Introduction
Experiment and instrumentation

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Outline of the talk

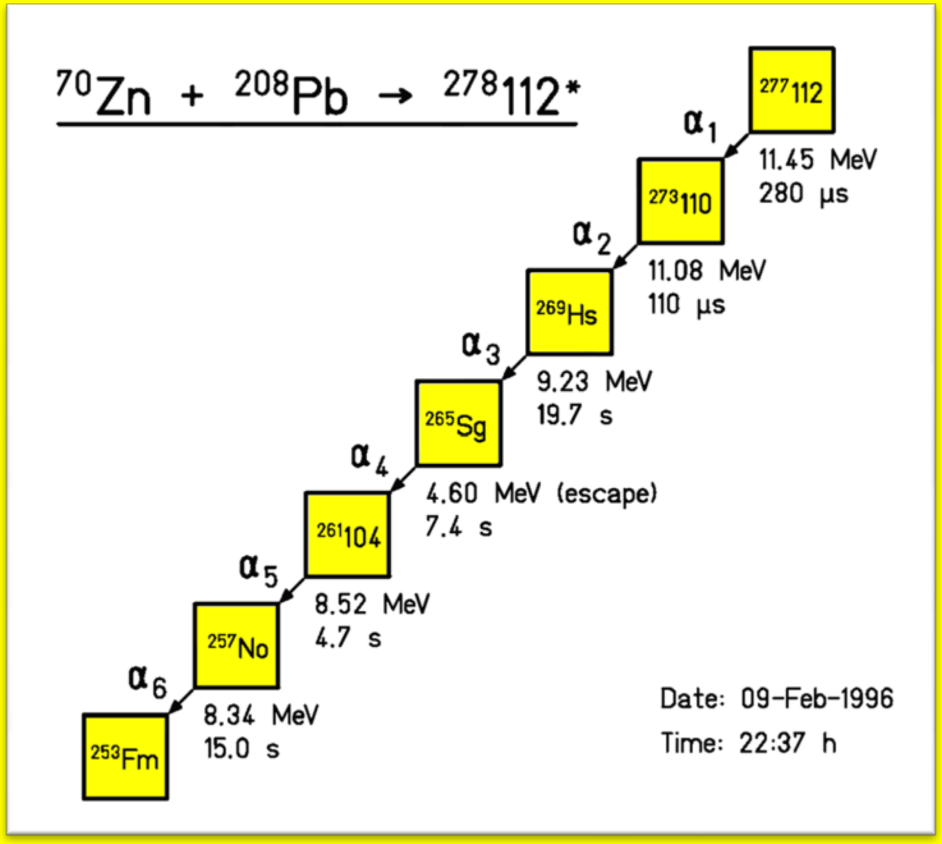
1. New elements

2. Structure studies
•Decay experiments
•In-beam experiments
•Quasi-particle states

3. Developments in spectroscopy, electronics, DAQ,…

4. Developments in on-line recoil separators

5. Final thougths



1. Synthesis of new elements

118
First made at Dubna $^{48}Ca+^{249}Cf$

117
First made at Dubna $^{48}Ca+^{249}Bk$

116
First made at Dubna $^{48}Ca+^{248}Cm$
Confirmation from GSI

115
First made at Dubna $^{48}Ca+^{243}Am$

114
First made at Dubna $^{48}Ca+^{244}Pu$
Confirmation from LBNL, GSI

113
First made in RIKEN $^{70}Zn+^{209}Bi$
Also Dubna $^{48}Ca+^{243}Am,^{237}Np$

112 (Cn)
First made at GSI $^{70}Zn+^{208}Pb$
Confirmation from RIKEN,
Later at Dubna $^{48}Ca+^{238}U$,
Confirmation from GSI

Discovery claims and the view of IUPAC

Robert C. Barber *et al*., Pure Appl. Chem. **83**, 1485 (2011)

In accordance with the criteria for the discovery of elements previously established by the 1992 IUPAC/IUPAP Transfermium Working Group (TWG), and reinforced in subsequent IUPAC/IUPAP JWP discussions, it was determined that the ***Dubna-Livermore collaborations share in the fulfillment of those criteria both for elements Z = 114 and 116****.*

To exclude the possibility that a proton might be stripped from the projectile (or the target) in the same event in which a superheavy is subsequently produced by fusion cannot be eliminated.

…would welcome further study of the matter. (Especially regarding hot fusion reactions.)

How to proceed

Firm assignment of the products from hot fusion reactions

Spectroscopic techniques

Separators

Electronics

Reaction studies (e.g. transfer)

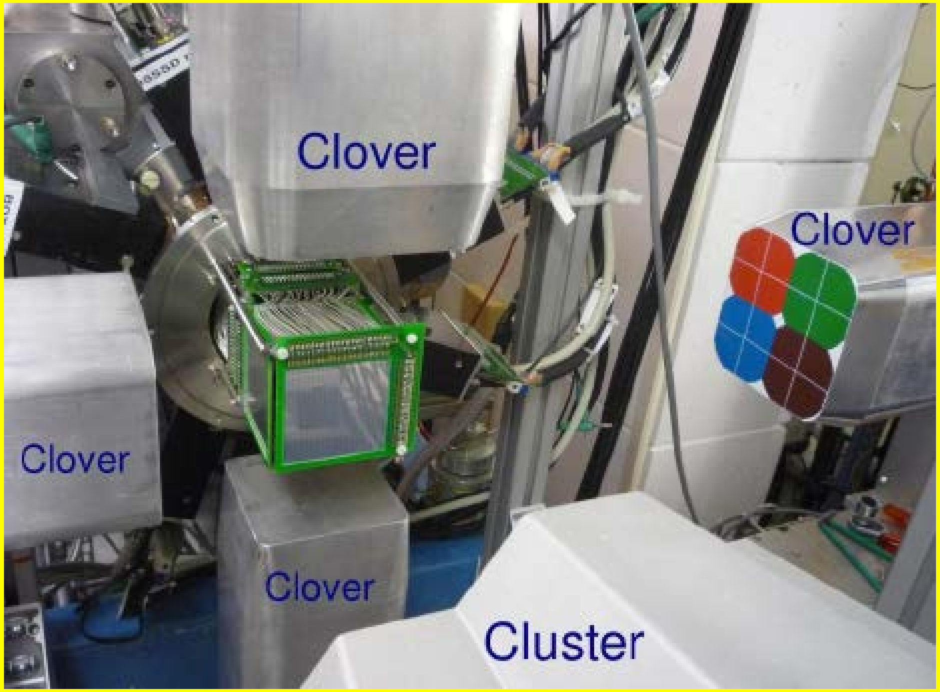
Target situation (^{251}Cf)

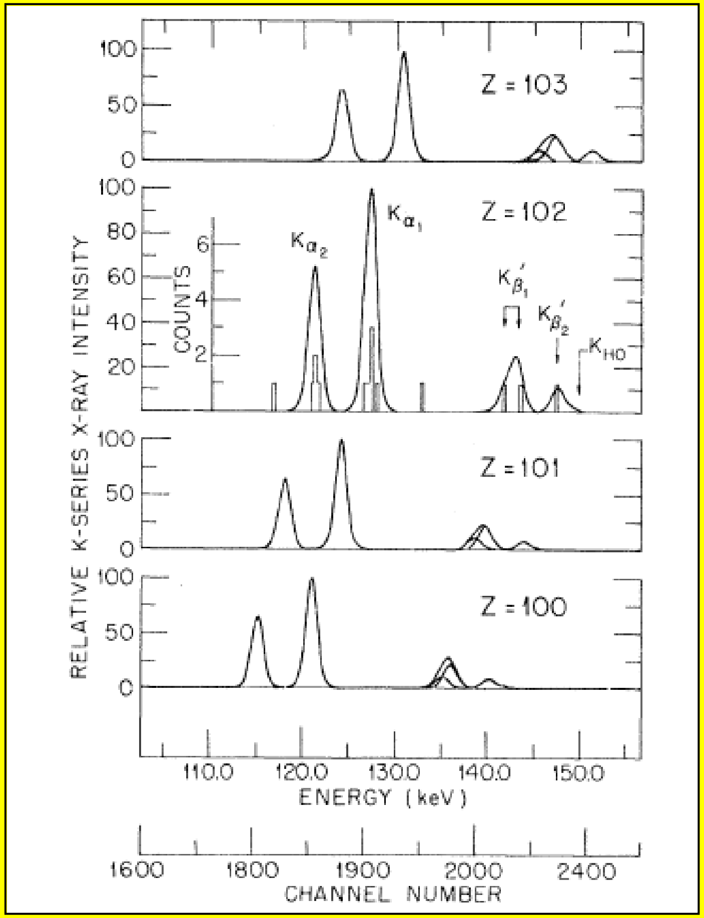
Accelerators

Z identification

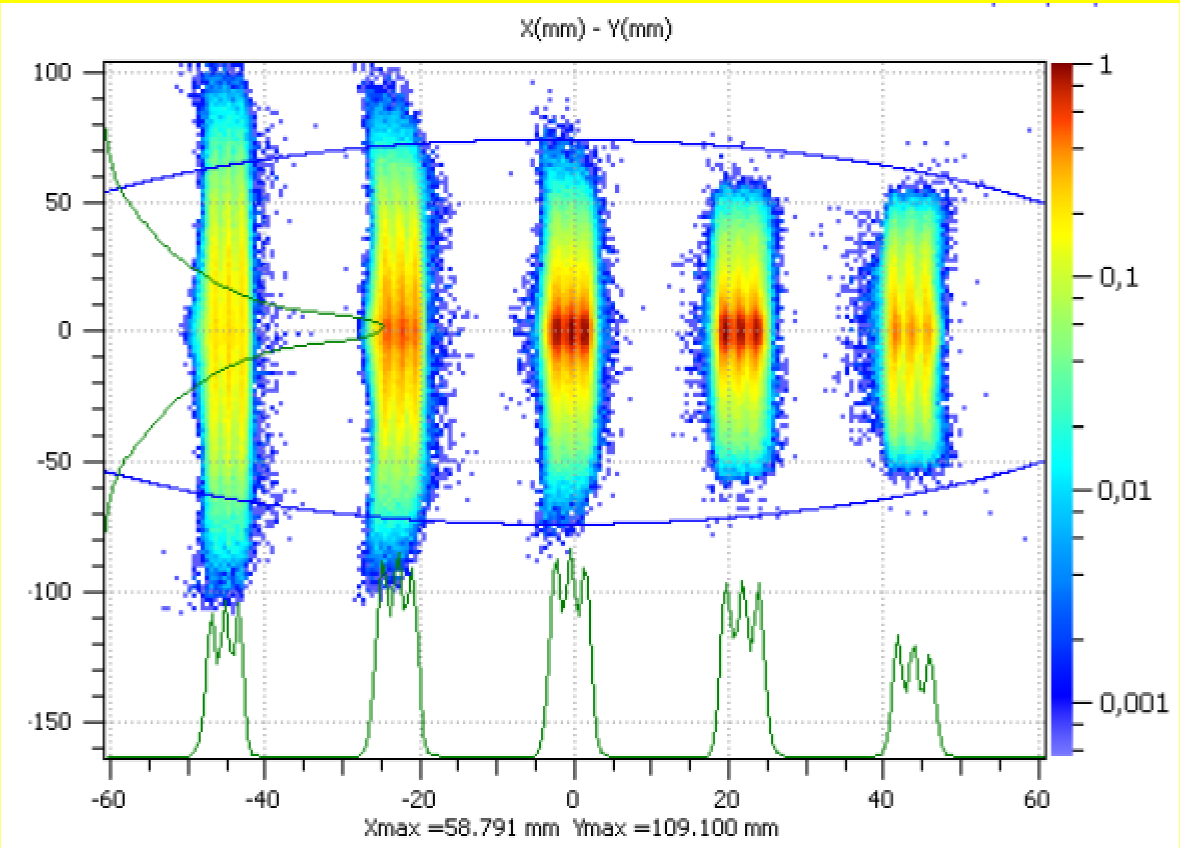
TASISpec at TASCA (Dirk Rudoplh et al.)

Expect K X-rays from the decay chain of $^{287}115$ ($^{48}Ca+^{243}Am$)
Cf. Bemis et al. PRL **31**, 647 (1973) ^{257}Rf decay



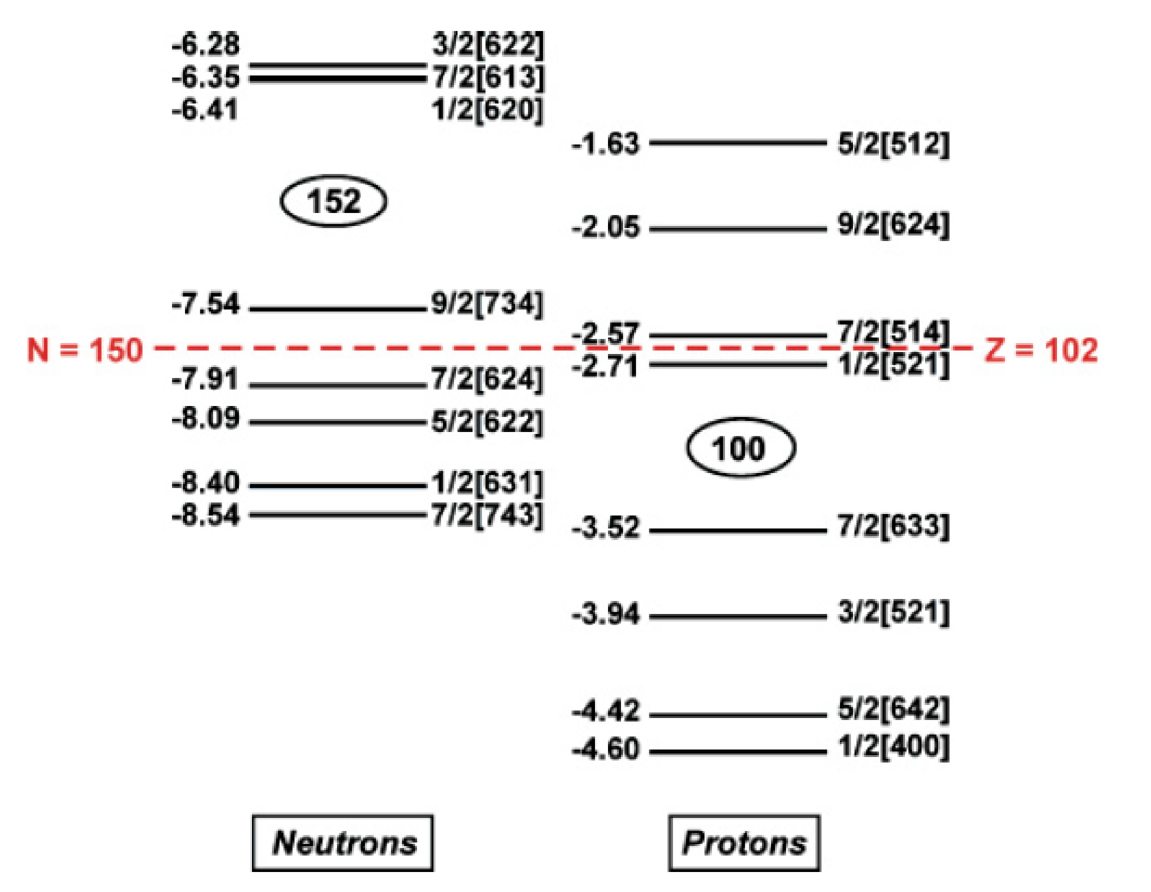


Mass determination



S^3 simulation; $^{48}Ca + ^{248}Cm \rightarrow ^{291,292,293}116$ with q = 22+…26+ M/ΔM ≈ 300

2. Nuclear structure studies

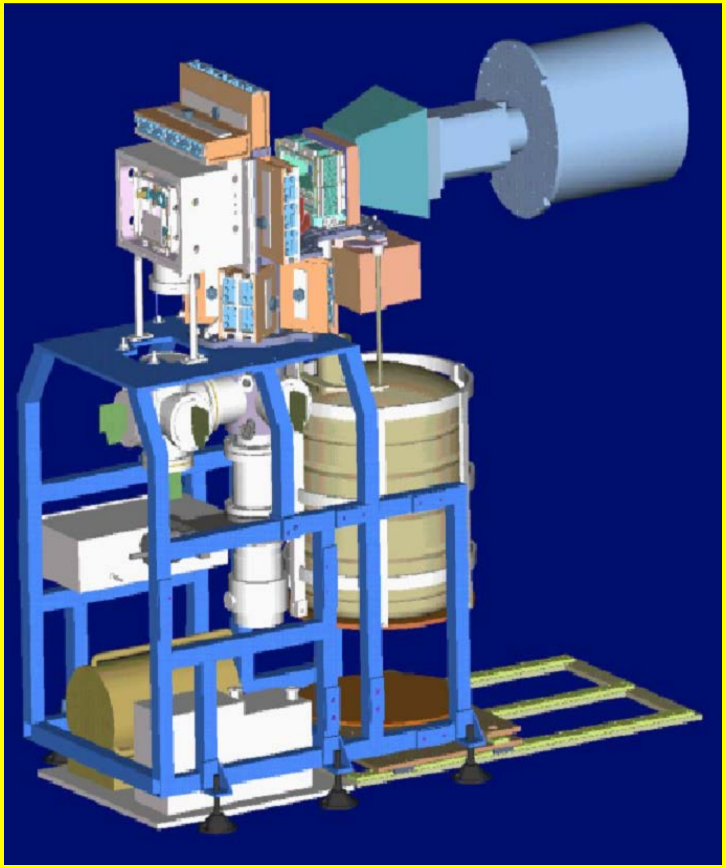


A. P. Robinson *et al*., Phys. Rev. C **78**, 034308 (2008)

Experimental methods

- α-decay fine structure studies (α, α-γ, α-e^-)
- Delayed spectroscopy from isomeric states
- In-beam spectroscopy (γ, e^-)

α-γ detection system
at JAEA Tandem laboratory

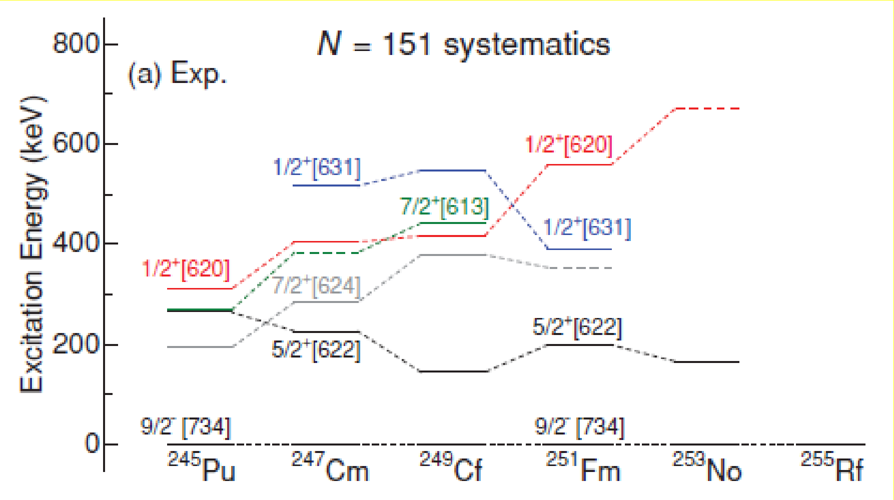


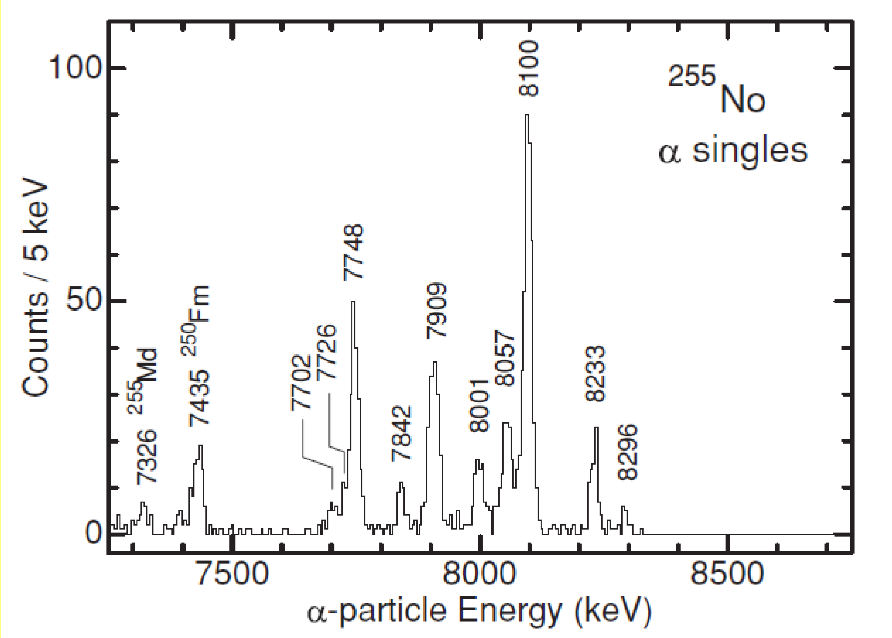
GREAT at JYFL

One-quasiparticle data 1

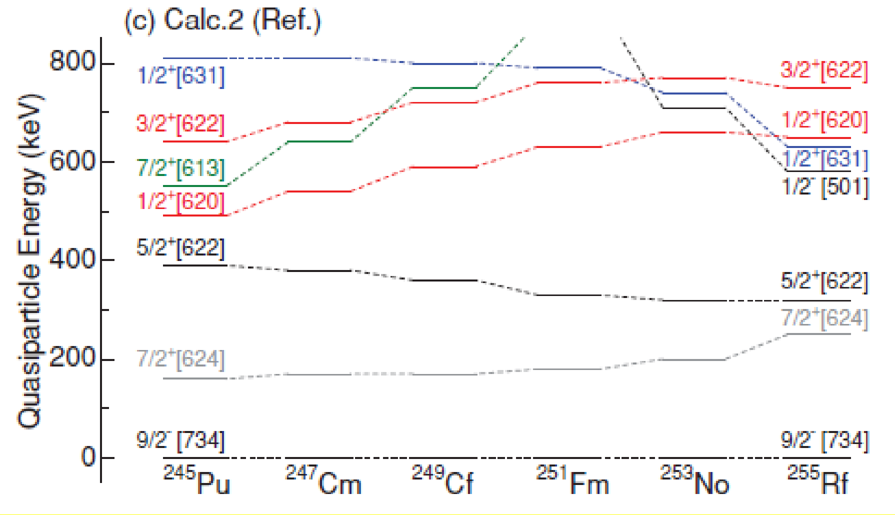
An example: Neutron states in ^{251}Fm populated via α-decay of ^{255}No

M. Asai *et al.*, P. R. C **83**, 014315 (2011)
α-γ coincidence and α fine structure data





Calculations: Parkhomenko and Sobiczewski

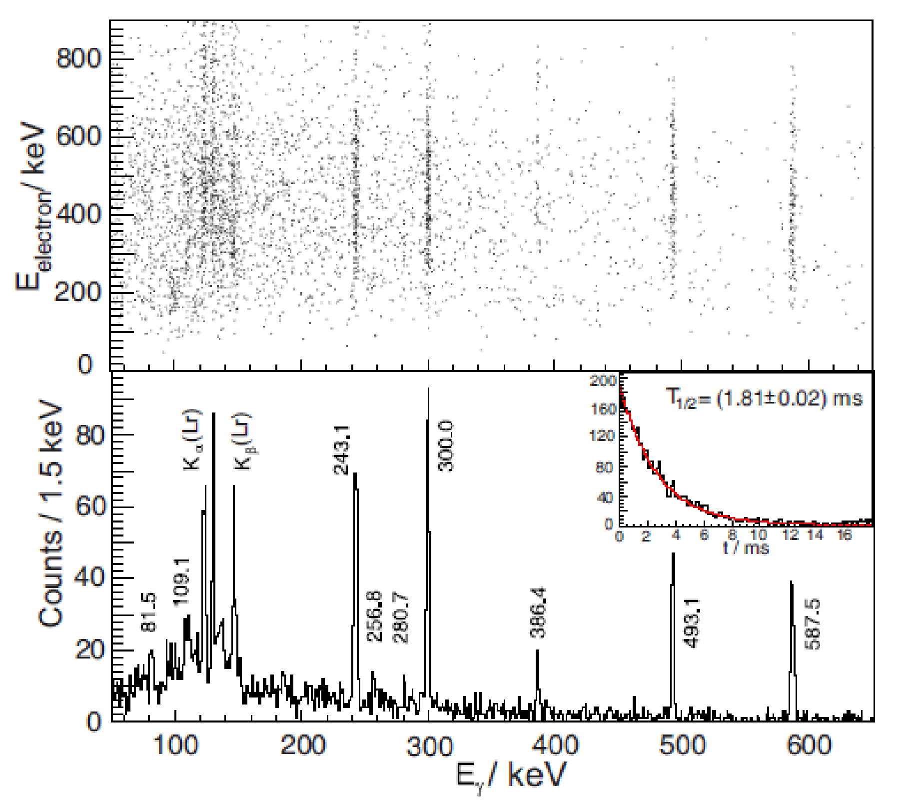


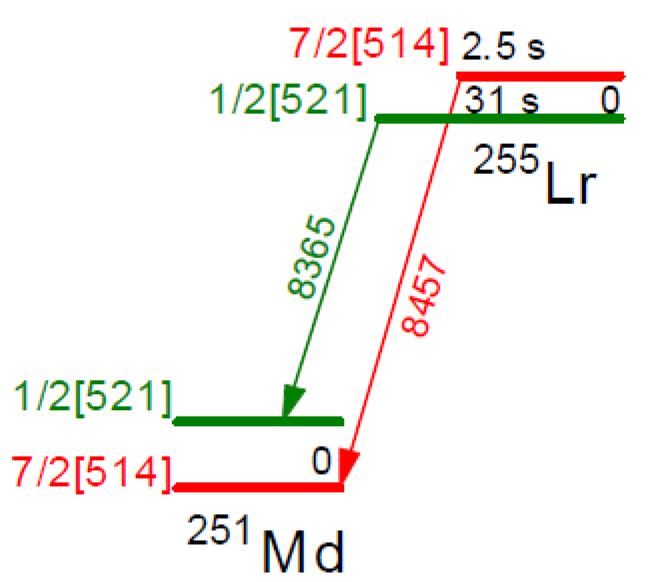
N.B. No summing effect

One-quasiparticle data 2

Decay of ^{255}Lr S. Antalic et al. EPJ A **38**, 219 (2008) SHIP

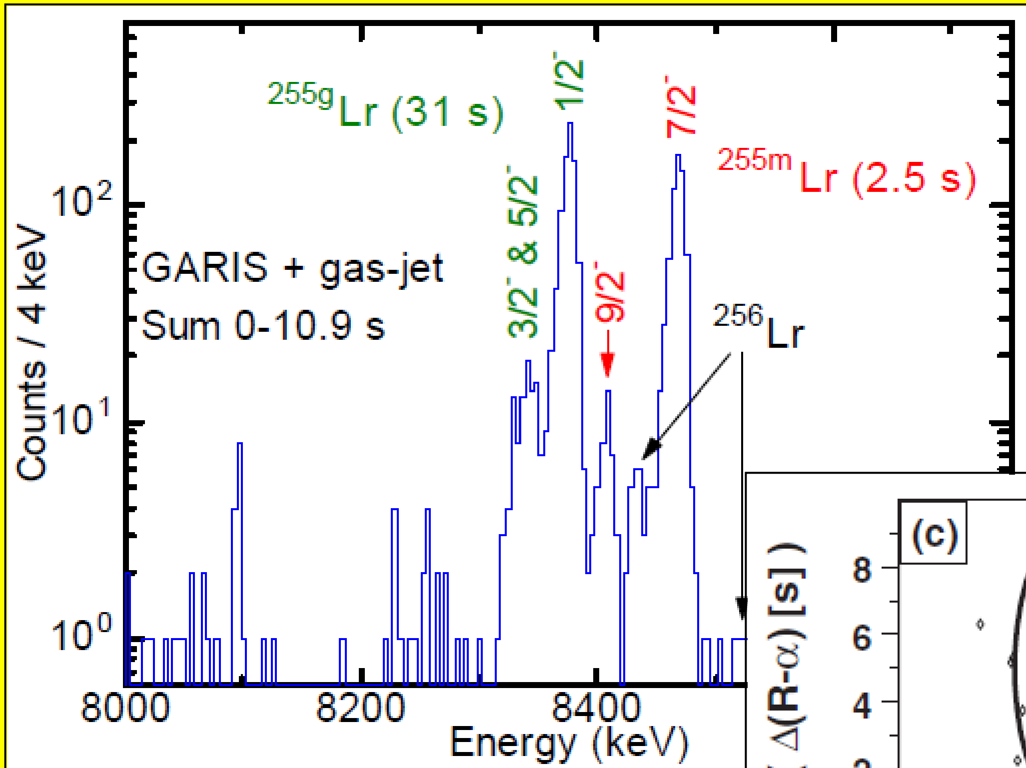
α, α-γ, e⁻-γ spectroscopy





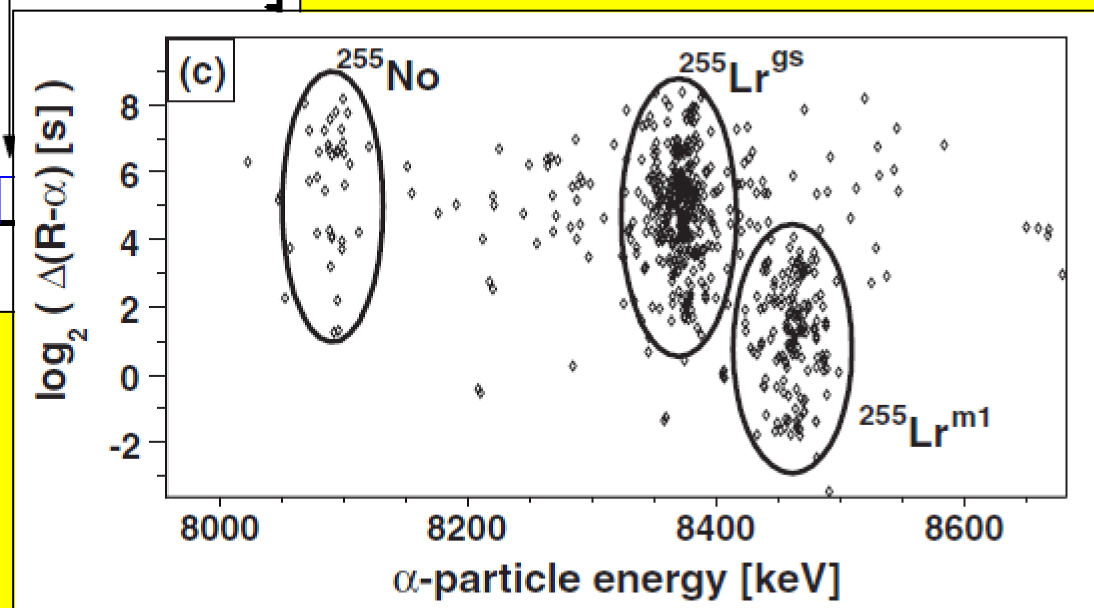
Also studied at BGS, LISE, GARIS, RITU and VASSILISSA

^{255}Lr

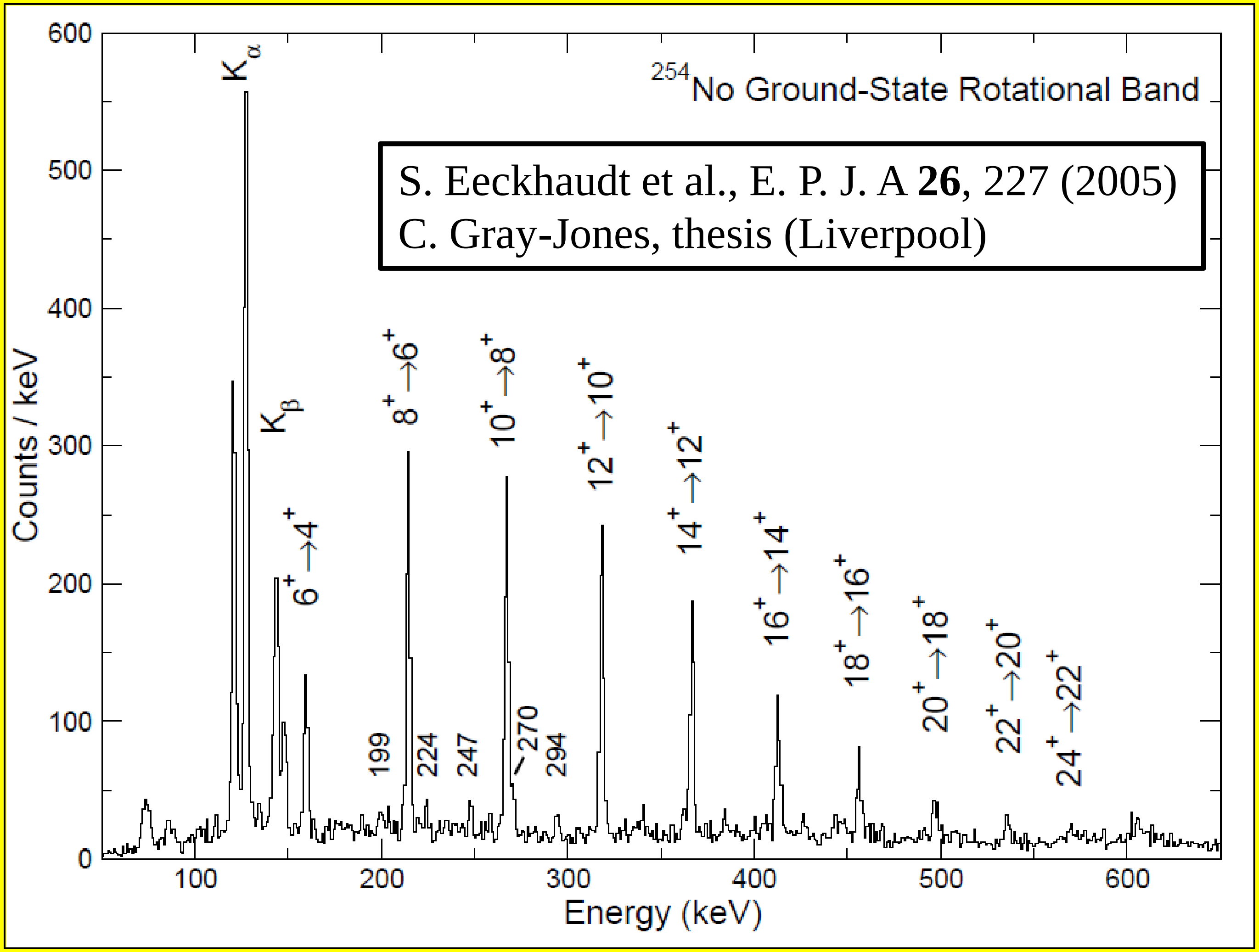


M. Asai @ TAN 11

K. Hauschild *et al.*,
PR C **78**, 021302(R) (2008)



In-beam experiments



^{256}Rf, the heaviest nuclide studied using in-beam spectroscopy

P. T. Greenlees et al.   JUROGAM + RITU

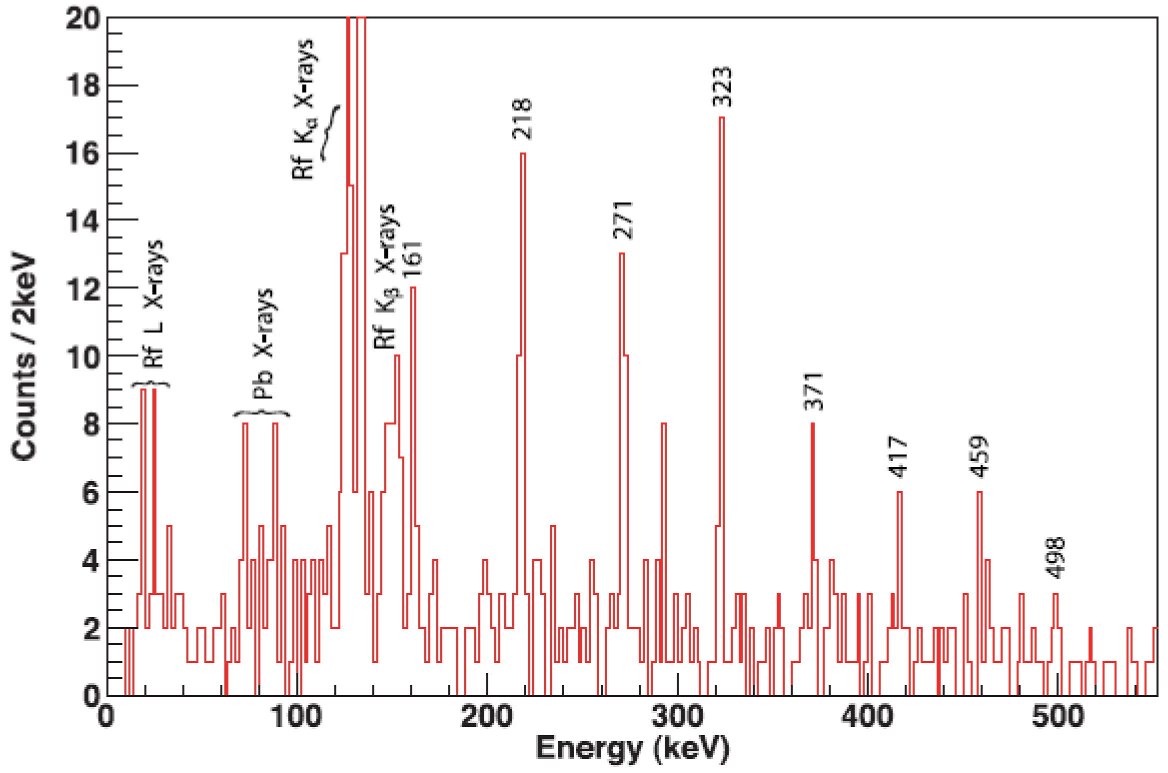


FIG. 2: Energy spectrum of prompt singles γ rays associated with fission-tagged ^{256}Rf recoils.

What do we learn from in-beam?

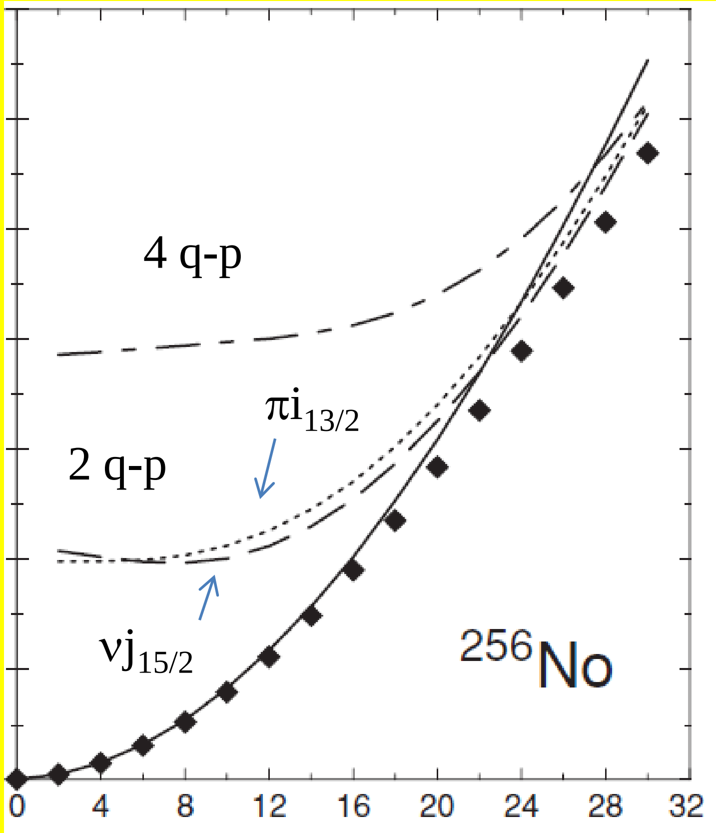
From the g.s. band we get the deformation and energy of the 2^+ state

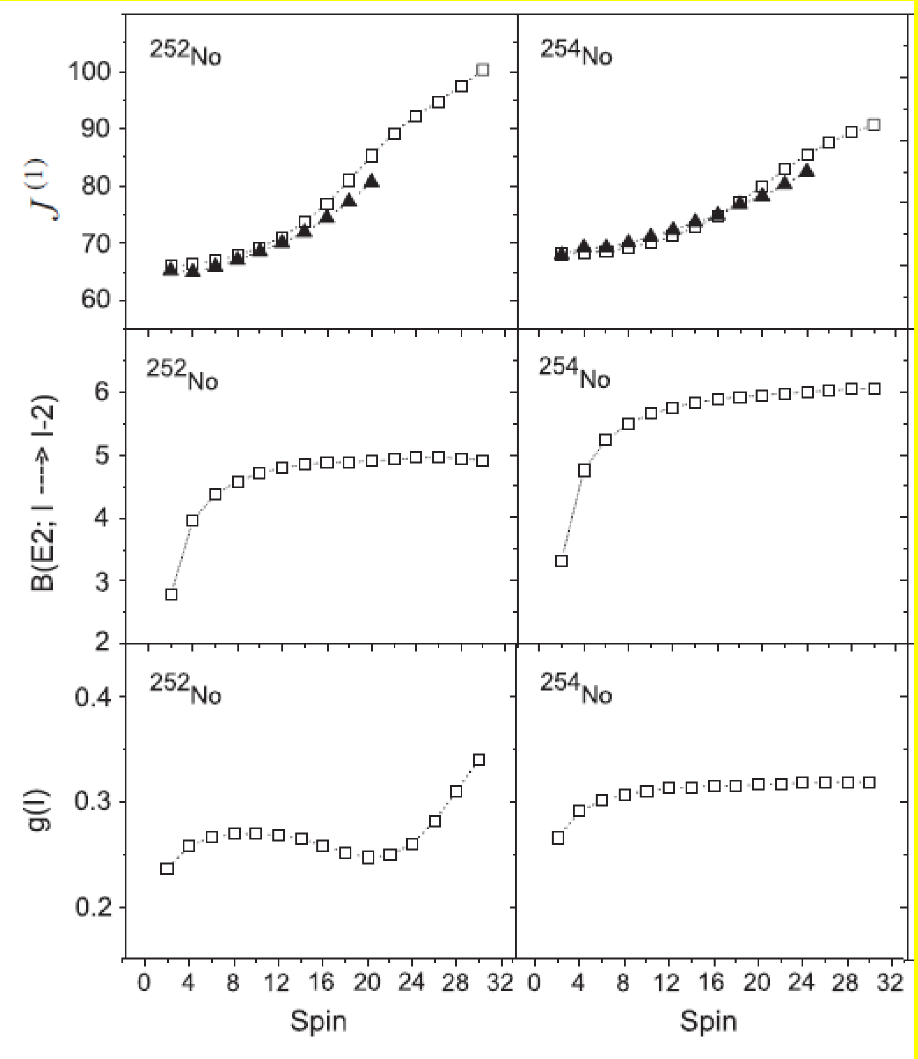
High-spin states with quasi-particle excitations tell us more
Plenty of theory support:
Egido, Robledo PRL **85**, 1198 (2000)
Bender, Bonche, Duguet, Heenen NP **A723**, 354 (2003)
Afanasjev, Khoo, Frauendorf, Lalazissis, Ahmad, PRC **67**, 024309 (2003)
Al-Khudair, Long, Sun PRC **79**, 034320 (2009)

Rotational alignment caused by the Coriolis interaction affects the high-j orbitals near the Fermi surface. Crossing of the aligning bands with the g.s. band show up in the measured data and tell us something about the orbitals.

Key observation: Strong competition between proton pairs from the $i_{13/2}$ orbital and neutron bands from the $j_{15/2}$ orbital

Quasi-particle alignment in No isotopes





Theory: Al-Khudair, Long and Sun Phys. Rev. C **79**, 034320 (2009)

How to make progress with in-beam experiments

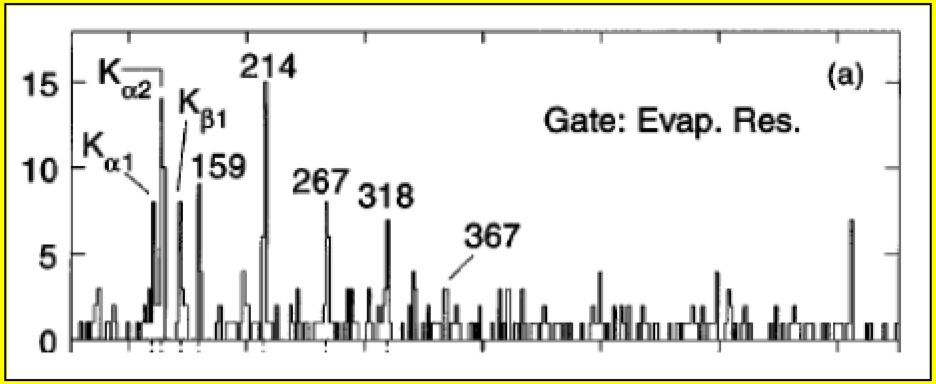
Need:

Better separators (but can only gain a factor of 2 or so in transmission)

Better arrays (ultimate gain factor of 5 in singles)
AGATA, GAMMASPHERE, GRETINA, EXOGAM

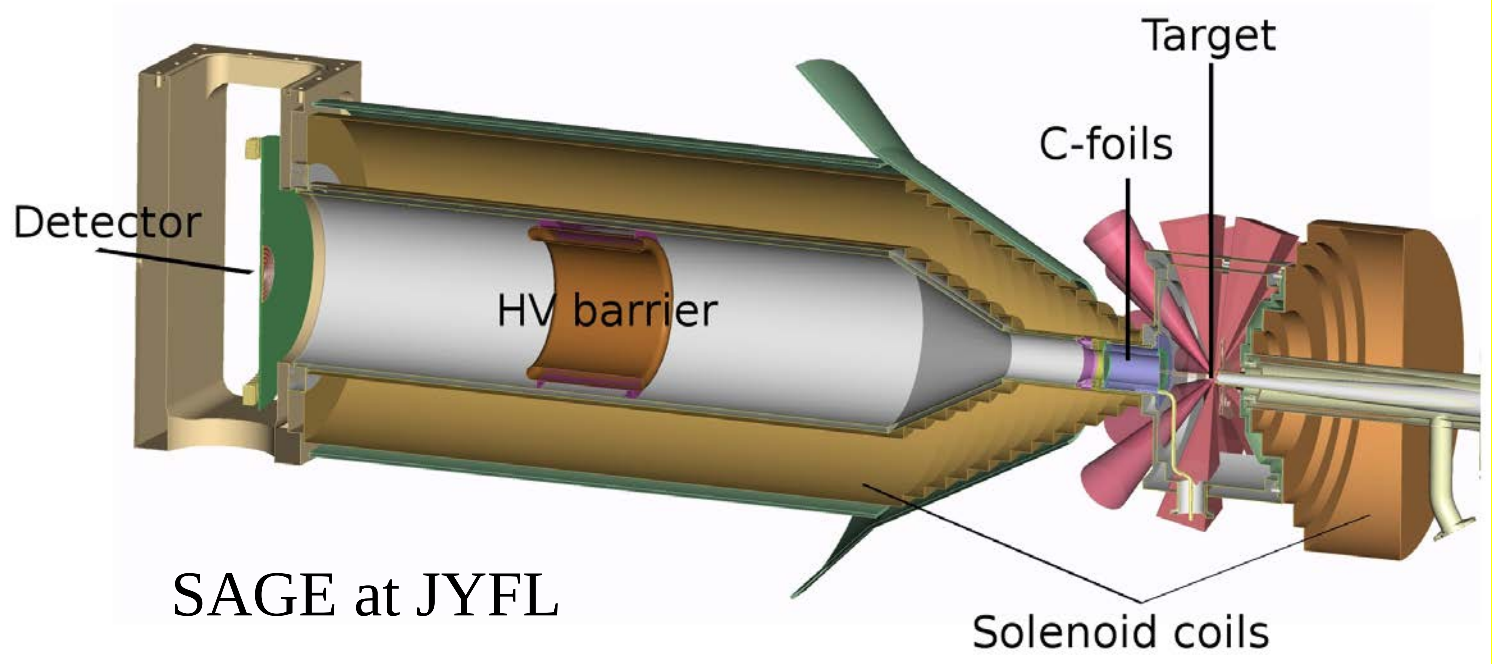
Higher beam intensities (digital electronics a must)

One can maybe reach cross sections of ~ 1 nb



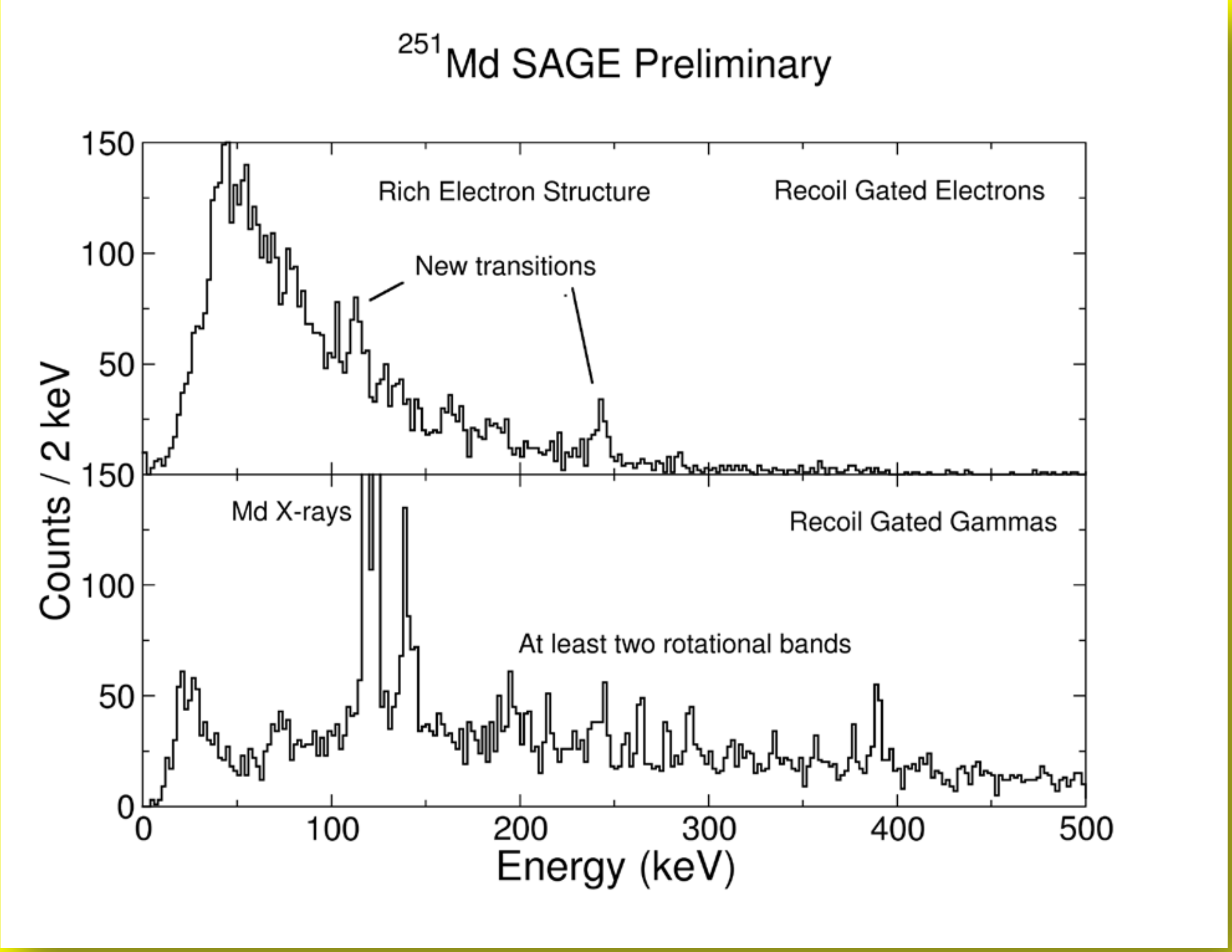
P. Reiter *et al.*, PRL **82**, 509 (1999)

Conversion electron spectroscopy



University of Liverpool
University of Jyväskylä
STFC Daresbury Laboratory

SAGE+RITU ^{251}Md preliminary data



Ch. Theisen et al.

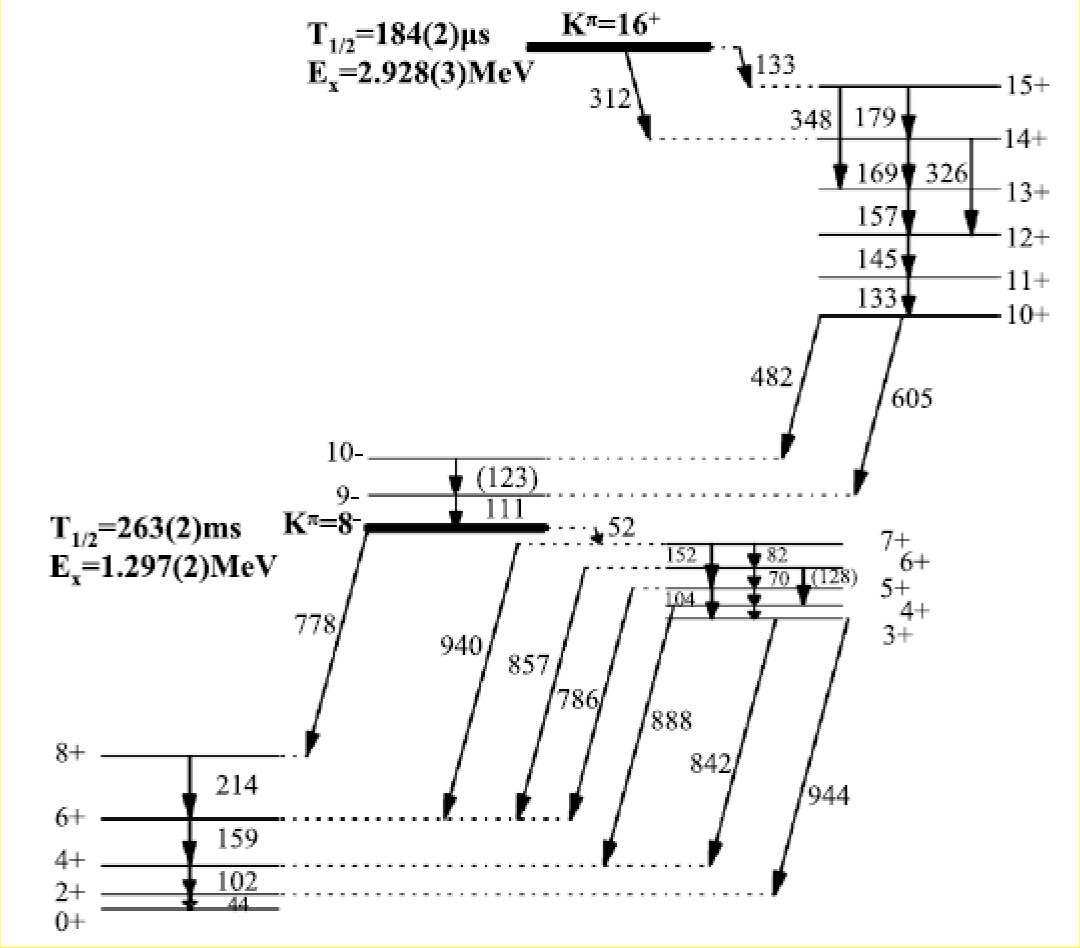
Multi-quasiparticle states in the No region

Important special cases: K-isomers

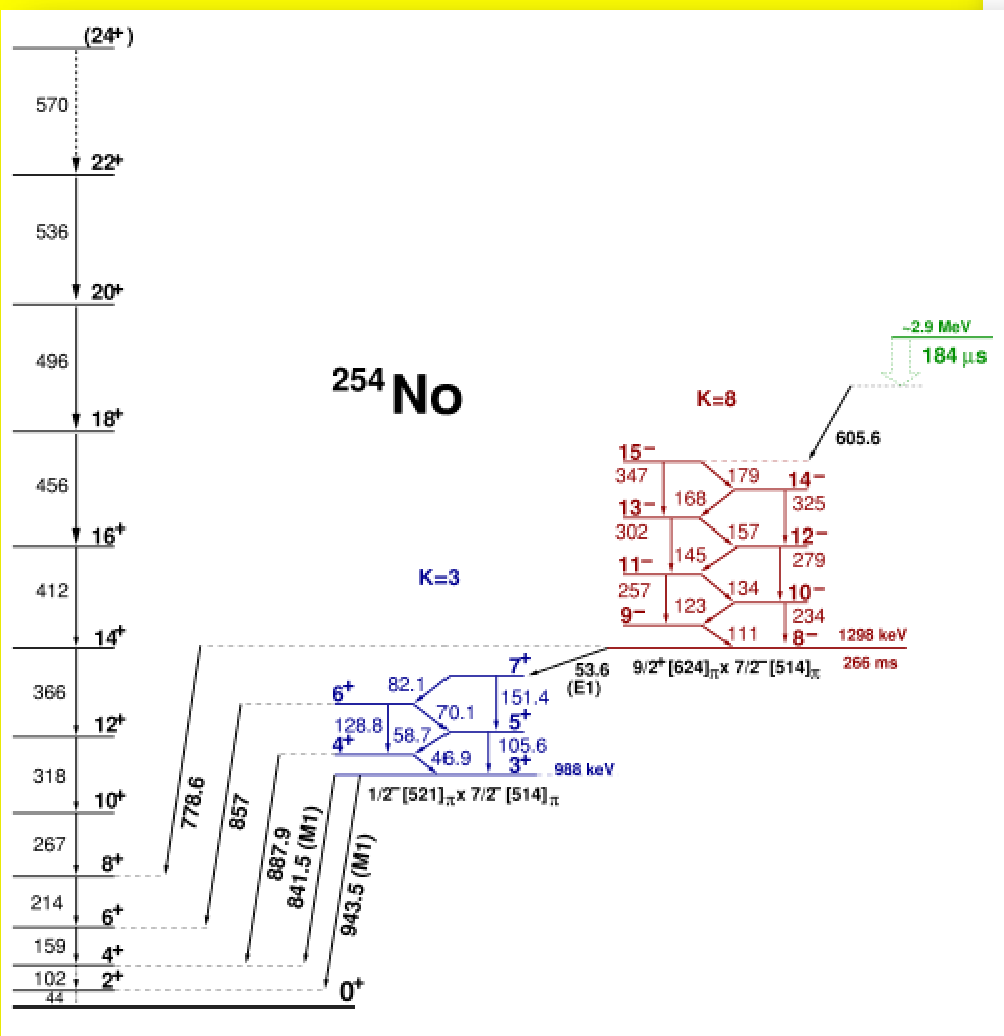
Work done *e.g.* at:

LBNL	^{256}Rf	Jeppesen *et al*. Phys. Rev. C **79**, 031303(R) (2009)
	^{254}No	Clark *et al*., Phys. Lett. B **690**, 19 (2010)
ANL	^{246}Cm, ^{252}No	Robinson *et al*., Phys. Rev. C **78**, 034308 (2008)
	^{254}No	Tandel *et al*., Phys. Rev. Lett. **97**, 082502 (2006)
	^{256}Rf	Robinson *et al*., Phys. Rev. C **83**, 064311 (2011)
JYFL	^{254}No	Herzberg *et al*., Nature **442**, 896 (2006)
	^{250}Fm	Greenlees *et al*., Phys. Rev. C **78**, 021303(R) (2008)
GSI	^{254}No	Heßberger *et al*., Eur. Phys. J A **43**, 55 (2010)
	^{252}No	Sulignano *et al*., Eur. Phys. J. A **33**, 327 (2007)

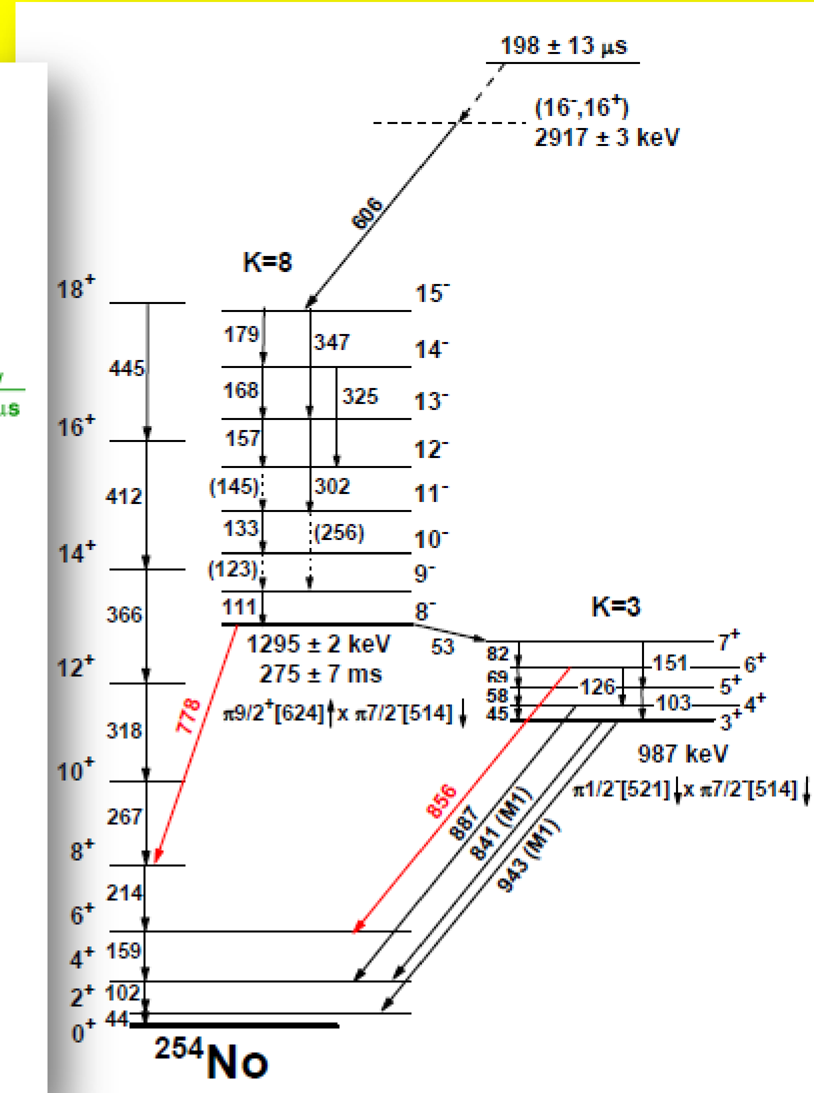
^{254}No Clark *et al*. PLB **690**, 19 (2010)



Graig-Jones, thesis (Liverpool, 2008)



Hessberger *et al*. EPJA **43** 55 (2010)



Is the 8^- state a proton state or a neutron state?

$7/2^+[624] \otimes 9/2^-[734]$ nn
$7/2^+[613] \otimes 9/2^-[734]$ nn
$7/2^-[514] \otimes 9/2^+[624]$ pp

Role of quenching:

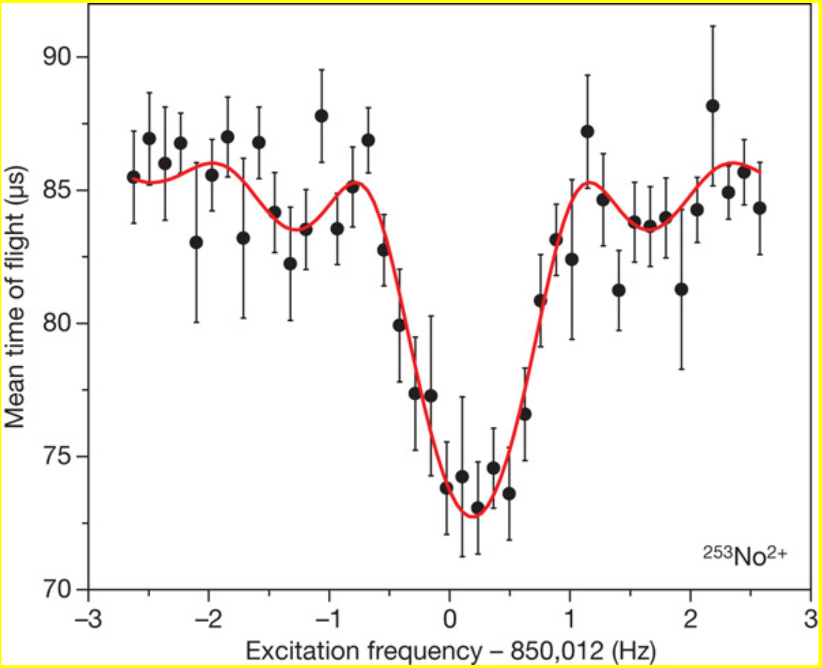
Branching ratios sensitive to $[(g_K - g_R)/Q_o]^2$

$g_R = q \cdot Z/A$ $\quad\quad$ $q < 1$: quenching

Depending on q, the 8^- state can be either a proton state or a neutron state

For comparison, in ^{252}No and ^{250}Fm, the 8^- is clearly a neutron state ($7/2^+[624] \otimes 9/2^-[734]$ nn)

Mass determination in the No region



M. Block *et al*. *Nature* **463**, 785 (2010)

…we have determined the mass values of $^{252\text{-}254}$No (atomic number 102) with the Penning trap mass spectrometer SHIPTRAP. The uncertainties are of the order of 10 keV/c^2 (representing a relative precision of 0.05 p.p.m.), despite minute production rates of less than one atom per second.

Urgently needed:(Firm) determination of key observables

Spin-parity: ^{253}Es $I^{\pi} = 7/2^{+}$ from optical spectroscopy, magnetic moment
How to proceed towards higher Z?

Life times: Possibility of using the charge plunger technique

g-factor determination:

g-factors are very sensitive to the configuration of the state, *e.g.* collectivity of 2^{+} states

M. Ionescu-Bujor *et al.*, PR C **81**, 024323 (2010) ^{188}Pb 8^{-}, 11^{-}, 12^{+} isomers

- Perturbed angular correlations/distributions (half-life restrictions apply)
- NMR

Possible case: ^{254}No 8^{-}

3. Technical developments in spectroscopy

Many projects are going on all over the world, *e.g.* work on digital electronics which will inevitably become a standard

There is most likely unnecessary duplication of efforts which is wasteful
e.g. detector chip design

Collaboration and coordination might be beneficial. Some kind of standardisation $\rightarrow$ Perhaps a sizable order from a (not so small) company

Small step: Standardised data format?

Movable detector systems; GREAT as an example

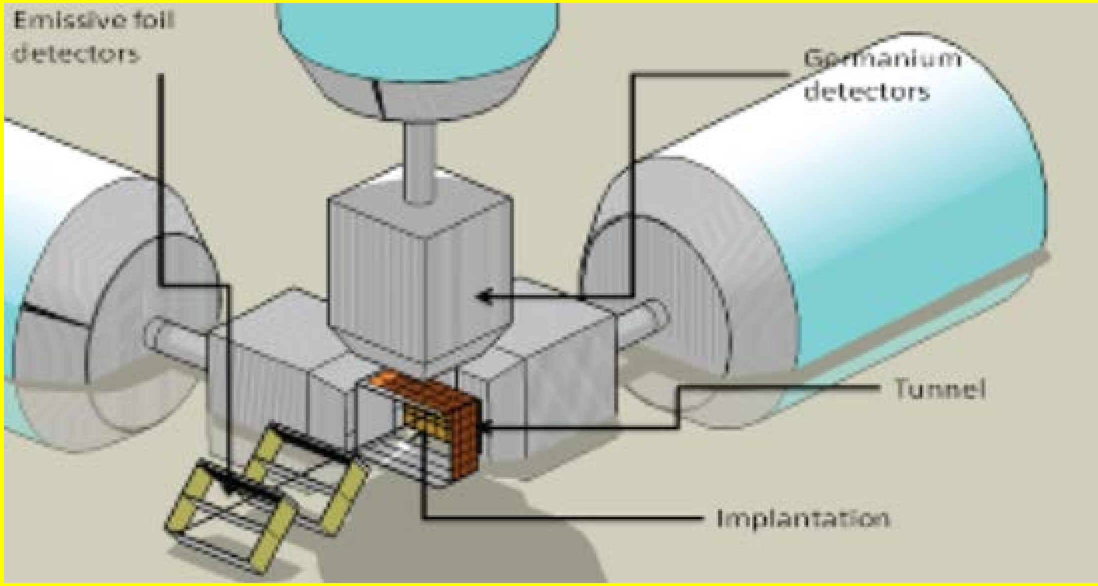
Sometimes overlooked? Low energy γ's, X-rays, L-conversion; need *e.g.* planar Ge

Focal plane detectors

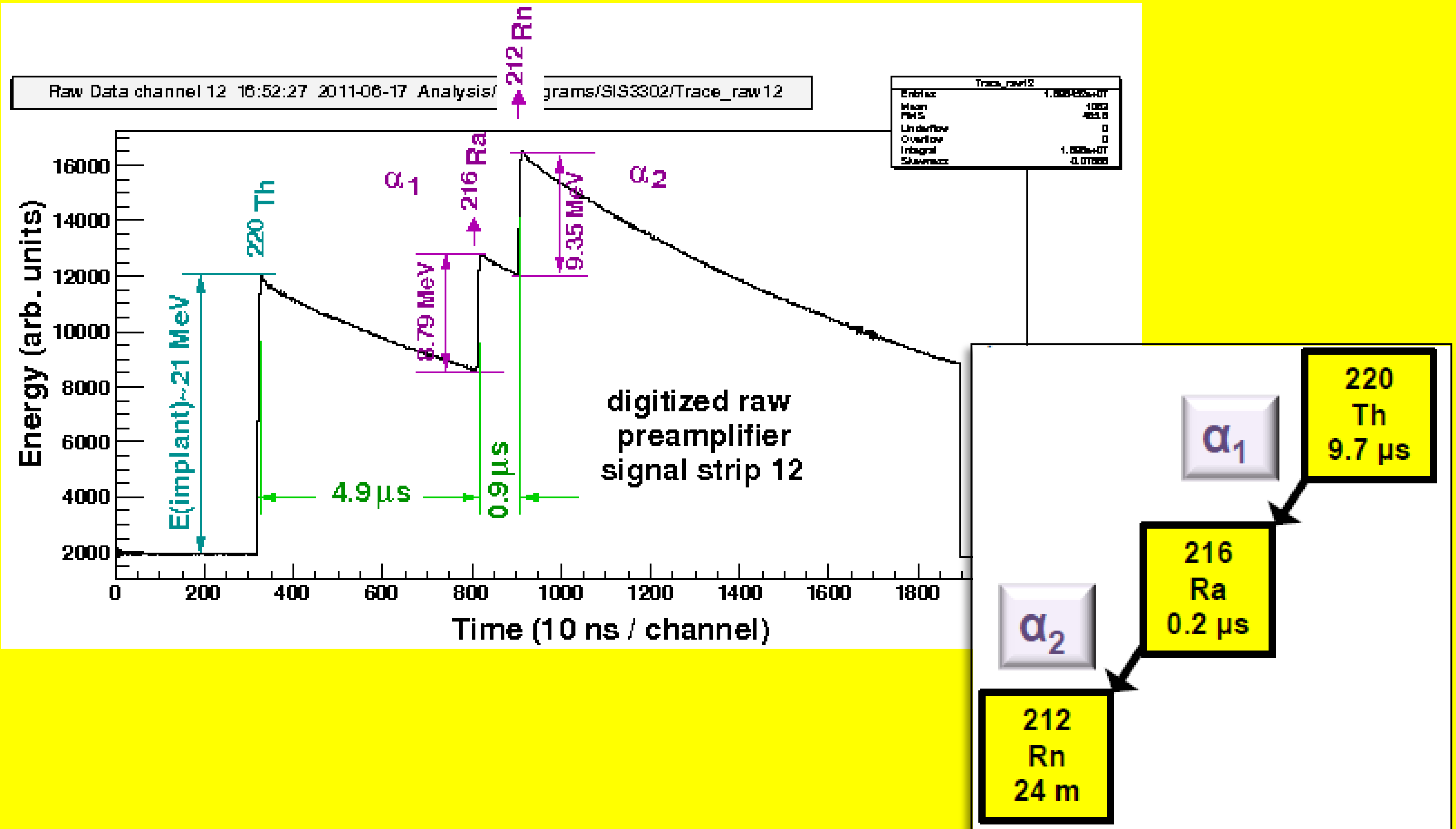
Size is an interesting question

Si is cheap
Electronics is not that cheap? (large size $\rightarrow$ large number of channels)
Many pixels $\rightarrow$ low accidental count rate
But: Need a reasonably high γ detection efficiency

An example: S^3 $< 10\times20$ cm^2

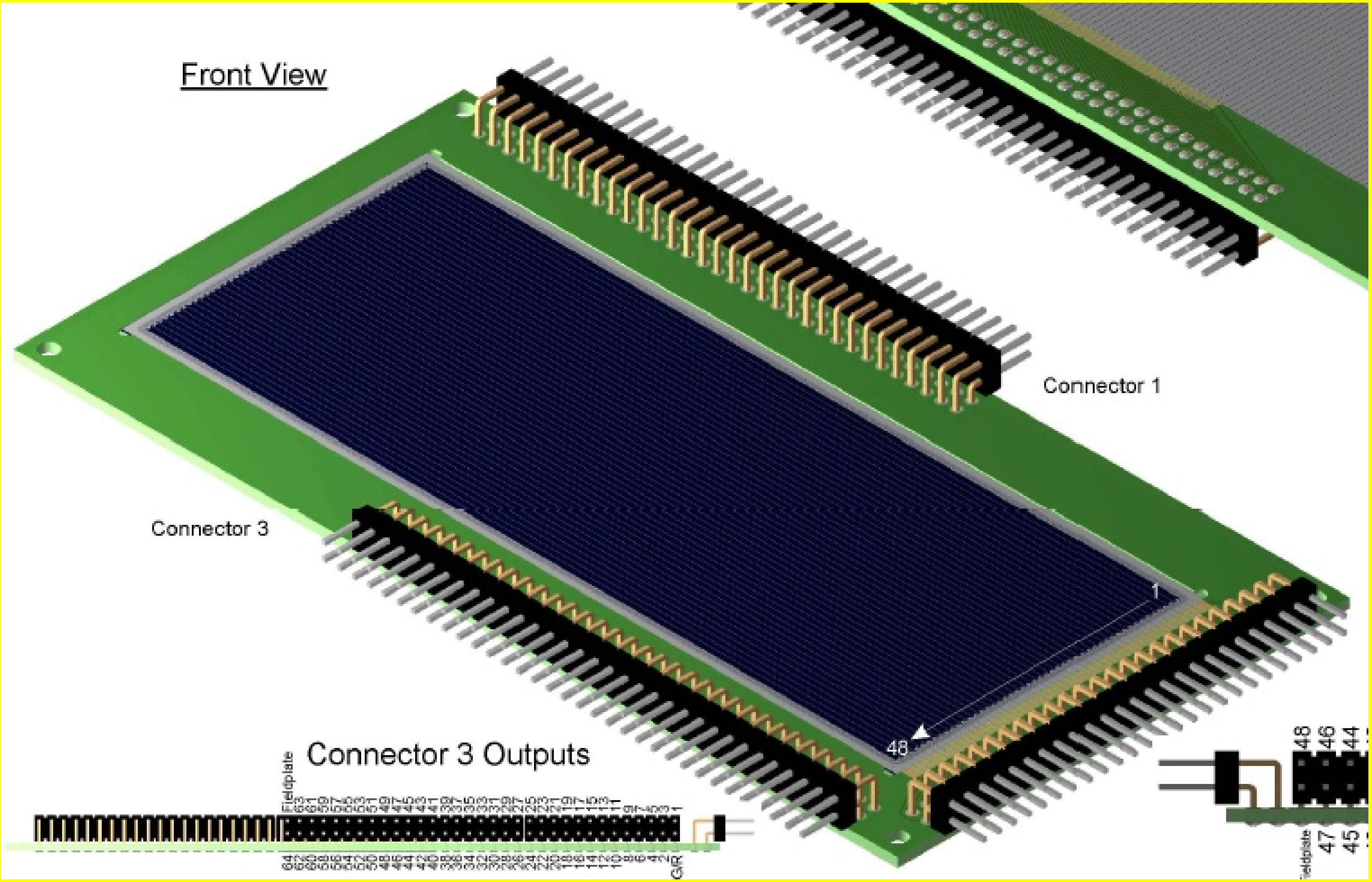


Nuclear traces



The 2011 Z=120 TASCA experiment was performed with dead-time free sampling ADC cards developed at GSI-EE N. Kurz *et al.*

MARA/JYFL detector chip from Micron; active area 128mm×48mm



4. Developments in on-line recoil separators

Key questions:
How to deal with hot fusion (asymmetric reactions)
How to get the mass number
How to cope with 10 pμA beam intensities
How to handle the problem: high transmission → high background

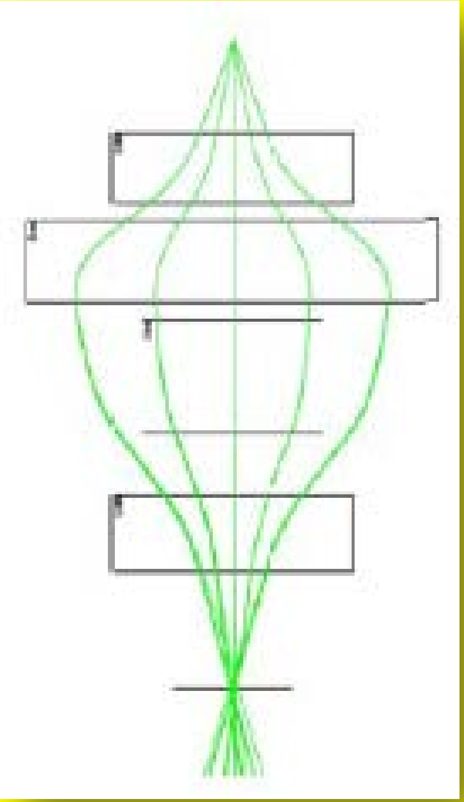
On-going projects
MASHA, VASSILISSA at FLNR
AGFA at ANL
VAMOS at GANIL
Mass analyzer at LBNL
S^3 at GANIL
SHANS/GFRS at Lanzhou
GARIS2 at RIKEN
…

Future devices

•Improved SHIP   G. Münzenberg *et al.*
Two velocity filters (compact) + magnet
Proven concept

•Gas-filled devices
Often increased acceptance; background problems?

•Separator for multi-nucleon transfer reaction products
IRiS



Almost universally planned:
Combine the separator with a Z/A device
(TOF, RFQ,…)

But: Can one *really* proceed beyond what has already been done using SHIPTRAP

Again: Maybe better join forces and get organised

Gas-filled everywhere?

Gas-filled VAMOS
C. Schmitt *et al*., NIM A **621** (2010) 558

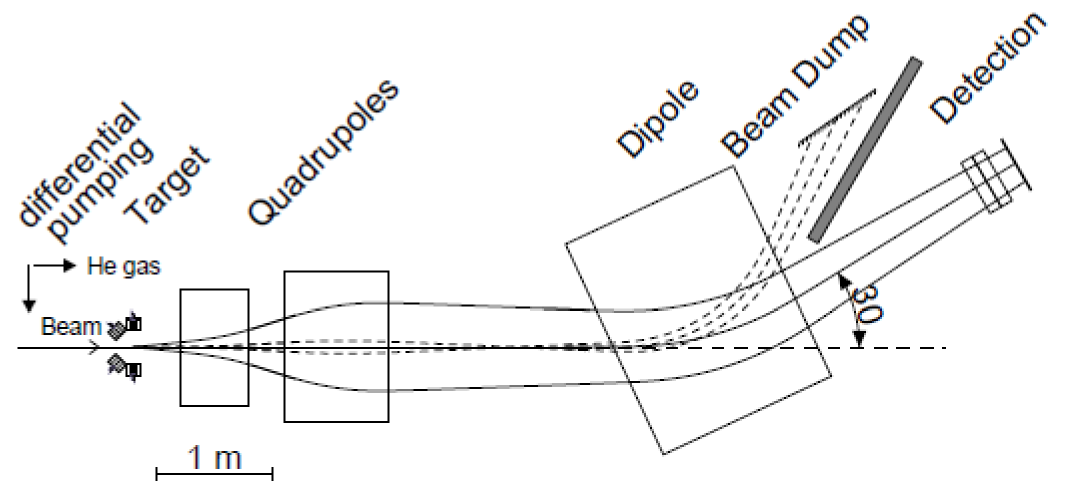
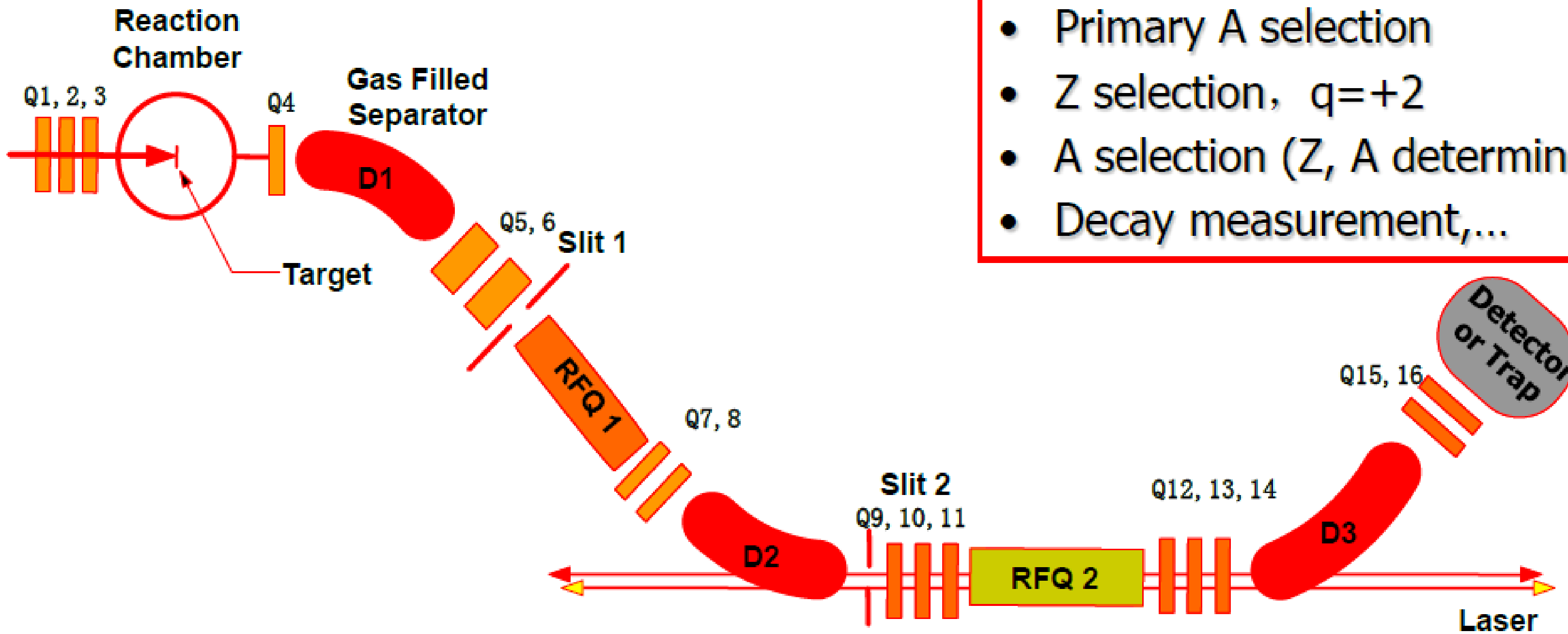


Fig. 13. Schematic layout of the planned upgrade of the gas-filled VAMOS.

$\Omega \sim 60$ msr, $\Delta B\rho/B\rho \approx \pm 7\%$; trajectory reconstruction

SHANS @ LANZHOU

Spectrometer for Heavy Atom and Nuclear Structure



- Production
- A/Z selection
- Collection & cooling， q=+1
- Primary A selection
- Z selection， q=+2
- A selection (Z, A determined)
- Decay measurement,...

Courtesy Hushan Xu / G. Münzenberg

5. Final thoughts

We need to divide the tasks somehow

Supposing El.120 is made, how to proceed
How to take nuclear structure measurements to higher Z

Who (and how) will take care of
- Dedicated accelerators
- Separators capable of dealing with hot fusion products
- Electronics
- Detectors
- Targets

Thanks

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