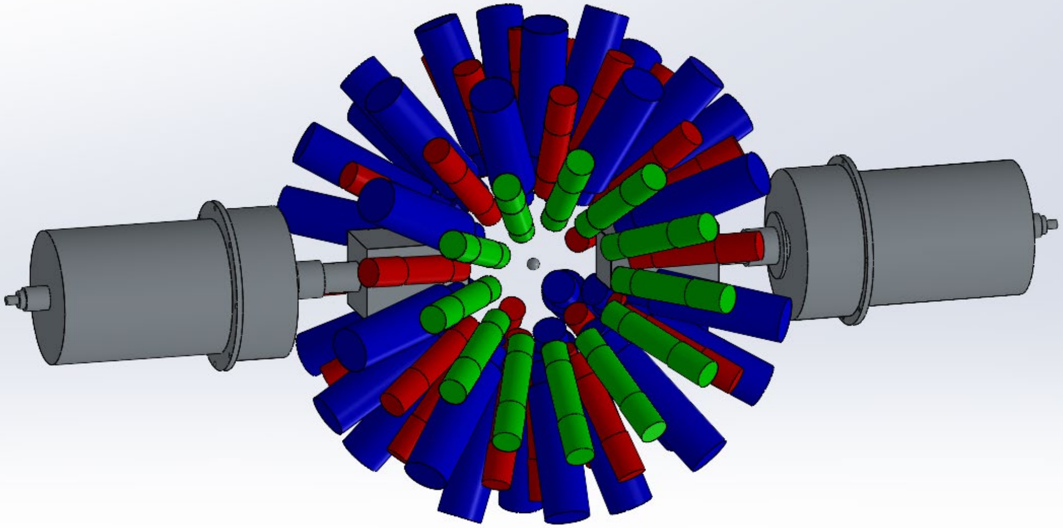


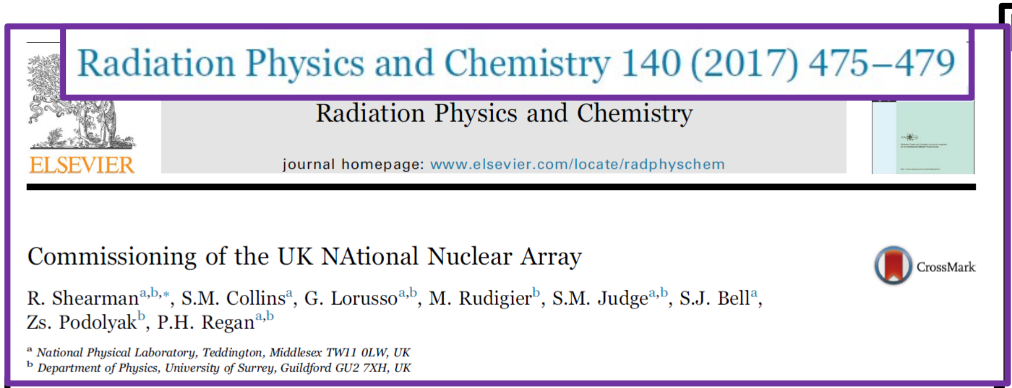


γ–γ–ΔT for transitions across individual states ^{96}Pd$_{50}$

The Future of FATIMA – IDATEN@ RIBF > 84 $LaBr_3$ detector gamma-ray array made up of IDATEN (UK) + KHALA (S. Korea) + RIKEN







Radiation Physics and Chemistry 140 (2017) 475–479

ELSEVIER

Radiation Physics and Chemistry

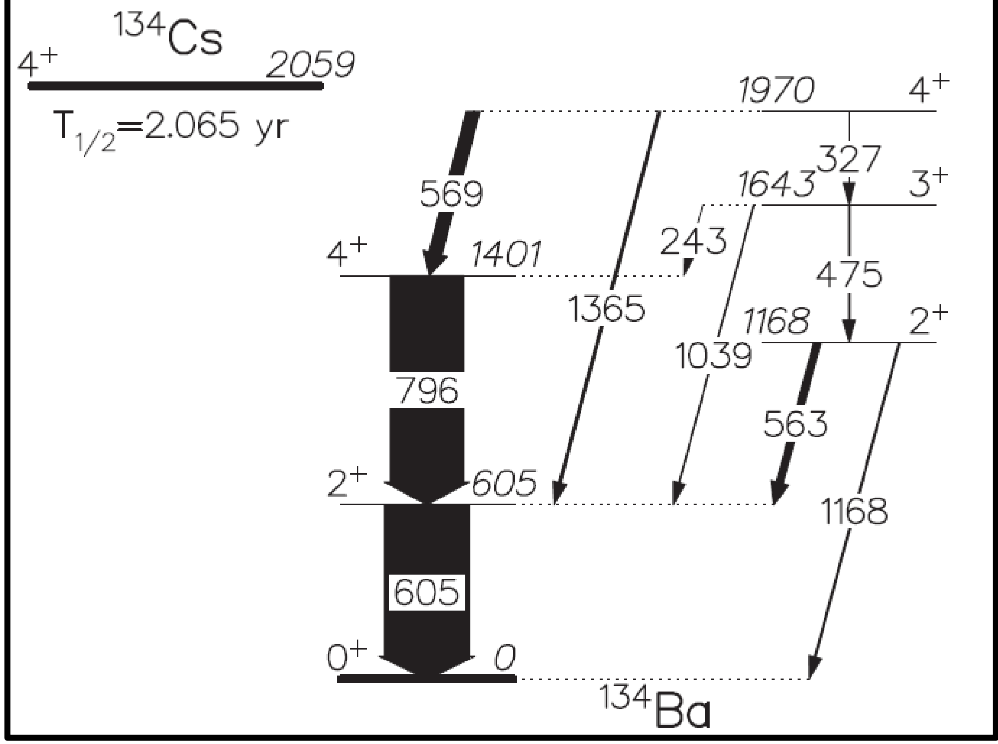
journal homepage: www.elsevier.com/locate/radphyschem

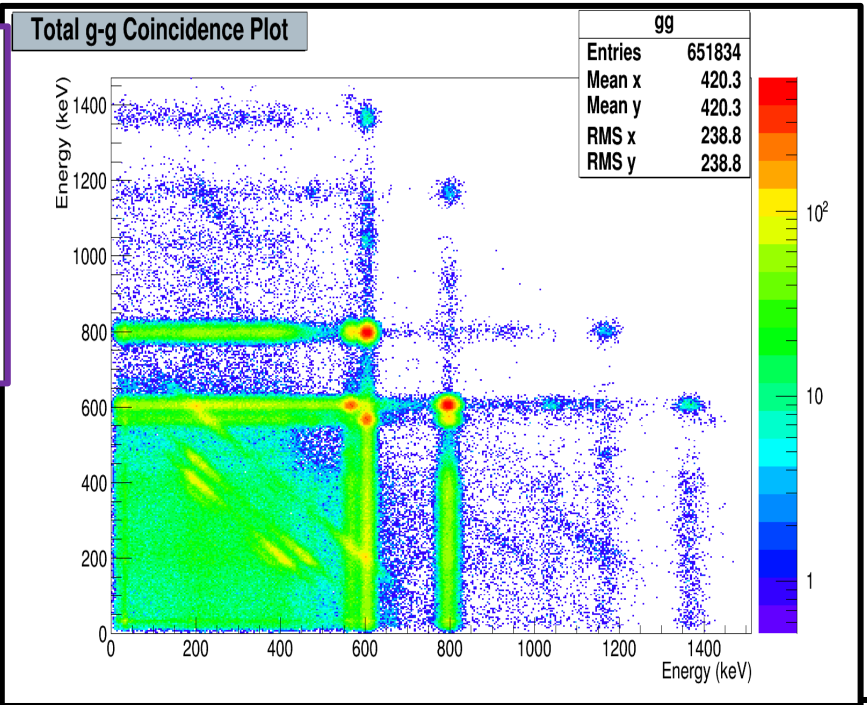
Commissioning of the UK NAtional Nuclear Array

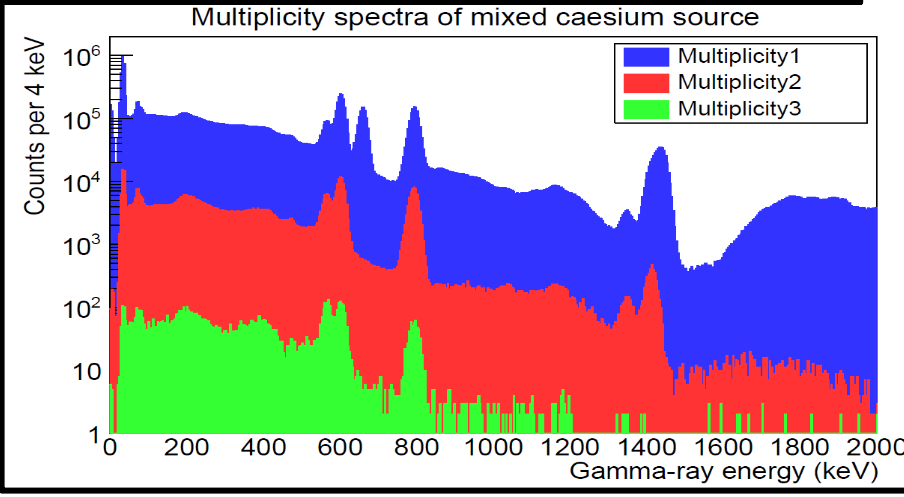
R. Shearman[a,b,*], S.M. Collins[a], G. Lorusso[a,b], M. Rudigier[b], S.M. Judge[a,b], S.J. Bell[a], Zs. Podolyak[b], P.H. Regan[a,b]

[a] National Physical Laboratory, Teddington, Middlesex TW11 0LW, UK
[b] Department of Physics, University of Surrey, Guildford GU2 7XH, UK

Radiation Physics and Chemistry 140 (2017) 475–479



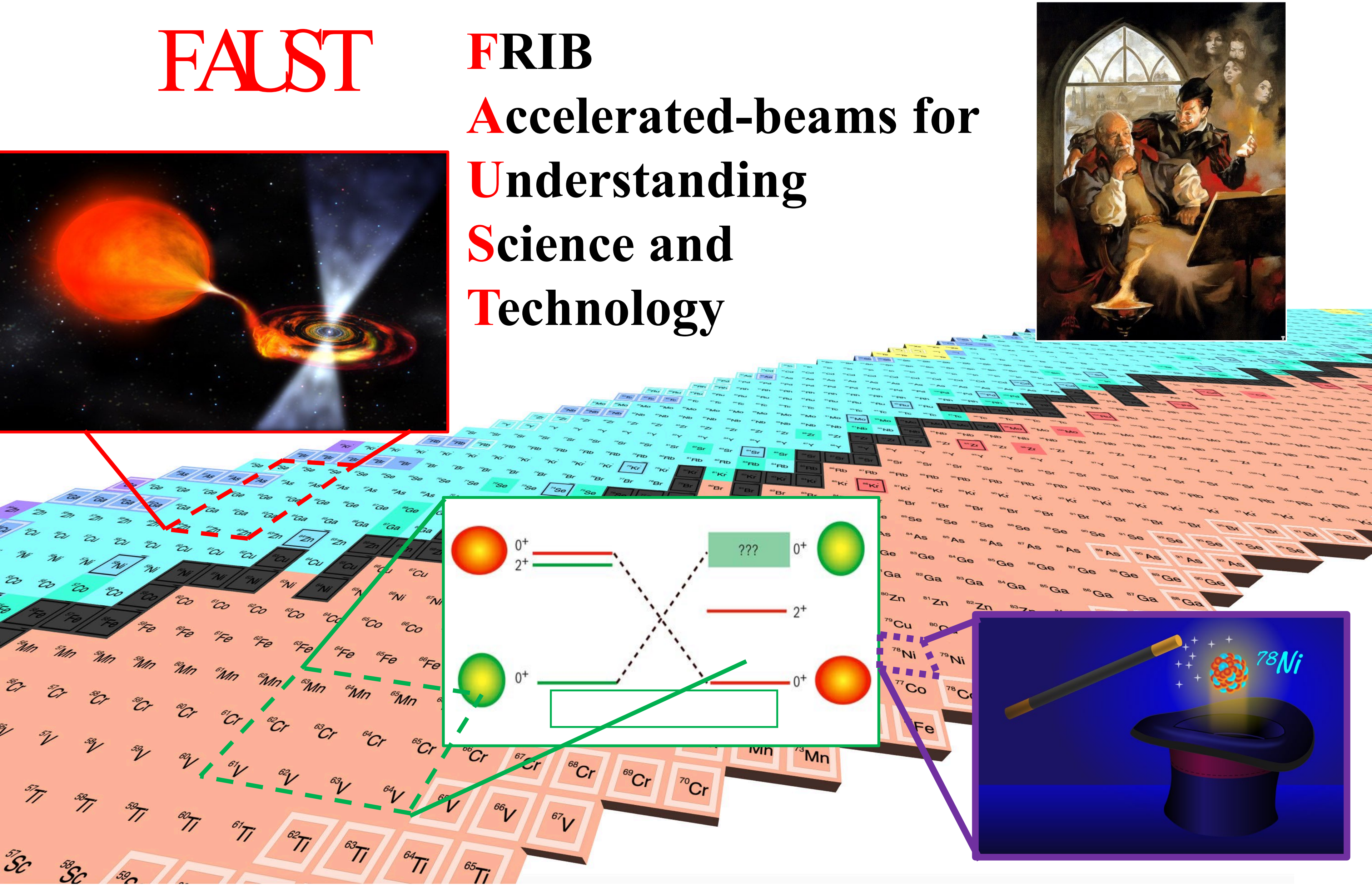




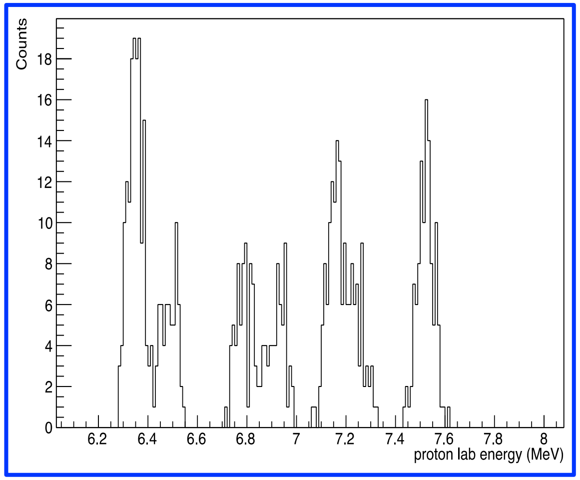
NANA for spent nuclear fuel assay: ^{134,7}Cs reactor products.
^{134}Cs → γ-ray coincidences; ^{137}Cs → single transition (662 keV).

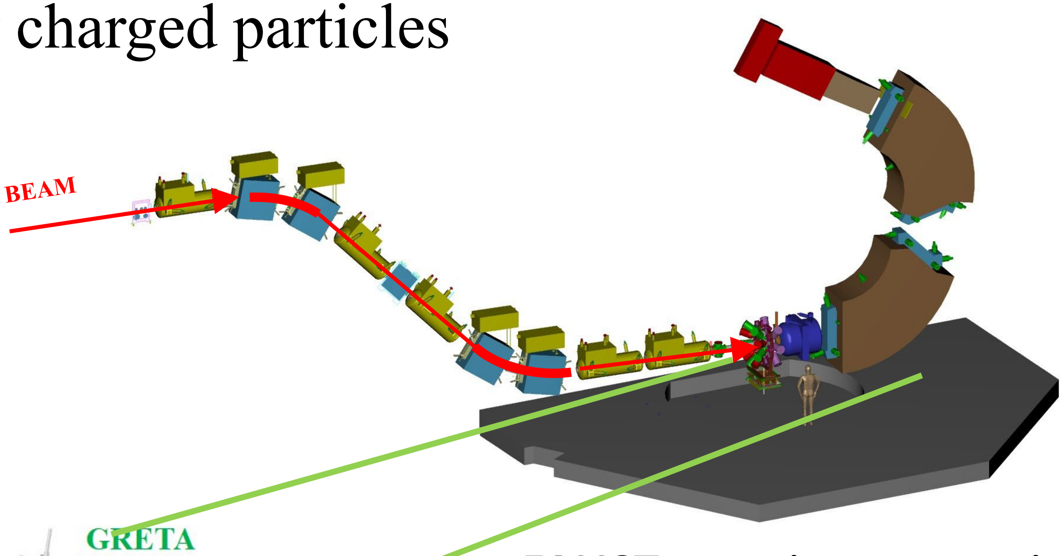
FAUST

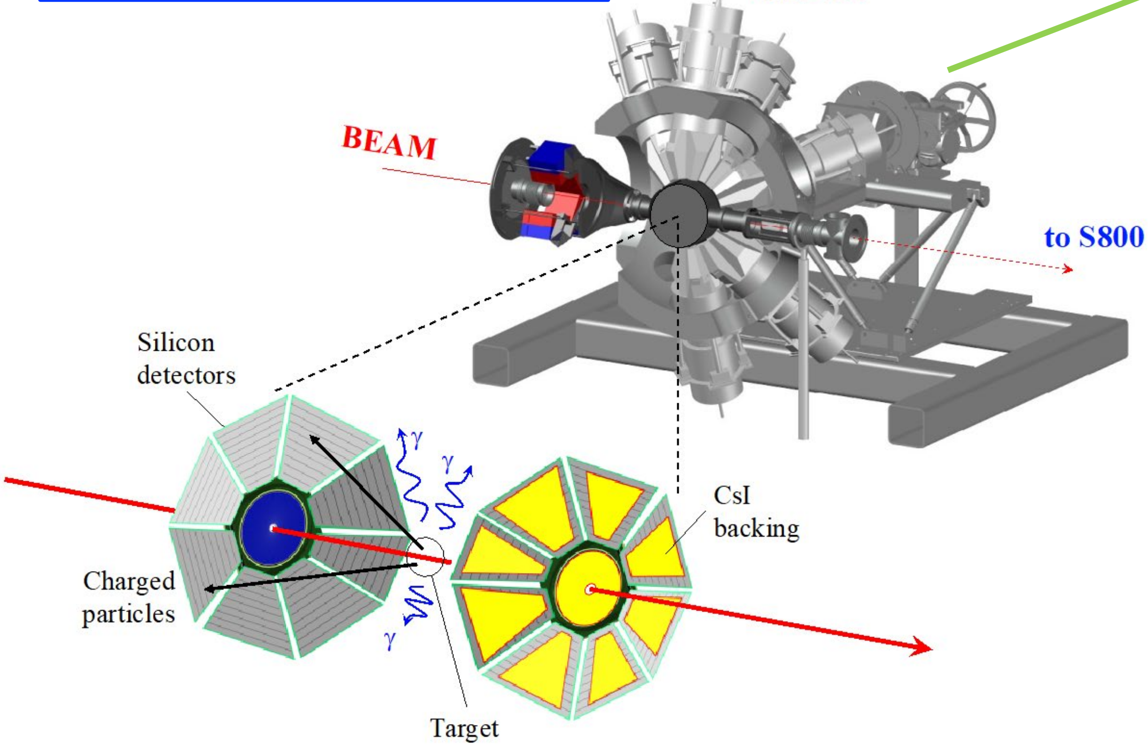
FRIB
Accelerated-beams for
Understanding
Science and
Technology



FAUST – Si backed with CsI provides stopping required for high-energy charged particles







FAUST constitutes a major UK contribution to the US DoE FRIB facility (Michigan State, USA) . Highly-pixelated, **game changing** Si-detectors-based instrumentation for precision nuclear reaction measurement of the most important nuclear astrophysics reactions using radioactive beams

G.Lotay, D.T.Doherty et al.,

The STFC Nuclear Security Science Network (NuSec)

- Novel imaging techniques, including compact gamma & neutron imaging systems; cosmic ray muon imaging of large objects.
- Radiation detection, detector development, digital pulse processing; new materials for radiation detectors.
- Advanced detection methods for nuclear fuel cycle monitoring.
- Robotics and remote inspection technologies.
- Non-proliferation technologies.

For further information, see: www.nusec.uk/ and p.sellin@surrey.ac.uk

NuSec Nuclear Security Science Network

UKRI Science and Technology Facilities Council

Consortium for Enabling Technologies & Innovation

UNIVERSITY OF SURREY

University of Manchester: STEFF @ n_TOF Spectrometer for Exotic Fission Fragments:

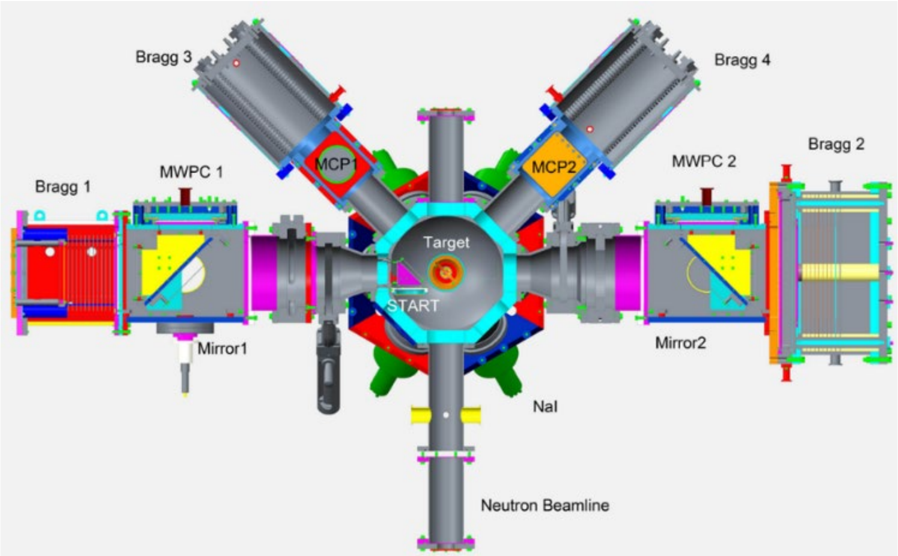
A.G. Smith, T. Wright, N. Sosnin, et al.

Goal:

- Provide data for NEA HPRL entry on ^{235}U and ^{239}Pu Prompt Fission γ-Rays

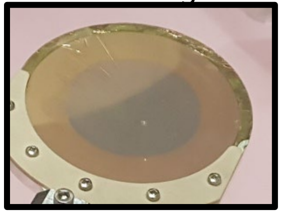
Realisation:

- Measure fission with STEFF and corresponding γs with NaI and LaBr$_3$ detectors



^{235}U target

^{239}Pu target



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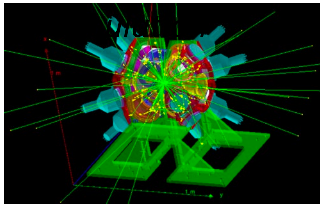
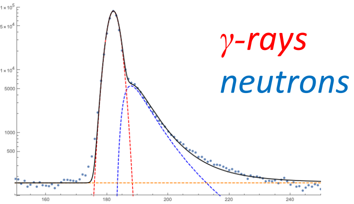


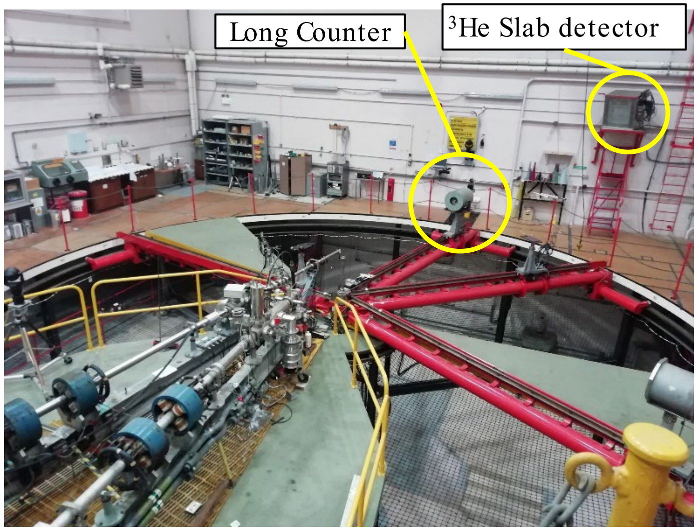
Fission neutron removal



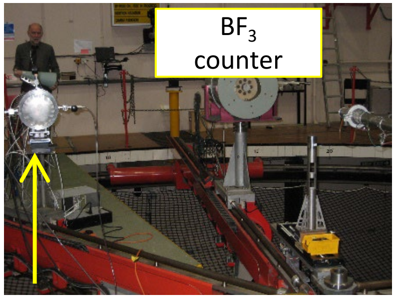
N. Colonna et al., “The fission experimental programme at the CERN n TOF facility: status and perspectives”, *Eur. Phys. J. A (2020) 56: 48. DOI: http://dx.doi.org/10.1140/epja/s10050-020-00037-8*

Toward ^{237}Np(n,f) and ^{238}U(n,f) reference cross sections

- NPL Low scattering area 18m x 18m x 26m
- Well known neutron fluence (within 2%)



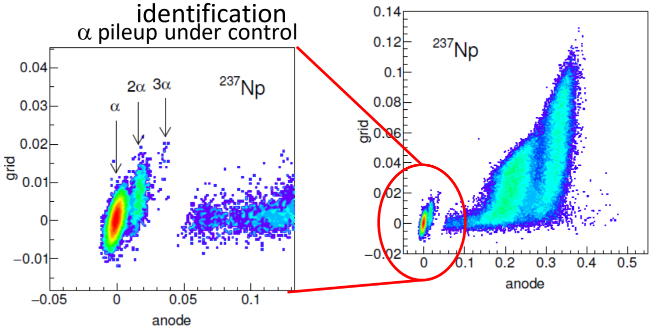
Neutron Flux measurement



TFGIC and targets from JRC (Geel)

Fission events identification

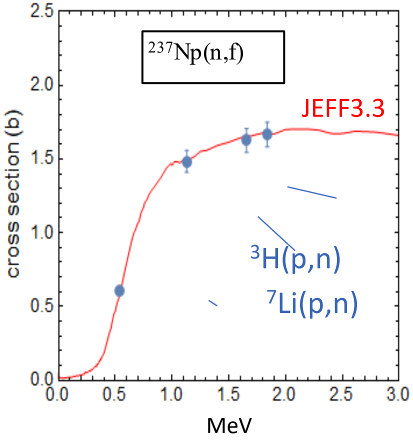
α pileup under control

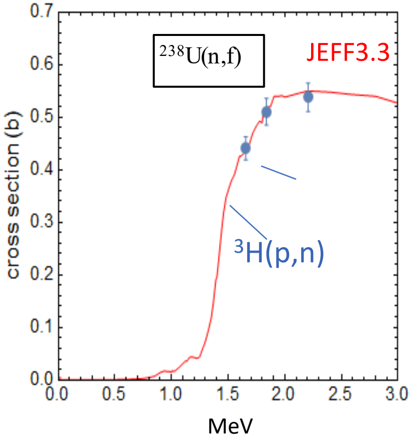


<u>Results are promising, agree with current libraries, more work needed to:</u>

- Improve reproducibility of the fission target position
- reduce error bars and more energies for ^{238}U → more neutrons needed (working on this with AFCP)

- 2/3 of the GEN-IV reactors are fast reactors
- Fast ^{237}Np(n,f) ^{238}U(n,f) are better reference cross section than ^{235}U(n,f)
- NPL absolute cross section will contribute the evaluation effort toward making ^{237}Np and ^{238}U standards





UK NP Radioactive Gas Metrology

UK Nuclear expertise in
A) Neutron activation facility & source prep;
B) Gas metrology, transport and engineering;
C) Gamma-ray and electron spectrometry;
D) Nuclear data analysis and interpretation.

Clear, direct impact in:

1) **Energy & Environment**: standardisations of **radioactive Krypton**. Real time signatures **for reactor criticality** .

2) Security & Resilience: New methodologies developed in collaboration with AWE & **CTBTO** for **radioactive Xenon** weapon signatures.


Journal of Environmental Radioactivity 238–239 (2021) 106733

Journal of Environmental Radioactivity

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Production and measurement of fission product noble gases

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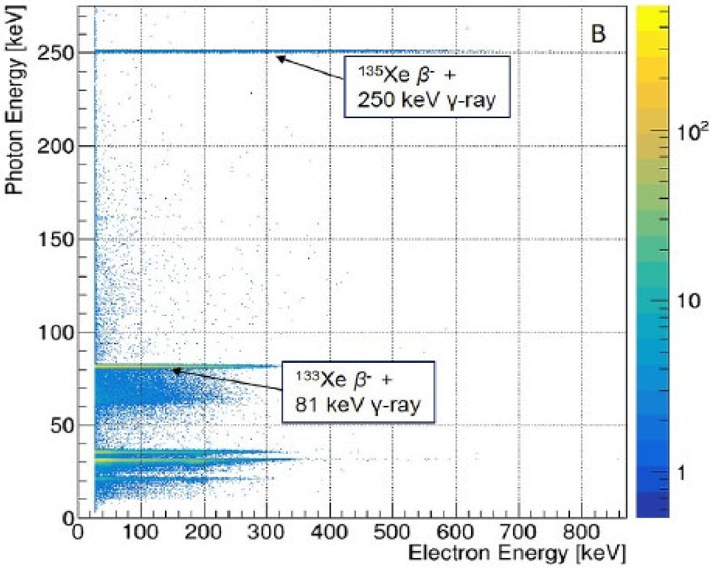
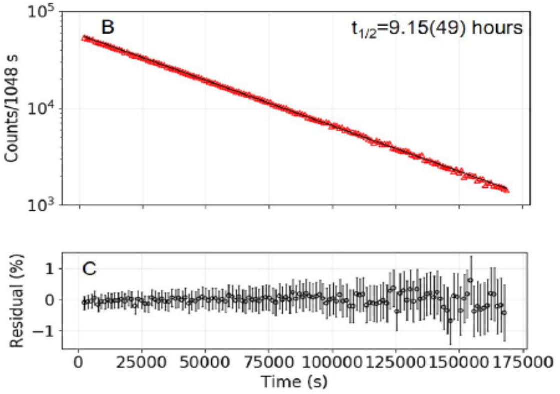
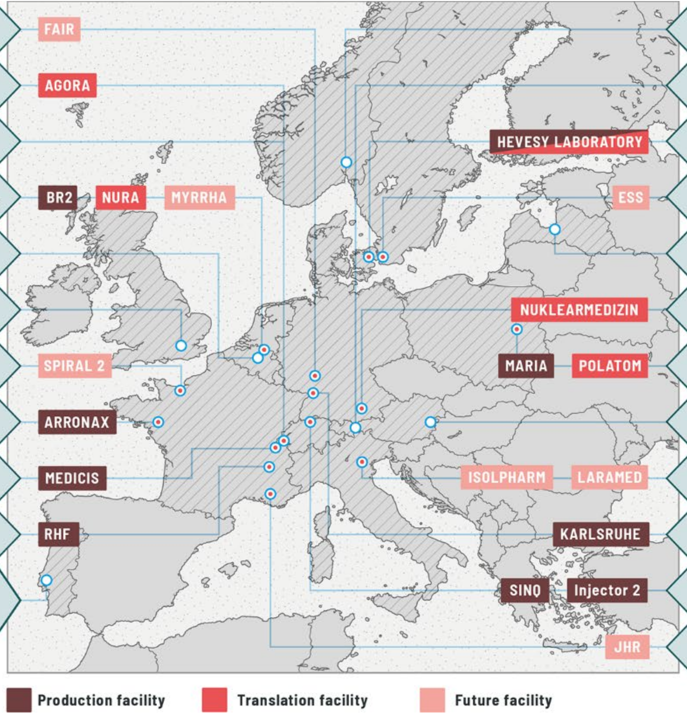




PRoduction of high purity Isotopes by mass Separation for Medical Applications

GSI	GSI Helmholtzzentrum für Schwerionenforschung GmbH
CHUV	Centre hospitalier universitaire vaudois
SCIPROM	SCIPROM Sàrl
SCK CEN	Studiecentrum voor Kernenergie / Centre d'étude de l'énergie nucleaire
KULeuven	Katholieke Universiteit Leuven
NPL	National Physical Laboratory
GANIL	Grand Accélérateur National d'Ions Lourds
ARRONAX	Groupement interet public ARRONAX
CERN	European organization for nuclear research
ILL	Institut Max von Laue - Paul Langevin
IST-ID	Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento



Universitetet i Oslo	UiO
Medizinische Universität Innsbruck	MUI
Danmarks Tekniske Universitet	DTU
European Spallation Source ERIC	ESS
Latvijas Universitāte	LU
Klinikum rechts der Isar der Technischen Universität München	TUM
Narodowe Centrum Badań Jądrowych	NCBJ
Entwicklungs- und Betriebs-gesellschaft MedAustron GmbH	MedAustron
Istituto Nazionale di Fisica Nucleare	INFN
Joint Research Centre - European Commission	JRC
Paul Scherrer Institut	PSI
Commissariat à l'energie atomique et aux énergies alternatives	CEA

https://www.prismap.eu/

Molecular radiotherapy and theranostics

- Recent successes for ^{223}Ra and ^{177}Lu has renewed interest for molecular radiotherapy.
- Search for new suitable radioisotopes continues…
- Over 3000 radioisotopes synthesised in the lab - only a fraction currently used for medical procedures.
- Limited by:

    Physical characteristics e.g. $T_{1/2}$,

    Production purity