

# Coulomb excitation with TIGRESS for nuclear structure

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Jack Henderson

ARIEL Science Workshop, 21/04/2026

# Why Coulomb excitation?

The nucleus is a **finite strongly-interacting, many-body** system

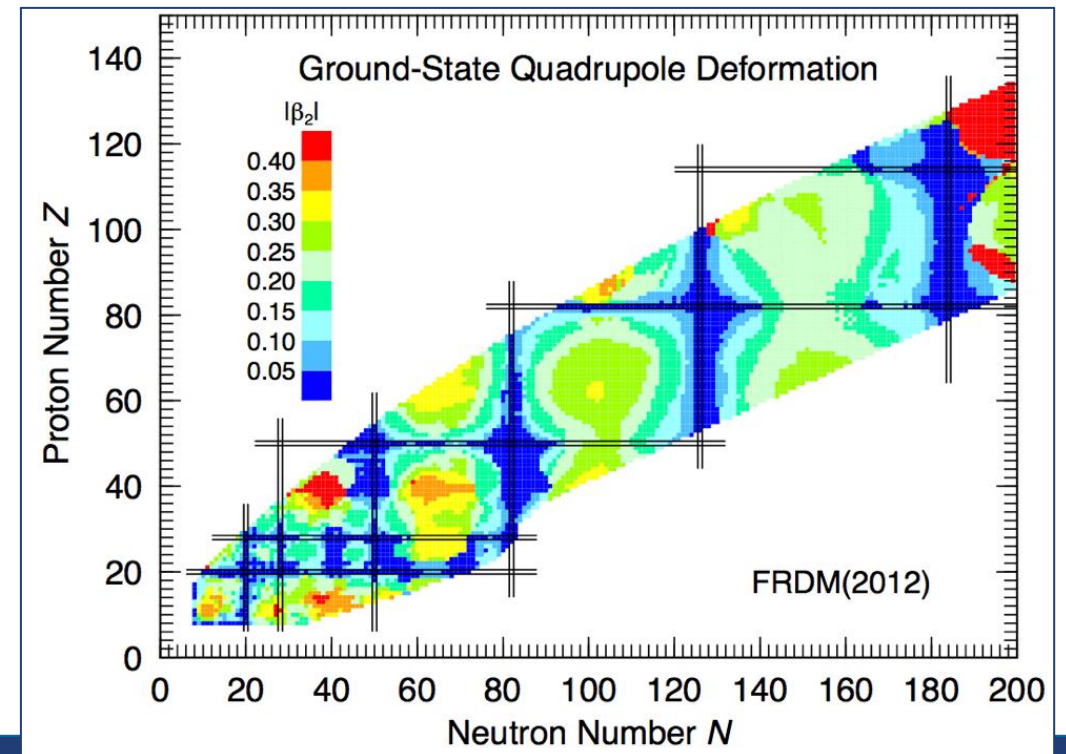
Collective nuclear properties are emergent properties of the nuclear system arising because of the strongly-interacting, many-body nature of the problem

Collectivity (and deformation) is an extreme test of nuclear models

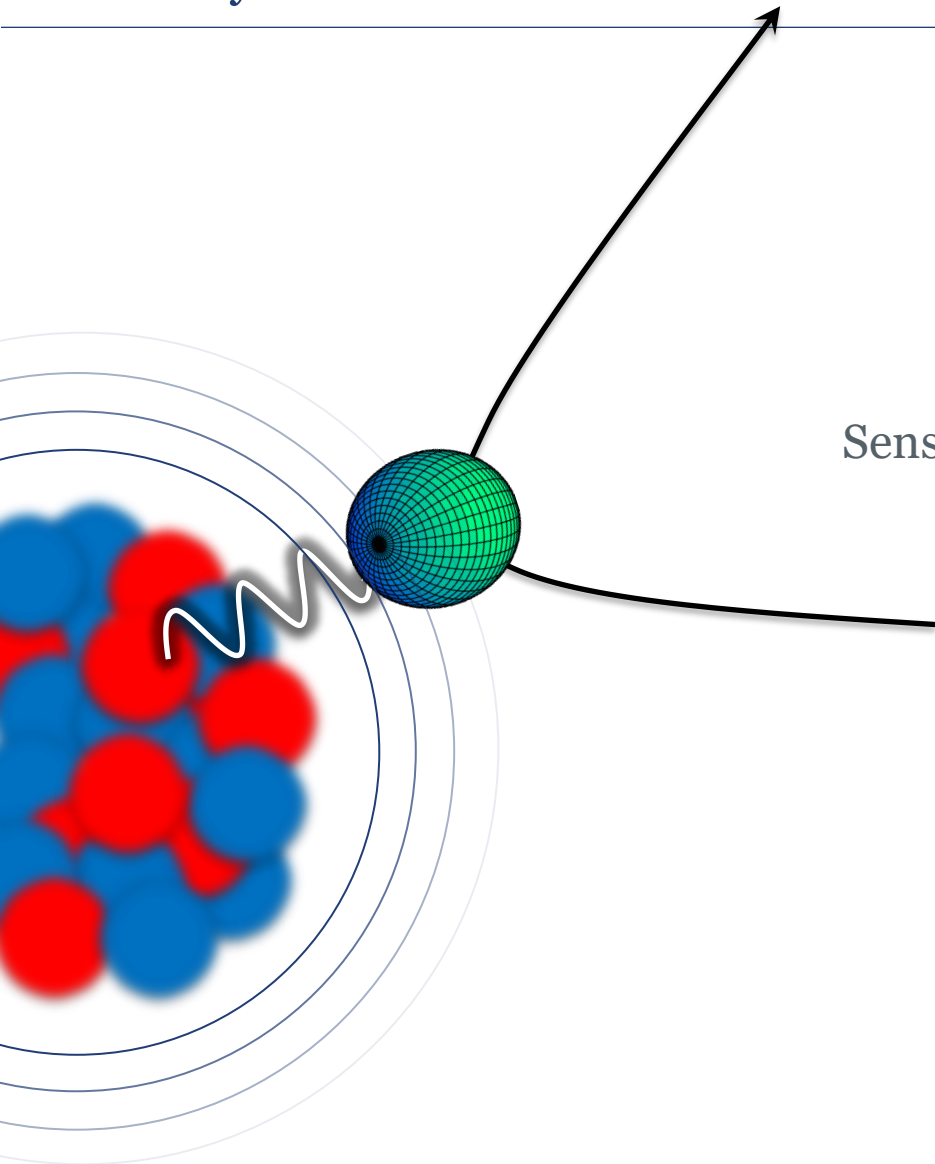
Experimental signature for collectivity is corresponding electric-multipole strength (e.g. E2, E3, E4, etc..)

Inhibited near nuclear magic numbers – but ... everywhere

P. Möller et al., At. Nucl. Data Tables **109** 1 (2016)



## Why Coulomb excitation?



Electromagnetic (“model independent”) probe of the nucleus

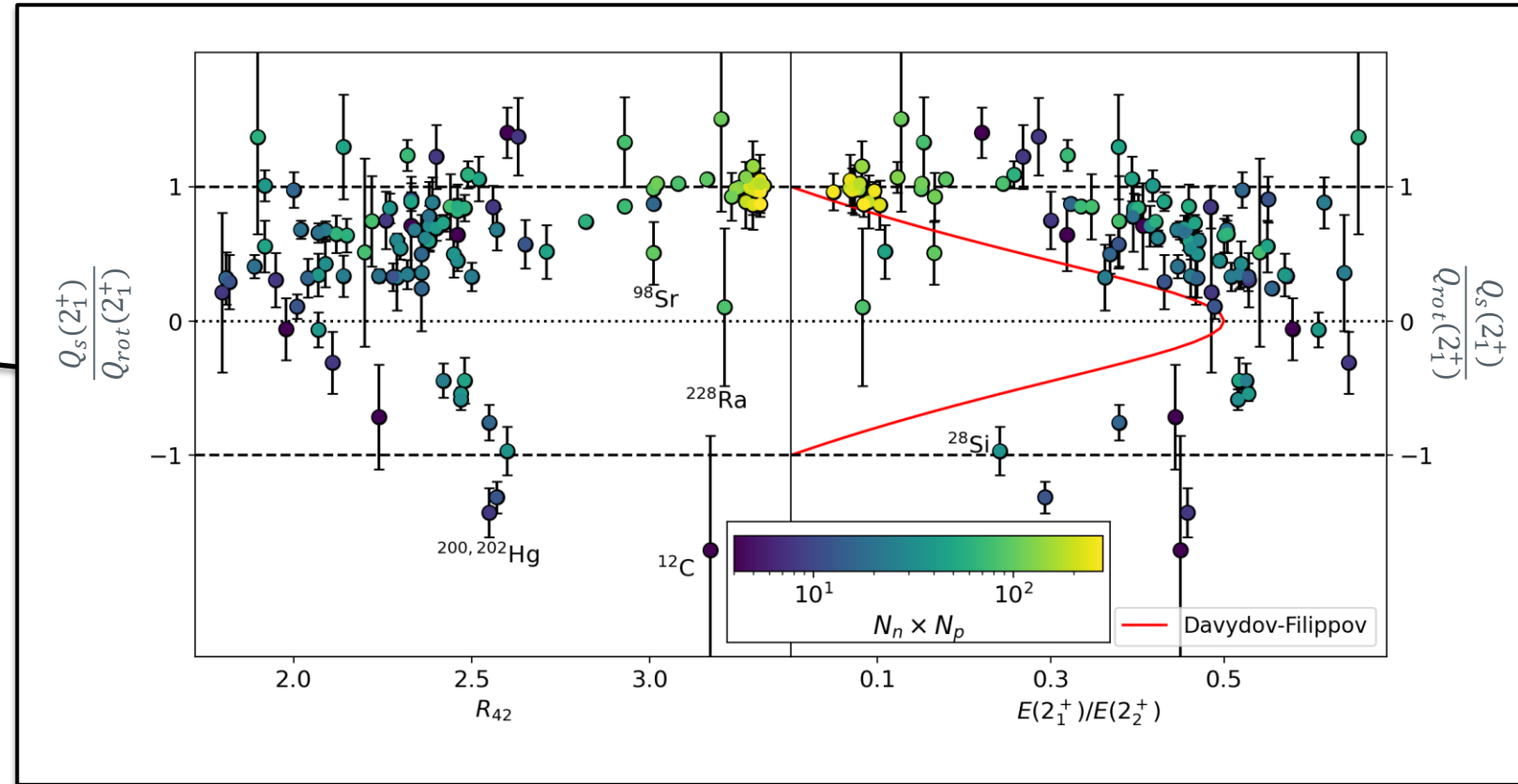
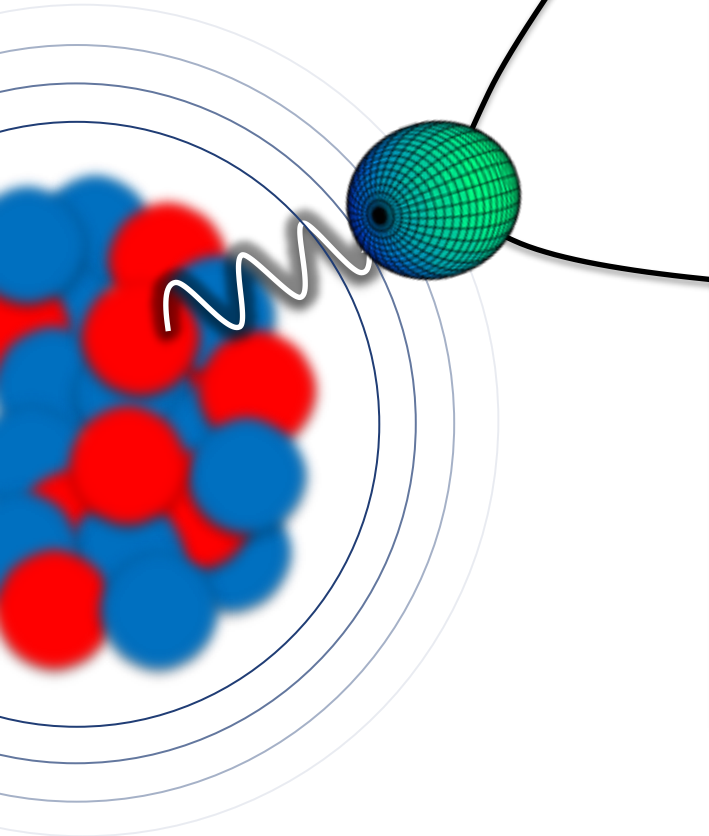
Sensitive to magnitudes and (relative) signs of electric multipole matrix elements including spectroscopic quadrupole moments

Large cross sections – well-suited to RIB

Exceptional probe of nuclear deformation through sum rules

Kumar PRL **28** 249 (1972)

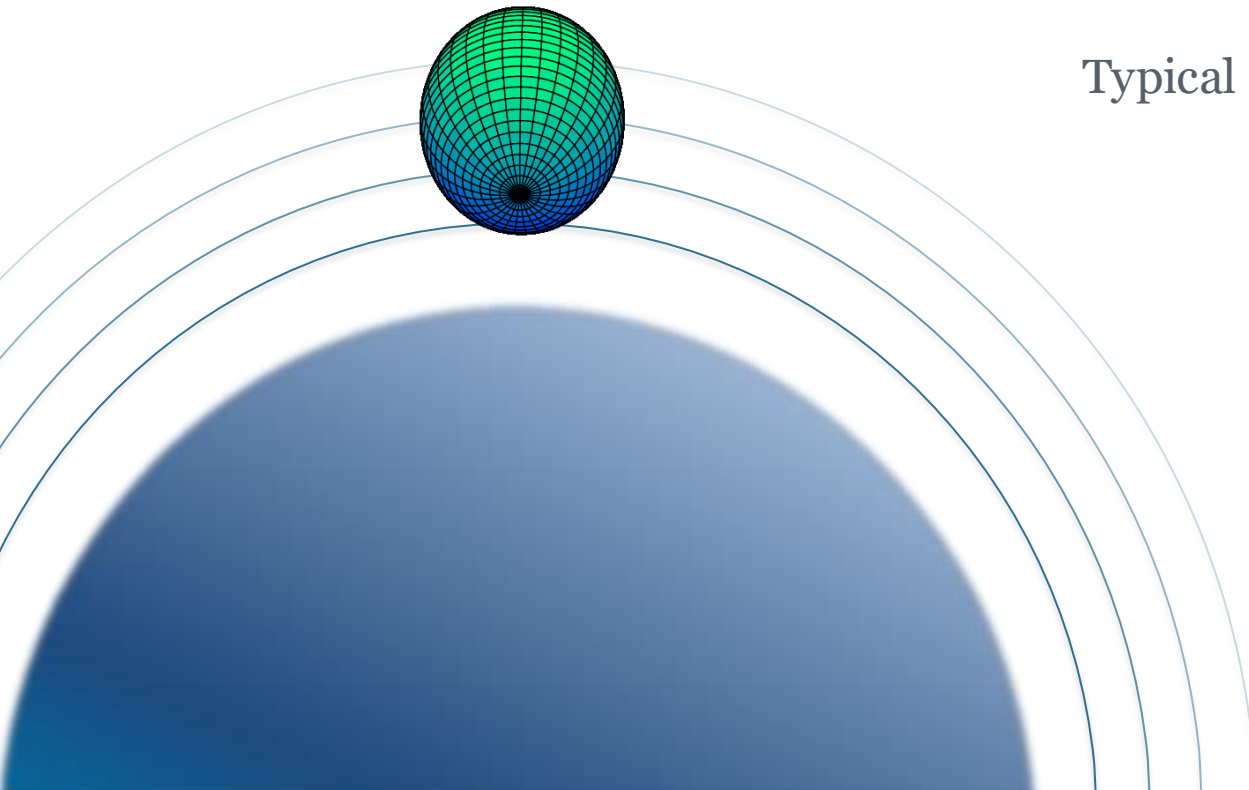
# Why Coulomb excitation?



# Why Coulomb excitation?

## How do we access quadrupole moments?

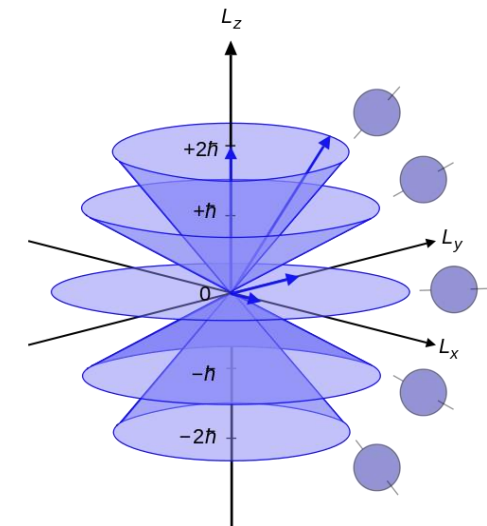
Qualitative picture: Nuclear moments cause a reorientation in an electric field gradient



Typical CoulEx reaction:  $dV/dr \approx 10^{30} \text{ V/cm}^2$

Nucleus aligns relative to symmetry axis

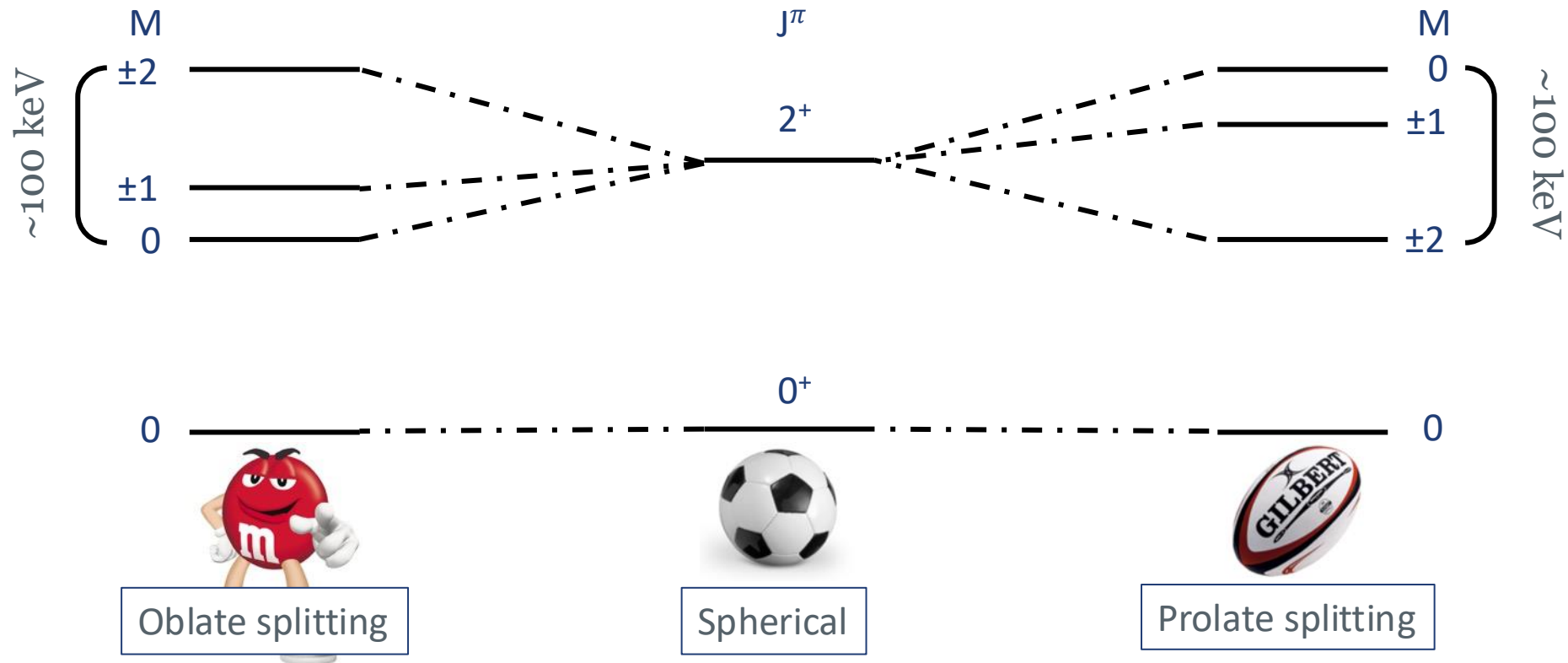
Breaks m-state degeneracy



# Why Coulomb excitation?

Splitting  $\propto dV/dr \sim 10^{30}$  V/cm

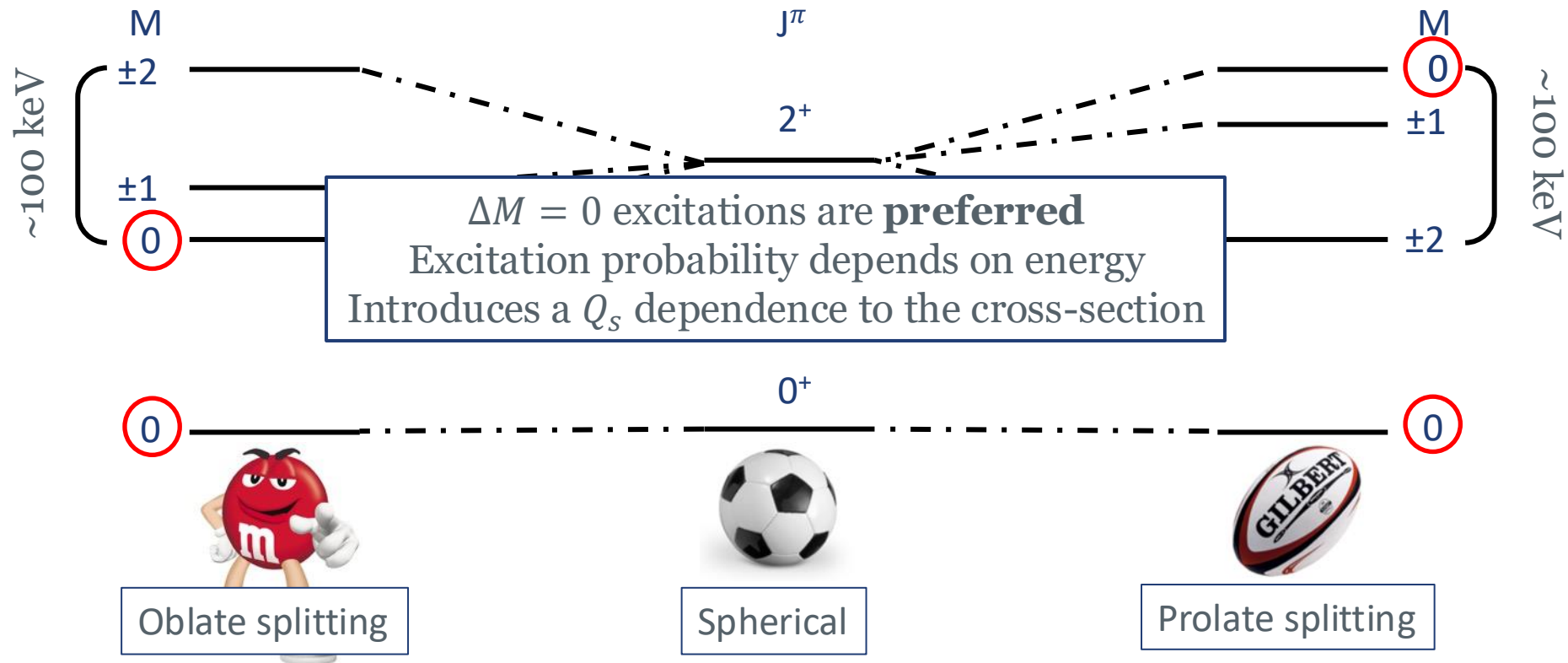
$$E(t) \propto eQ_s Z / r^3(t)$$



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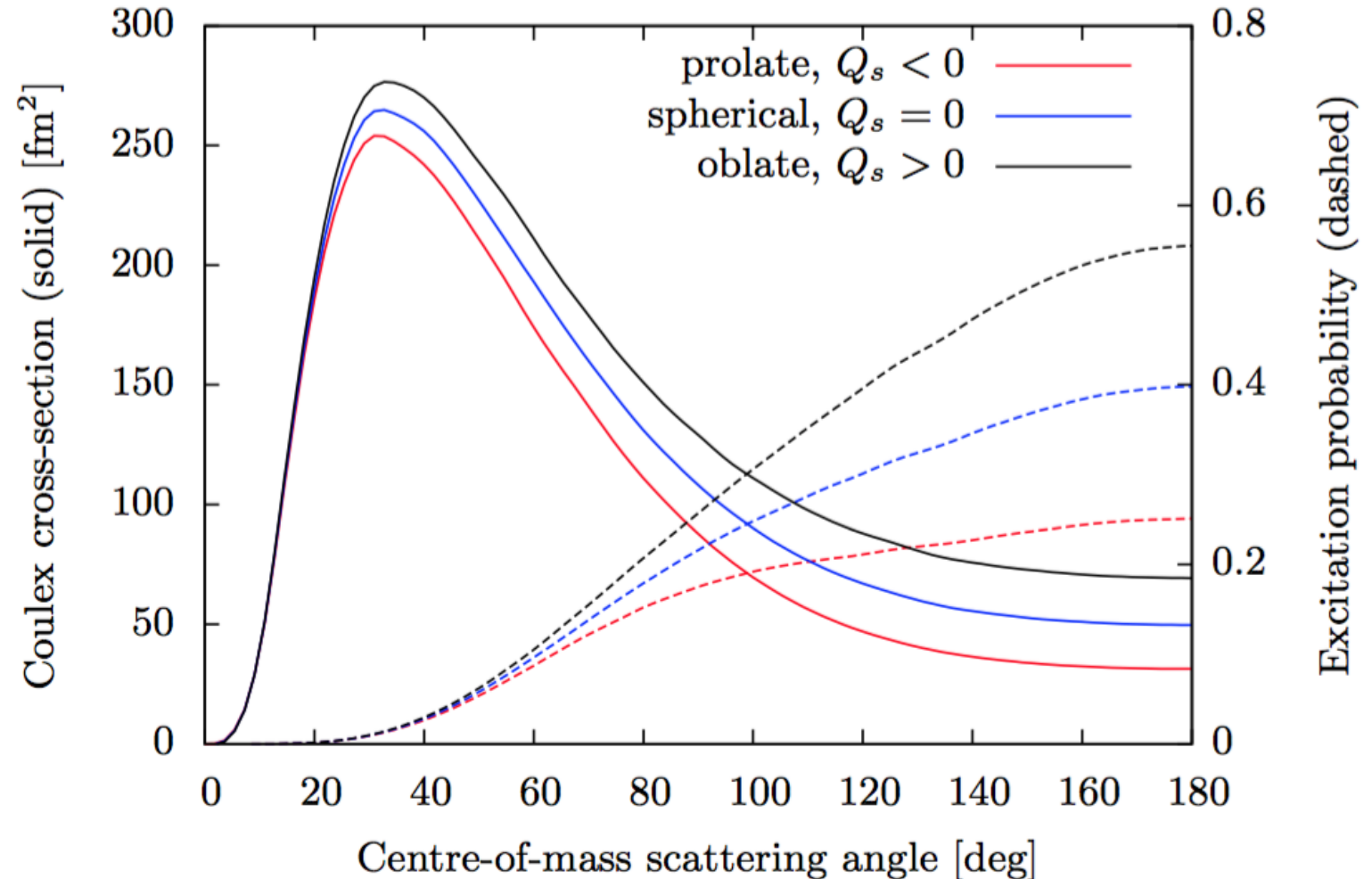
# Why Coulomb excitation?

Since angle and impact parameter are related, this introduces an additional angular dependence to the cross section

Also influences the angle-integrated cross-section

Measure the distribution and/or the integrated cross-section and access the quadrupole moment

M. Zielinska et al. Eur. J. Phys. A 52 99 (2016)



# Why Coulomb excitation?

## Approximate intensities required:

$B(E2; 0_1^+ \rightarrow 2_1^+)$ :  $\sim 10^3$  pps

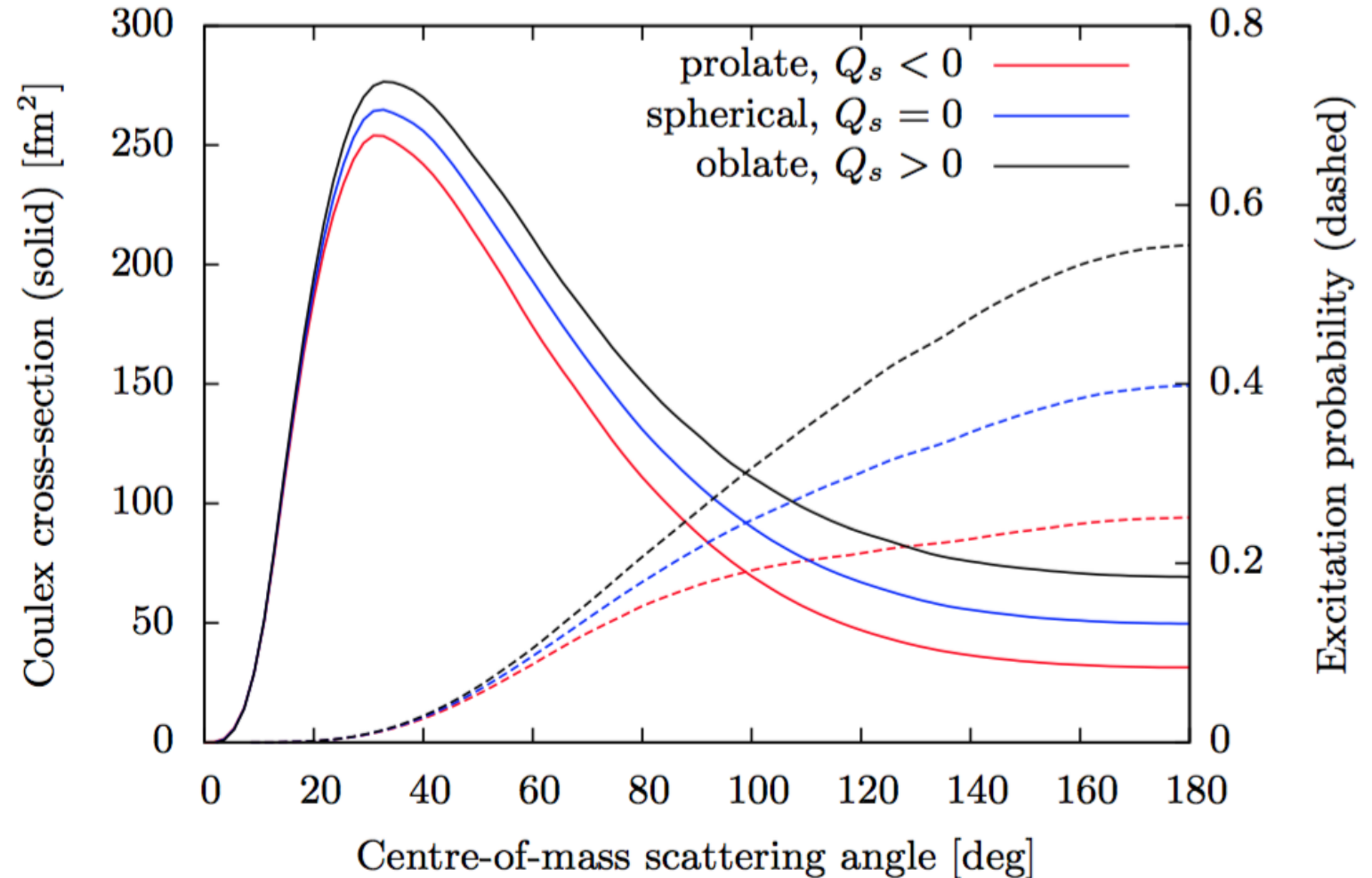
$Q_s(2_1^+)$ :  $\sim 10^4$  pps

Multi-step ( $4^+$ , more  $2^+$  states):  $\sim 10^5$  pps

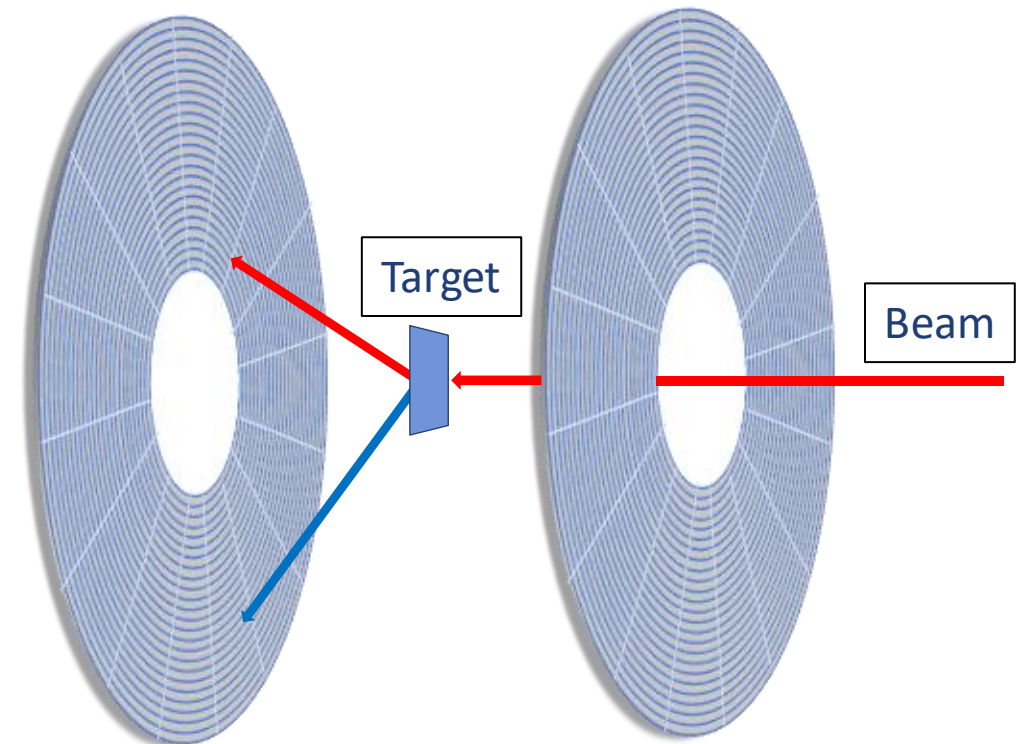
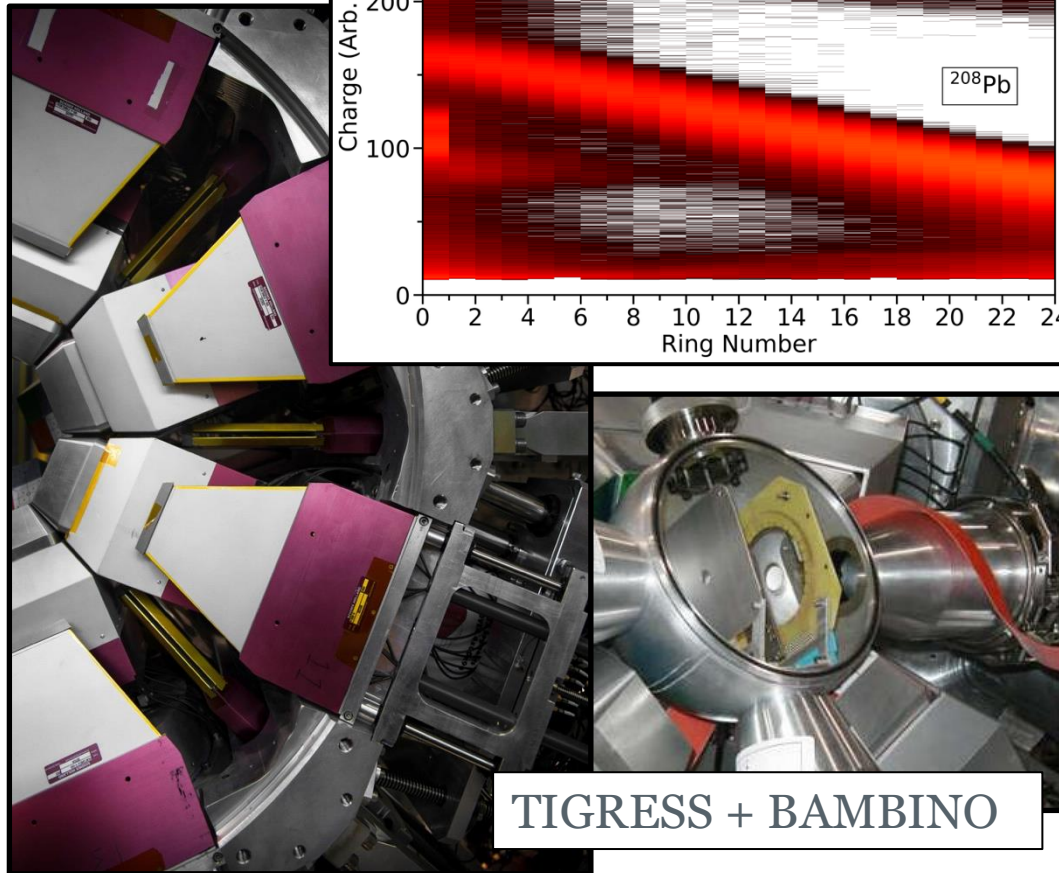
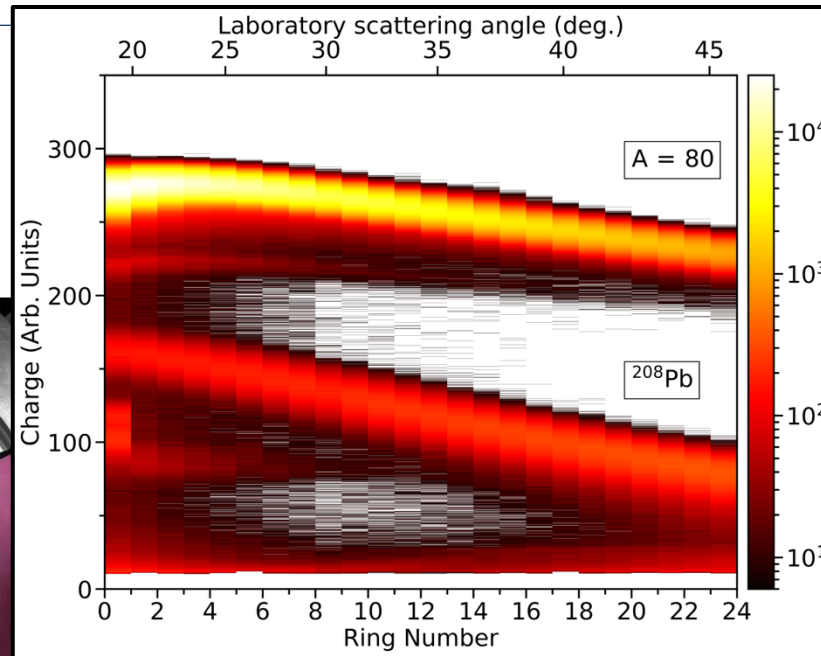
Sum-rule analysis:  $\sim 10^6$  pps

$\sim$ EBIS limit:  $10^6$  pps

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# TIGRESS and BAMBINO



# (Some) Past results

## Tests of *ab initio* theory:

$^{21}\text{Mg}$  [Ruotsalainen PRC 2019]

$^{22}\text{Mg}/^{22}\text{Ne}$  [JH PLB 2018]

$^{23}\text{Mg}/^{23}\text{Na}$  [JH PRC 2022]

$^{10}\text{Be}$  [Orce PRC 2021]

$^{12}\text{C}$  [Raju PLB 2018]

## Shape-coexistence/evolution:

$^{80,82}\text{Sr}$  [Russell PRC 2025]

$^{78,80,82,(84,86)}\text{Kr}$  [Gillespie PRC 2021]

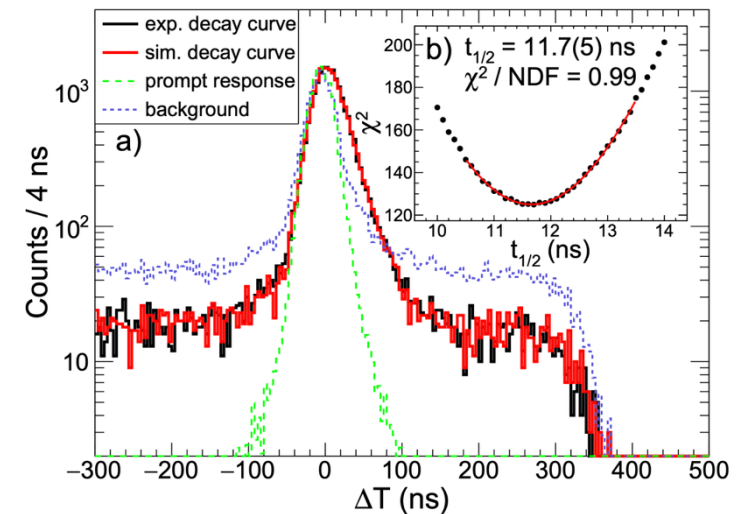
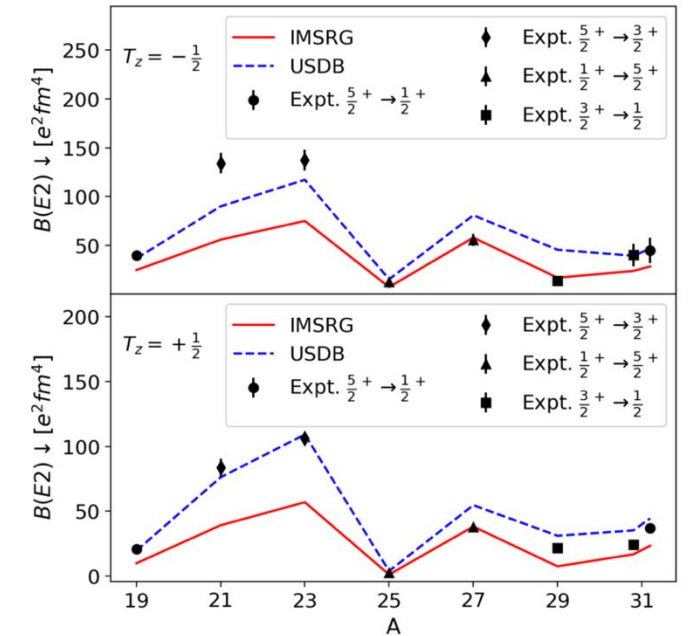
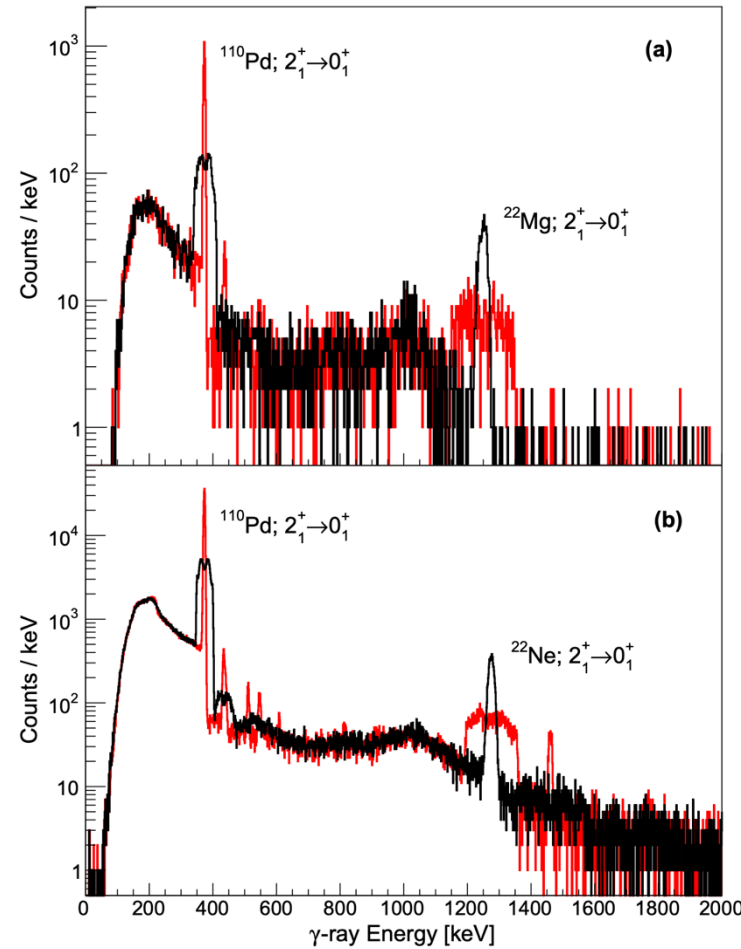
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$^{84\text{m}}\text{Rb}, ^{84}\text{Sr}$

$^{29}\text{Na}$  [Hurst PLB 2012]

## Rare-earth:

$^{156,158,160}\text{Er}$



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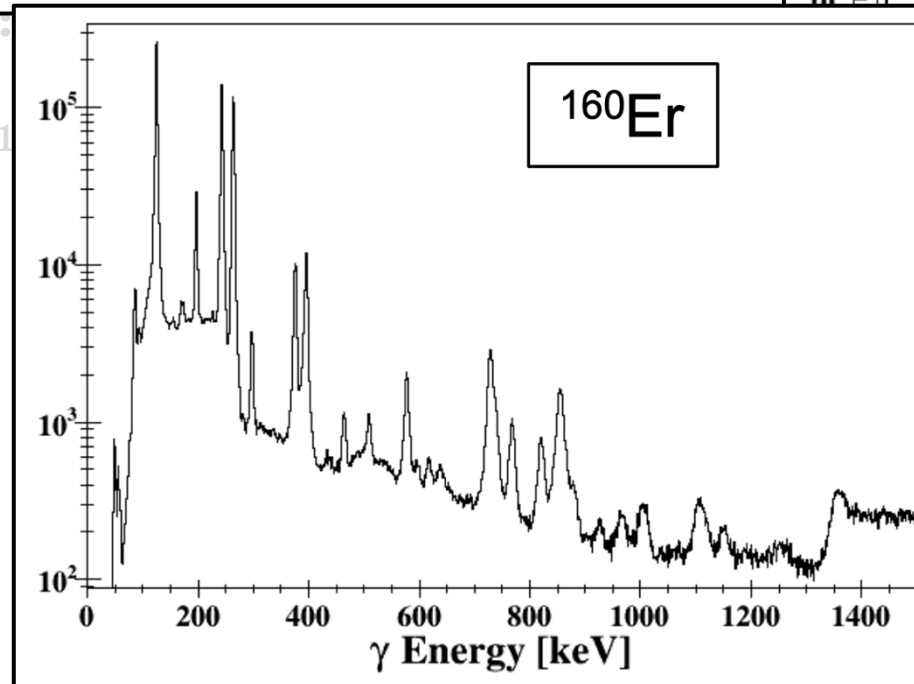
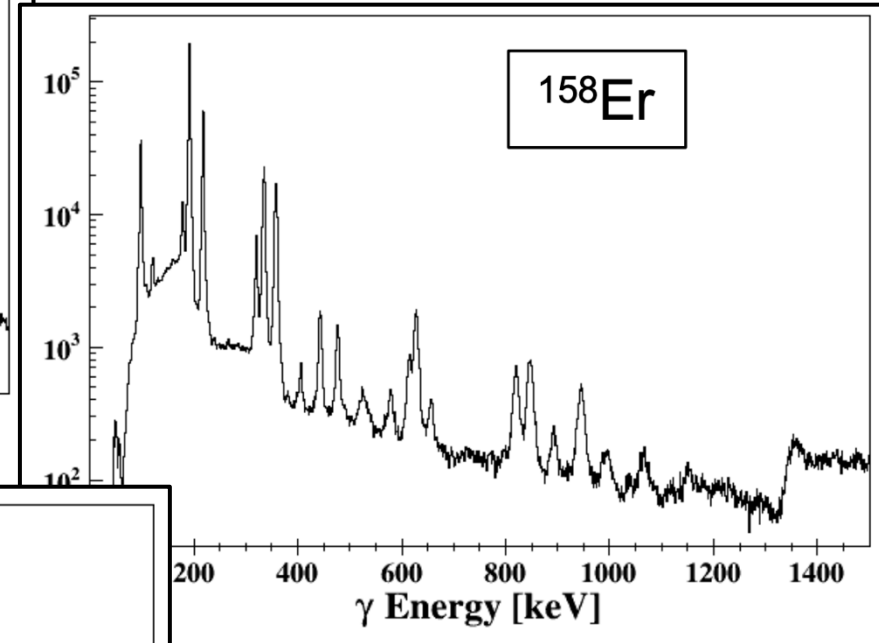
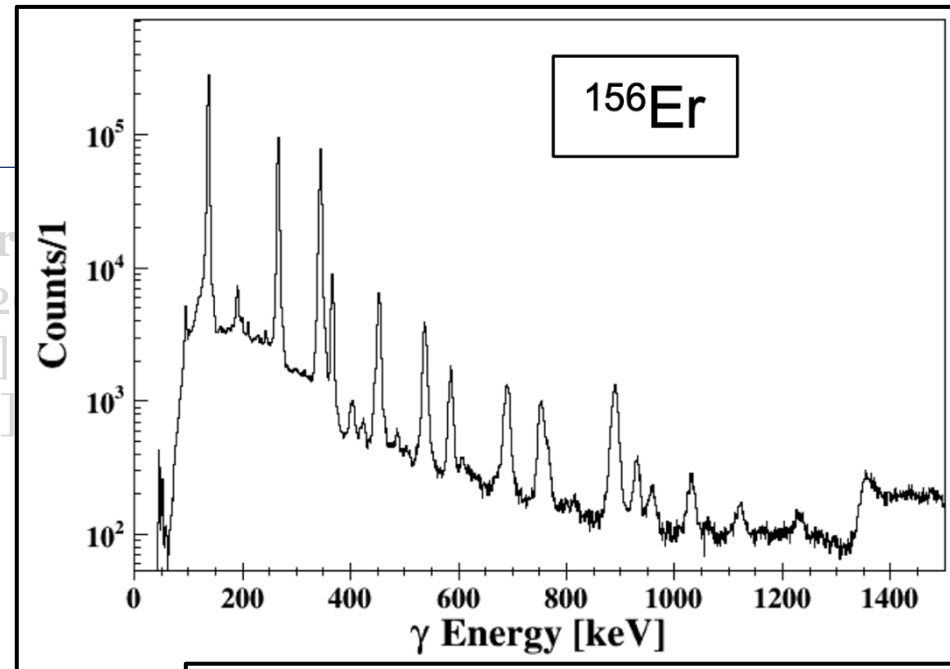
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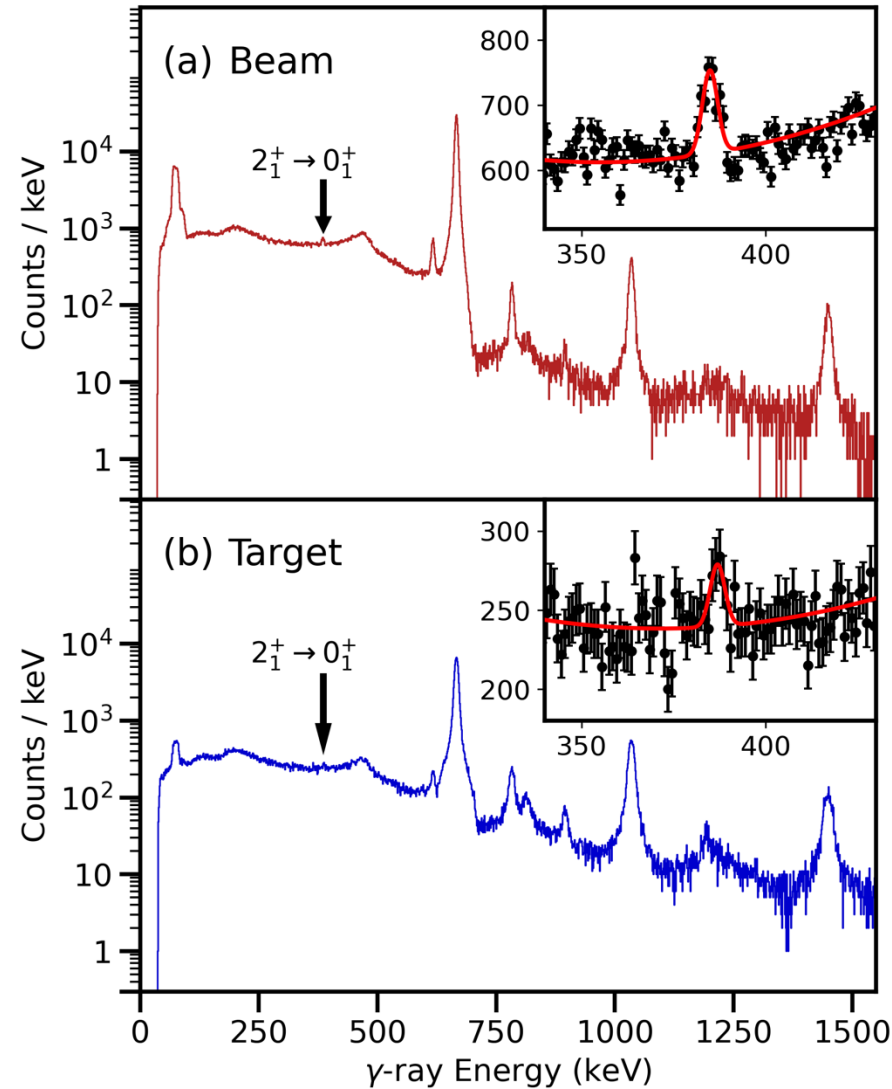
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Current limitation(s):

Charge breeding efficiency,  
Cleanliness

IG-LIS useful but CSB  
contaminants (often) a  
bigger problem

## Rare-earth region:

Well-produced and extracted from ISOL targets

Two significant regions of shape evolution  
[neutron-deficient quasi-SU(3) & N=90]

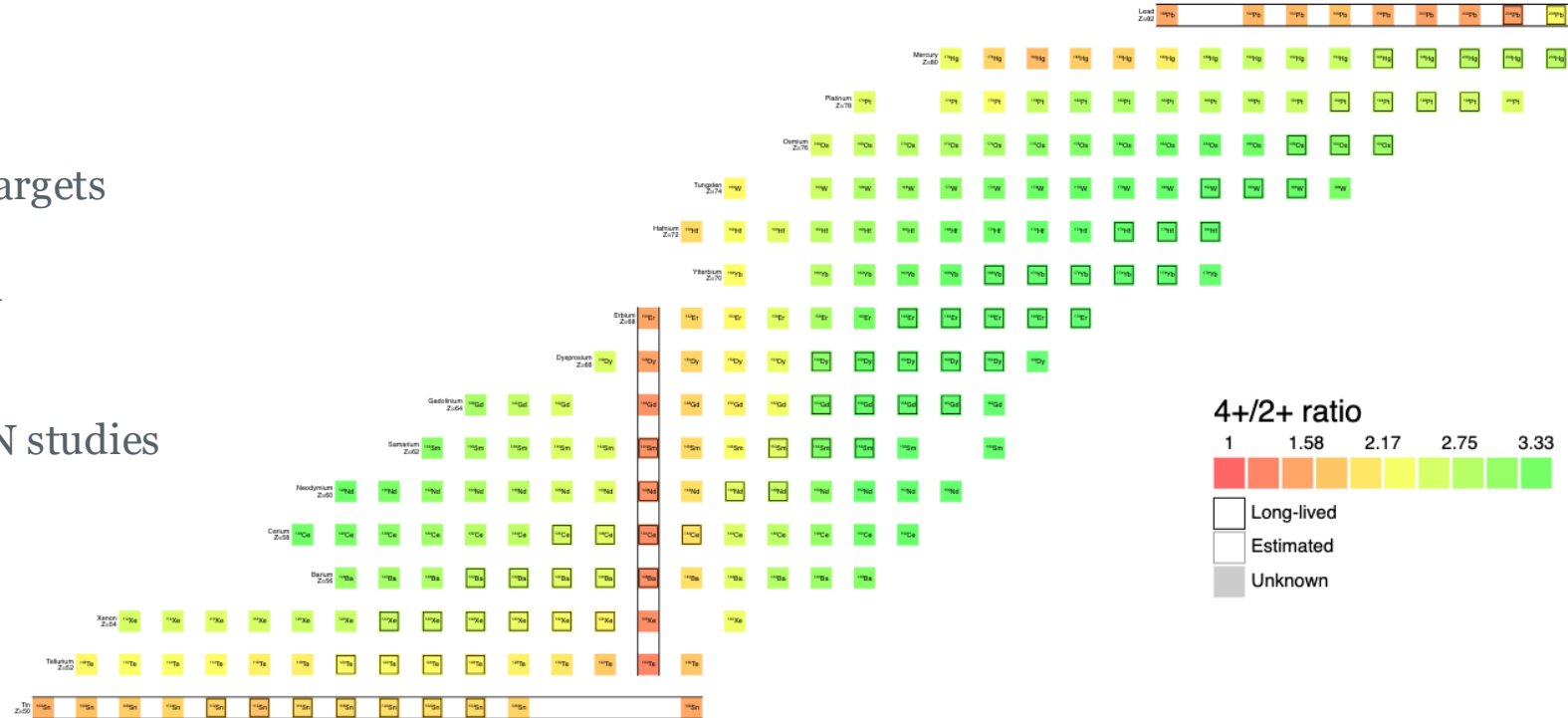
Well-matched to complementary GRIFFIN studies  
[e.g., Smallcombe S1716]

... but

*Needs* IG-LIS to suppress neighbours

*Needs* efficient charge-breeding to compensate for IG-LIS losses

*Needs* additional spectroscopy to guide complex analyses



# The future?

## Neutron-deficient quasi-SU(3) region

Neutron-deficient Sr and Kr isotopes (should be) good for ISOL facilities

fp-gds interactions drive exceptional degrees of deformation  
[Ha, Nature Comms 2025]

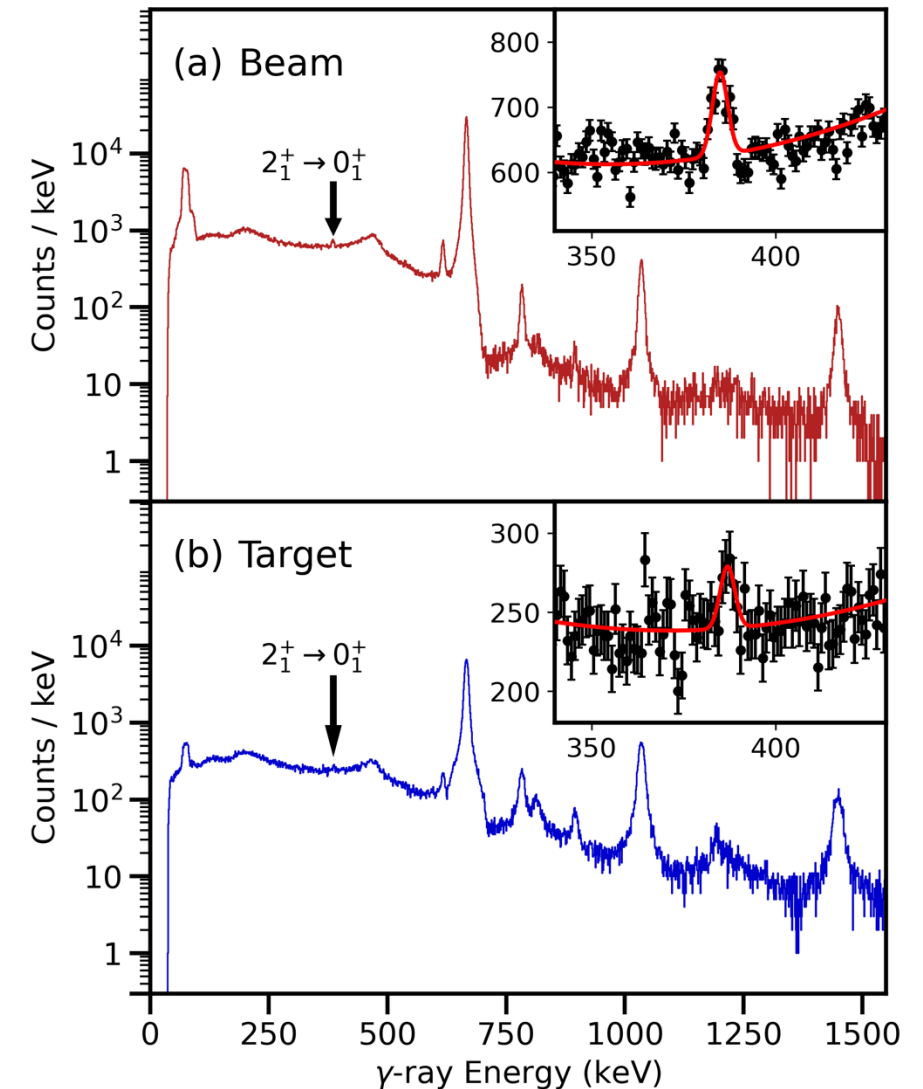
Matrix element analysis essential to understand drivers (what is the shape?)

... but

*Needs* IG-LIS to suppress neighbours

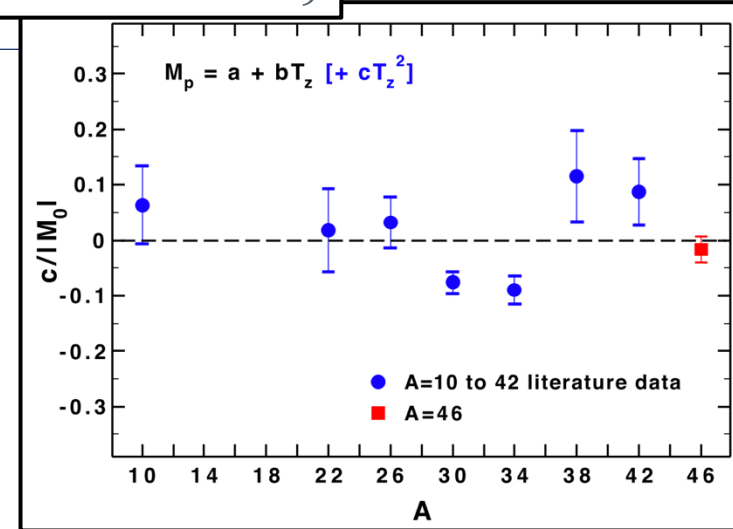
*Needs* efficient charge-breeding to compensate for IG-LIS losses

*Needs* to be competitive with alternative extraction methods (e.g. ReA@FRIB)



# The future?

Boso *et al.* PLB 2019



## Push towards N=Z (esp. odd-odd)

Odd-odd N=Z nuclei some of the most curious in the nuclear landscape

Sensitive to isospin dependence through matrix elements

Isospin mixing effects also important

... *and* everything is enhanced by p-n overlaps

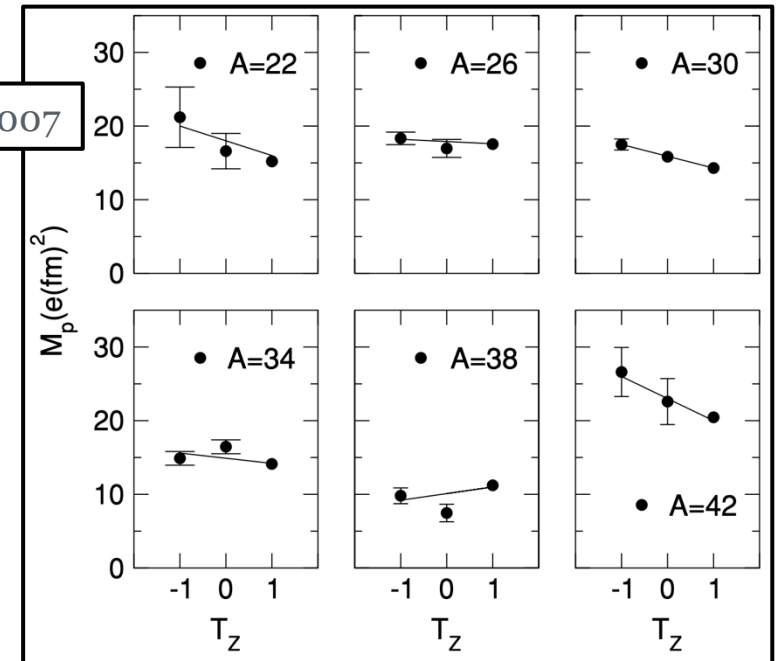
... **but**

Beyond A~26 (i.e.  $^{34}\text{Cl}$  and  $^{38}\text{K}$ ) *need* efficient charge breeding

*Needs* extraction methods for ... tricky... elements (i.e., Cl)

*Needs* to be competitive with alternative extraction methods (e.g. ReA@FRIB)

Prados Estevez *et al.* PRC 2007



**Coulomb excitation** with TIGRESS @ ISAC-II has been a successful research programme, working strongly in the *sd*-shell

A future programme *needs* access to mid- and high-mass nuclei, with good **charge breeding efficiency** and **selective extraction** to be competitive with alternatives

**Potential areas of future investigations include...**

Rare-earth nuclei,  
Neutron-deficient mid-mass systems,  
Heavier systems? [Actinides?]

Investigations of precision  $B(E2)$  measurements could be enabled with additional technology

**Coulomb excitation** with TIGRESS @ ISAC-II has been a successful research programme, working strongly in the *sd*-shell

A future programme  
**selective extraction**

An active Coulomb-excitation programme would be highly complementary to an investment in a ScRIT-like electron-scattering facility.

efficiency and

**Potential areas**

Rare-earth nuclei,  
Neutron-deficient  
Heavier systems?

Targeted investigations of key nuclei to provide comprehensive measurements of their deformation parameters.

Investigations of precision  $B(E2)$  measurements could be enabled with additional technology

