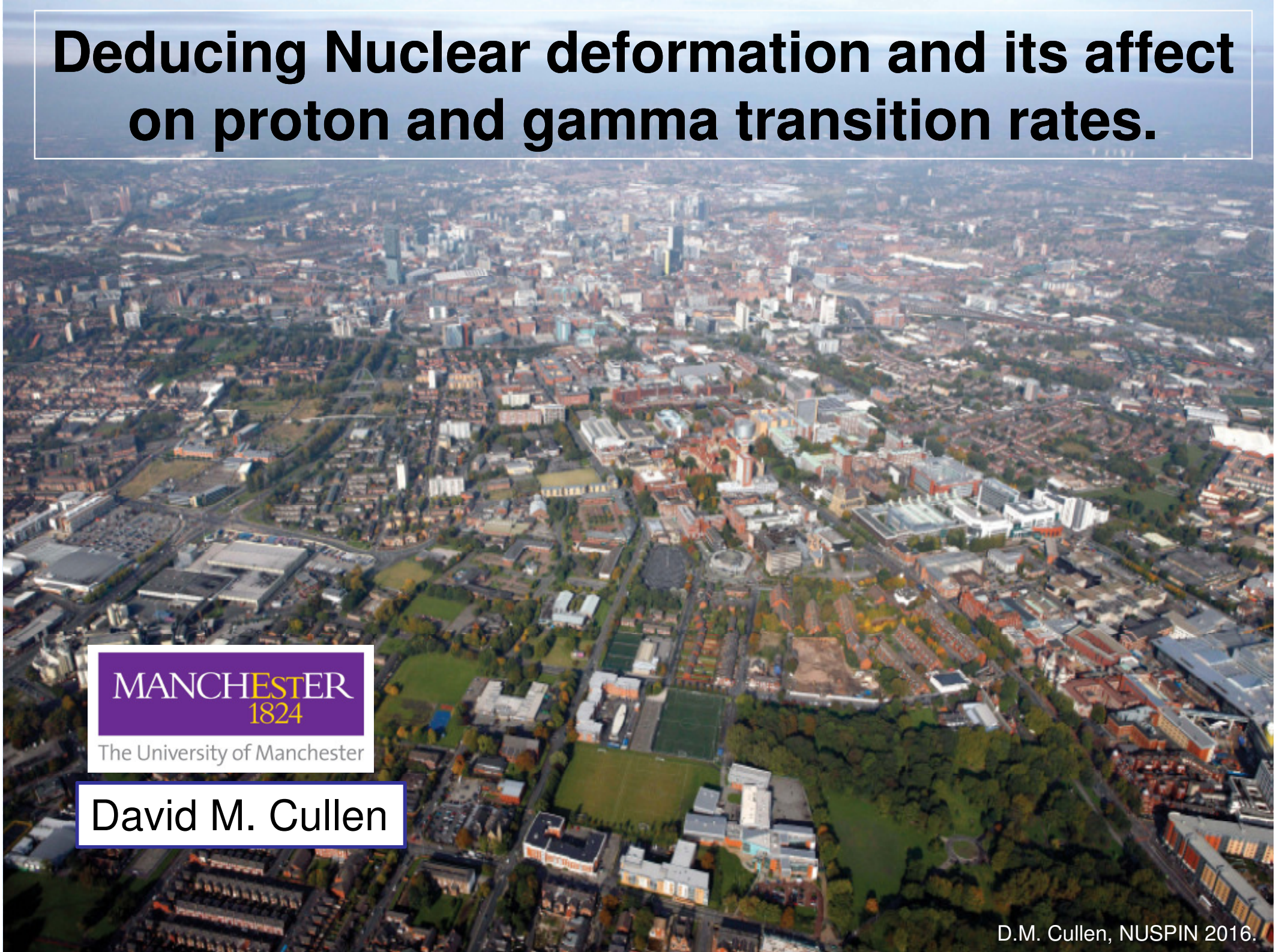
Deducing Nuclear deformation and its affect on proton and gamma transition rates.



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David M. Cullen

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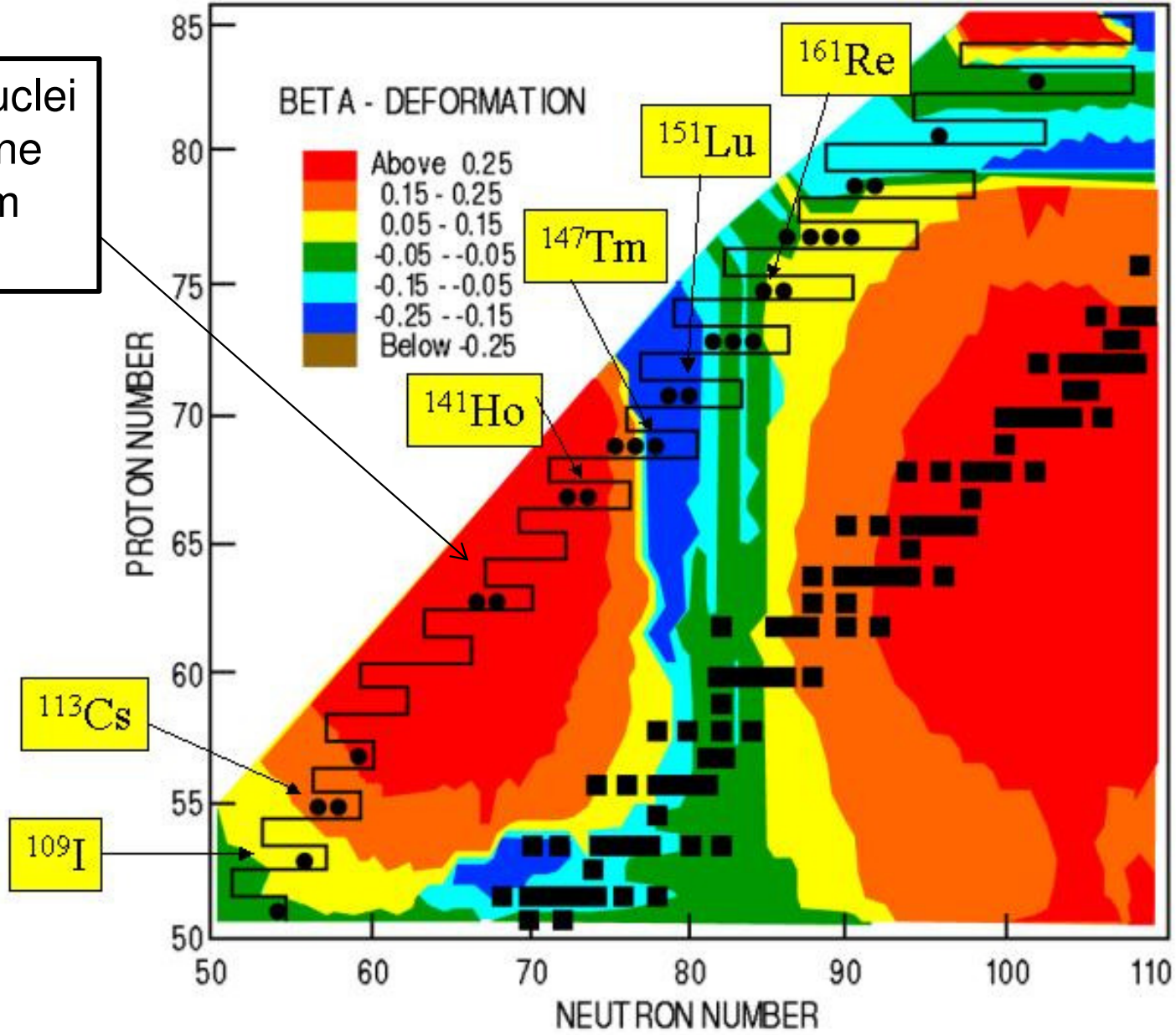
Research on transition rates in proton emitters as deformation changes across a shell:

Region of the chart of nuclei around the proton drip line (black line) modified from Argonne National Lab.

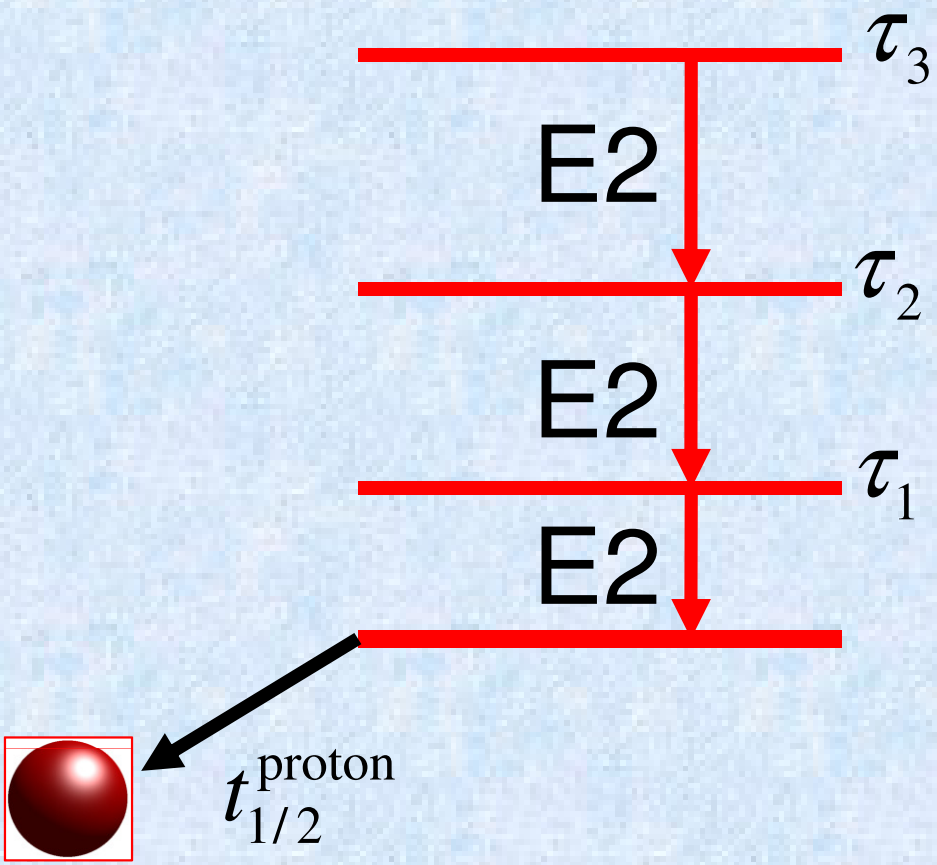
Yellow, green ~ spherical
red ~ prolate deformed
blue ~ oblate deformed

nuclei according to calculations [1].



[1] P. Möller et al., Phys. Rev. Lett. 97 (2006) 162502.

The Method:



Lifetime ⇔ Deformation

τ => B(E2) => Q_0 => β_2

Needed an efficient differential plunger to use with proton tagging...

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Nuclear Instruments and Methods in Physics Research A 707 (2013) 143–148

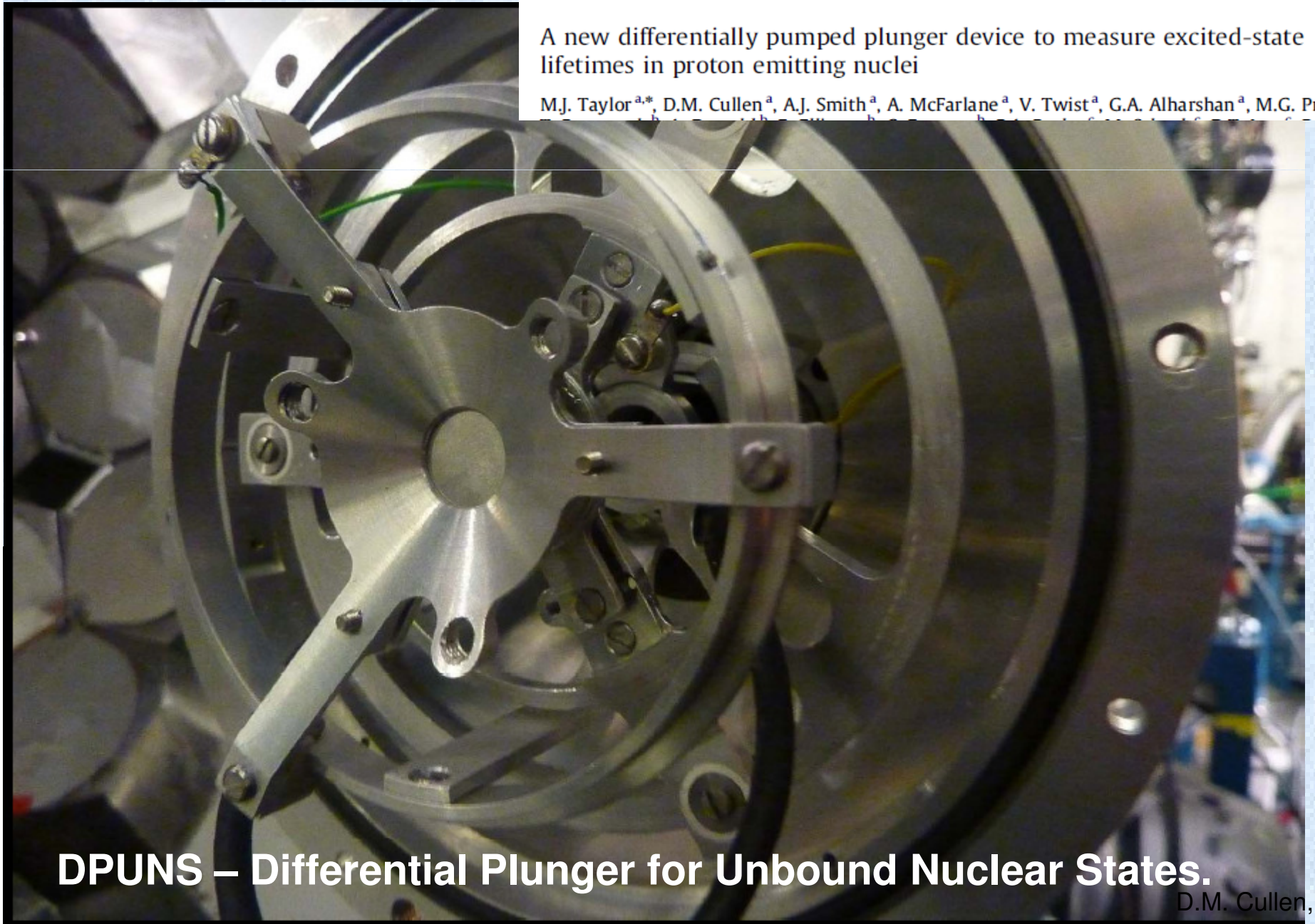
Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

A new differentially pumped plunger device to measure excited-state lifetimes in proton emitting nuclei

M.J. Taylor [a,*], D.M. Cullen [a], A.J. Smith [a], A. McFarlane [a], V. Twist [a], G.A. Alharshan [a], M.G. Procter [a],



DPUNS – Differential Plunger for Unbound Nuclear States.

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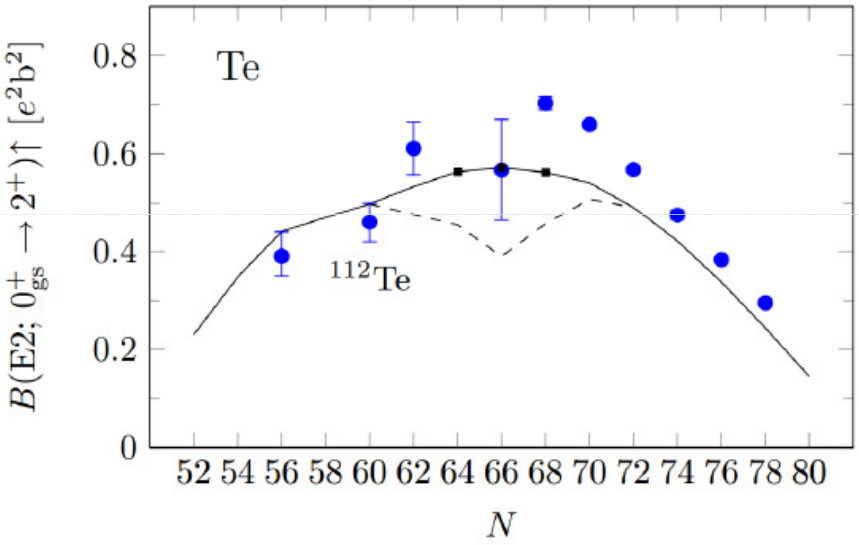
DPUNS Proton Emitters studied so far...



Physics Letters B 704 (2011) 118–122

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Anomalous transition strength in the proton-unbound nucleus $^{109}_{53}I_{56}$

M.G. Procter [a,*], D.M. Cullen [a,b], C. Scholey [b], P. Ruotsalainen [b], L. Angus [c], T. Bäck [d], B. Cederwall [d],

Physics Letters B 725 (2013) 79–84

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Proton emission from an oblate nucleus ^{151}Lu

M.G. Procter [a,*], D.M. Cullen [a], M.J. Taylor [a], G.A. Alharshan [a], L.S. Ferreira [b], E. Maglione [c],

Many other isomer-tagged experiments in this region, cross sections ~40μb (2 weeks)

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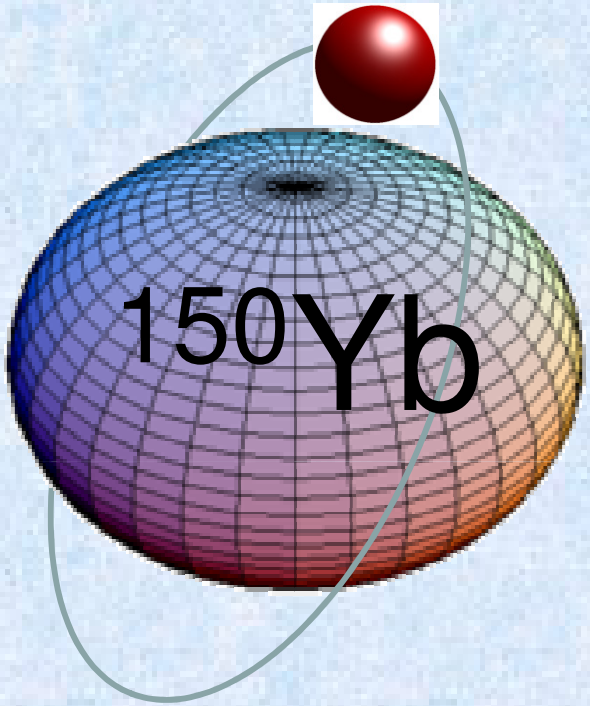
Lifetime Methodology

1. Measuring experimental nuclear lifetimes to constrain theoretical calculations at and beyond the proton drip line.

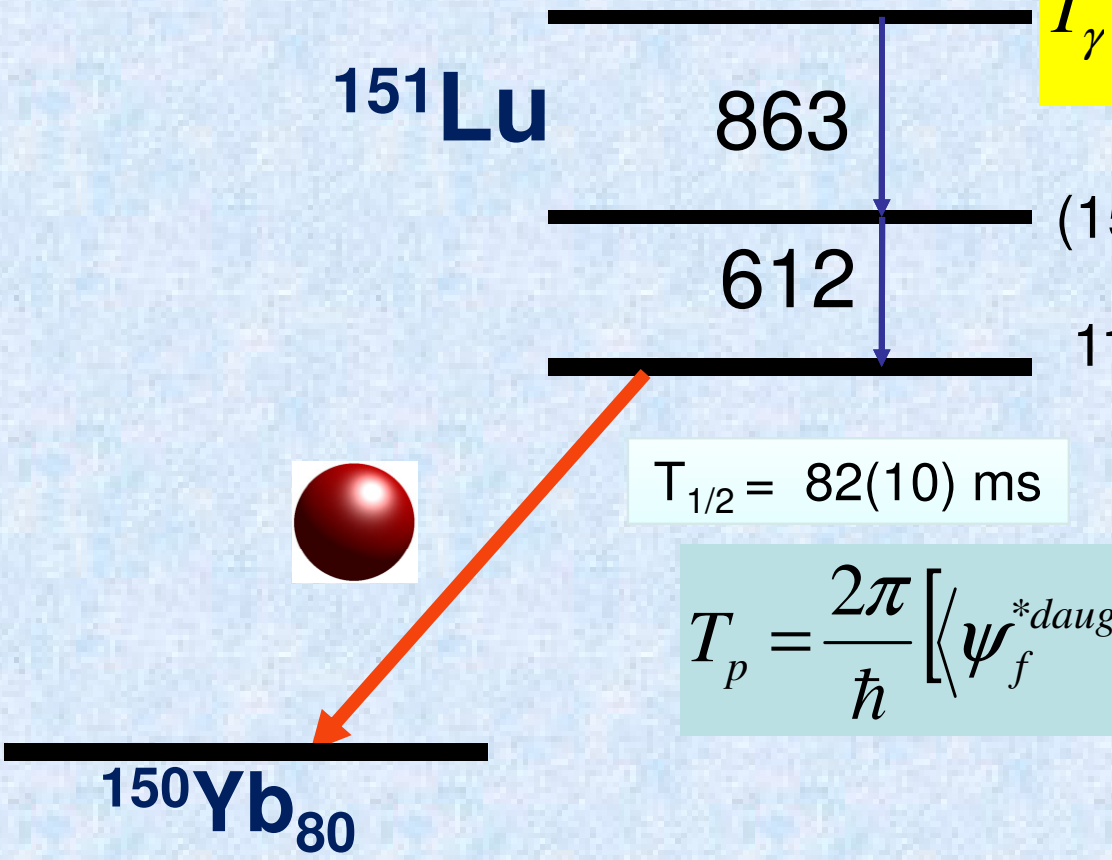
2. Quasi-particle model based on a deformed mean-field Woods-Saxon potential with spin-orbit interaction.
   Ferreira, Maglione Internat. Journal Modern Physics E15 (2006) 1789.
   Deduce wave functions for odd proton + core in adiabatic (strongly coupled to rotational core).



3. Using this set of wave functions to calculate EM (gamma) and particle decay (proton) transition rates.

Theoretical Approach

Quasi-particle model generates excitation energy of states (compared with experimental level scheme)... and then extract wave functions.



$$T_\gamma = \frac{2\pi}{\hbar}\left[\left\langle \psi_f^* \middle| M(\sigma L) \middle| \psi_i \right\rangle\right]^2 \rho(E)dE$$

EM calculation

$t_{1/2}$??? ps

$T_{1/2}$ = 82(10) ms

Particle Decay calculation

$$T_p = \frac{2\pi}{\hbar}\left[\left\langle \psi_f^{*daughter} \middle| M(p) \middle| \psi_i^{parent} \right\rangle\right]^2 \rho(E)dE$$

Calculating Electromagnetic and Proton decays with a single set of wavefunctions

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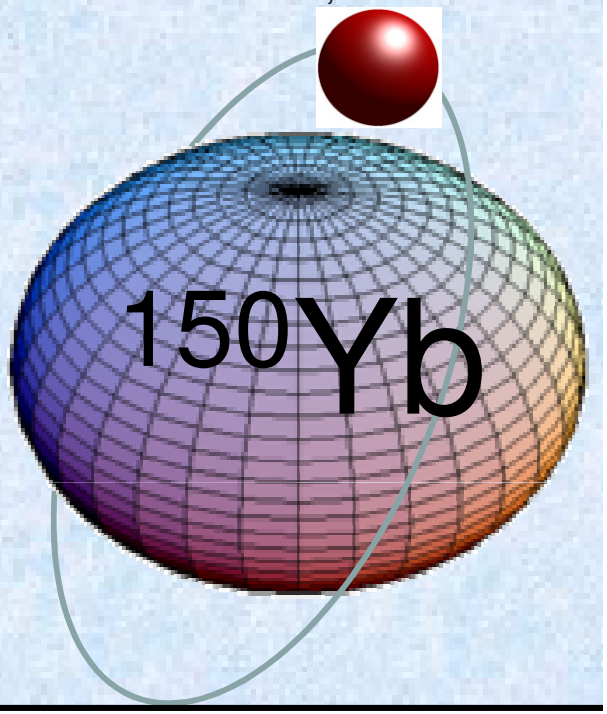
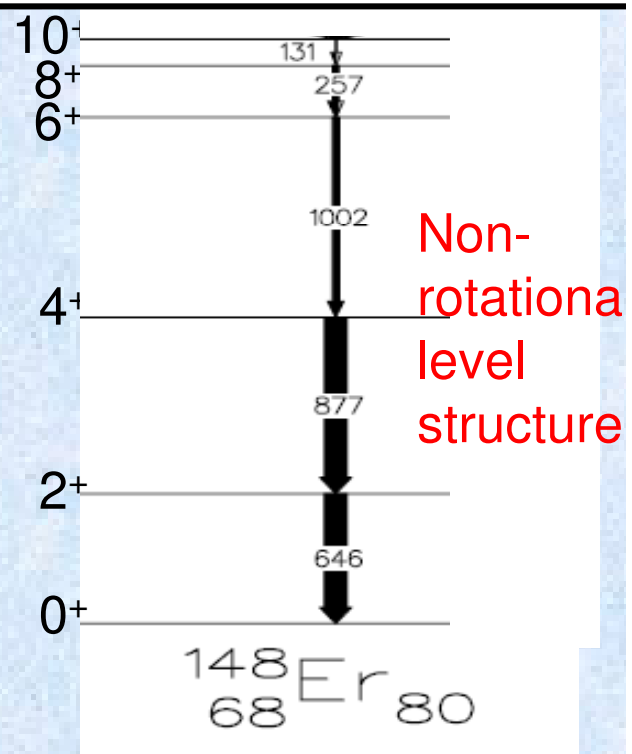
New non-adiabatic calculations 2013:

- **Previous calculations were *adiabatic* with proton strongly coupled to the core.**
- **New non-adiabatic calculations (Ferreira, Maglione) Procter et al. Phys Lett B 725 (2013) 79.**

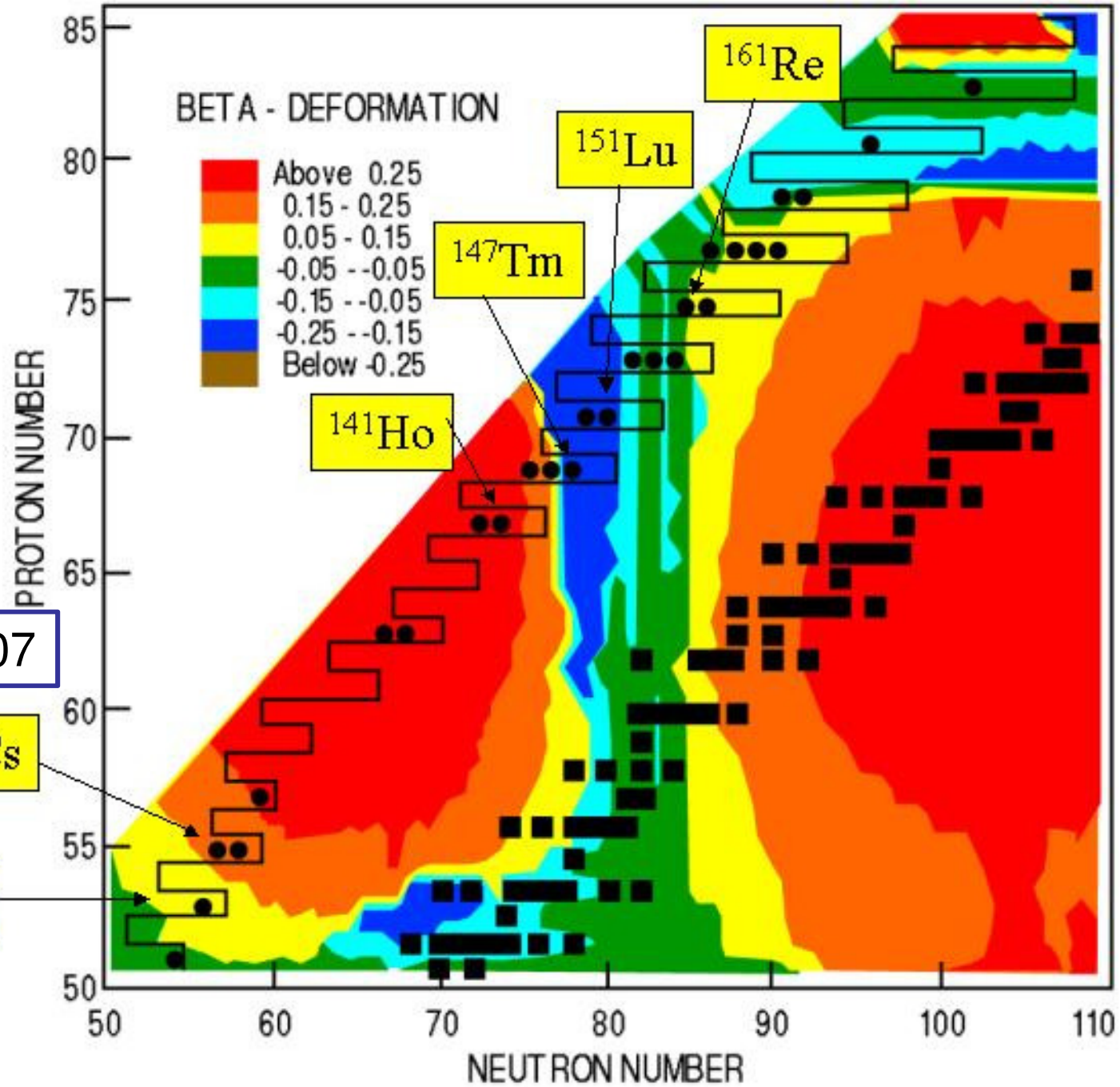
Calculate wave functions where core is softer which affects how the odd-proton couples to the core.



^{150}Yb Spectrum not known !

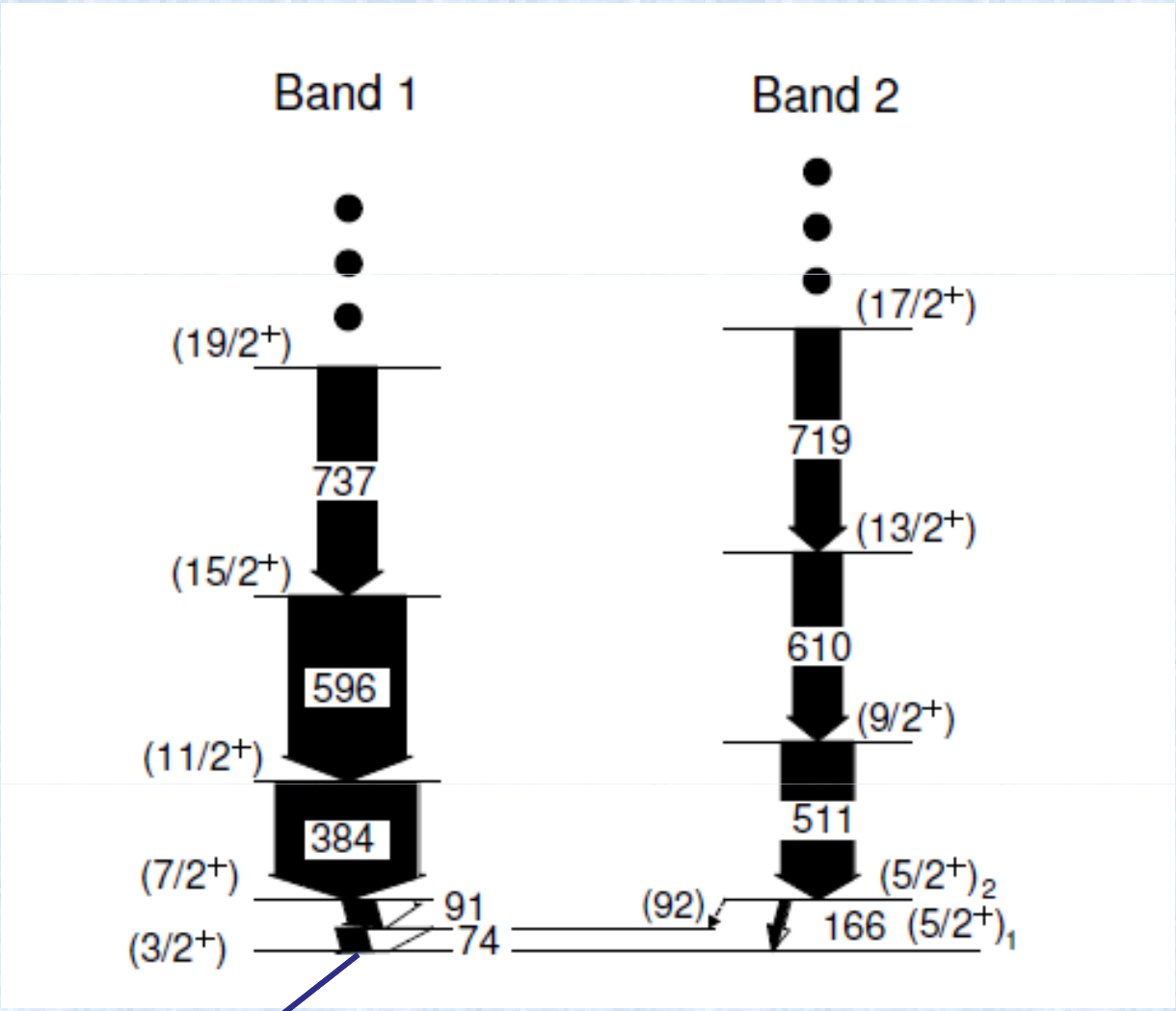


Lifetime of deformed proton emitter, ^{113}Cs



Möller-Nix β_2 =0.207

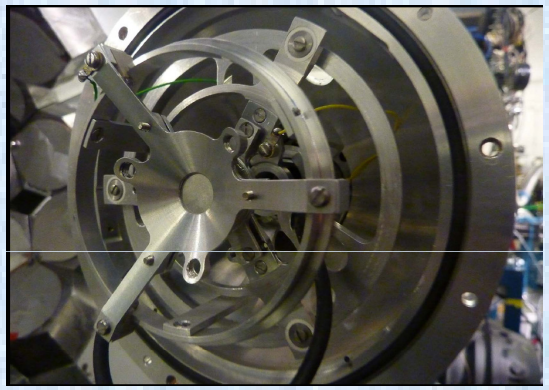
^{113}Cs deformed proton emitter?



$T^{P}_{1/2}$ = 16.9(1) μs

P. T. Wady *et al.*, Phys. Rev. C **85**, 034329 (2012).

^{113}Cs Experimental setup (12 days)



^{58}Ni(^{58}Ni,$p2n$)

1 μm < d < 10 mm (+optical contact)

230 MeV ^{58}Ni

3.8% v/c

σ ~ 20μb

1.8% v/c

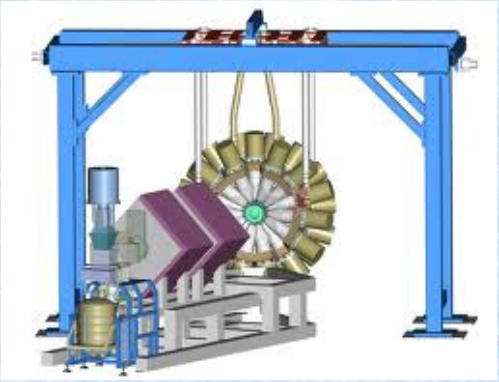
RITU

GREAT

Target: ^{58}Ni
1.1 mg/cm^2

Degrader:
1.5 mg/cm^2 Mg

r-p 0.2 ms



- Lifetime data (singles) from ring 2 @ 134°
- Coincidence data from sum of rings 3 & 4

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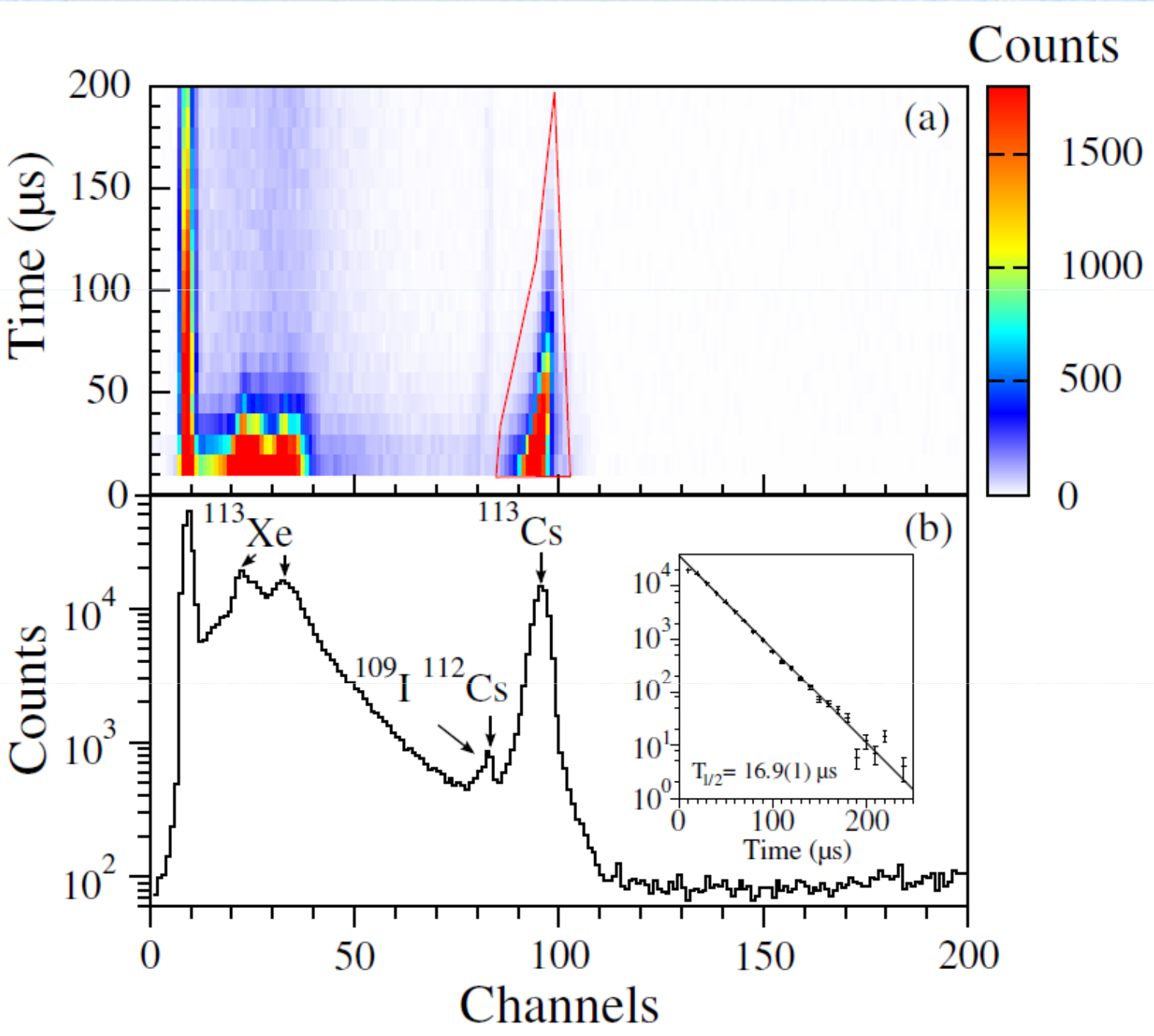
^{113}Cs Decay events in DSSD



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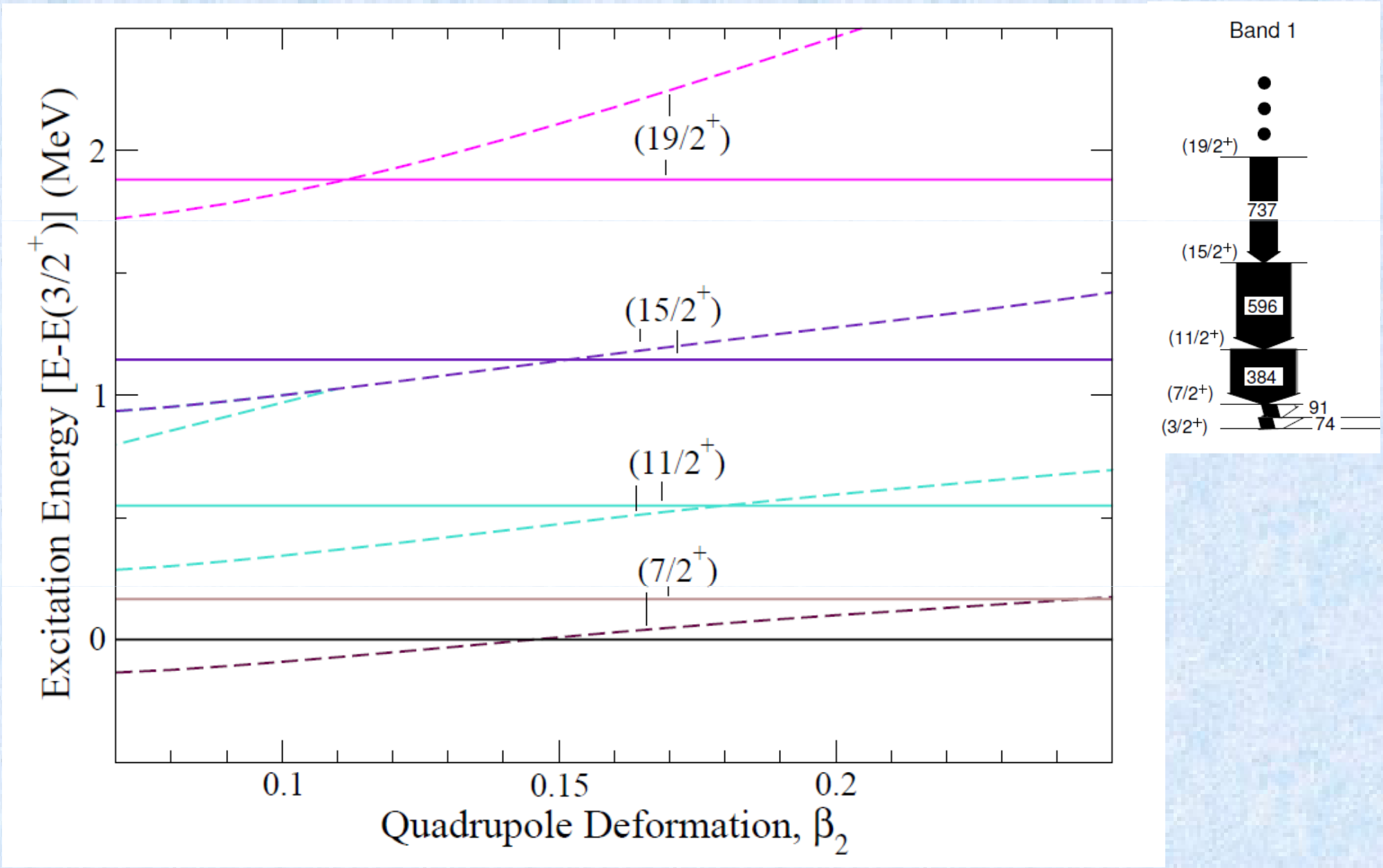
^{113}Cs Theoretical Calculations.

^{113}Cs Theoretical excitation energies of states



Extract wave functions from model and use in EM and P decay calculations

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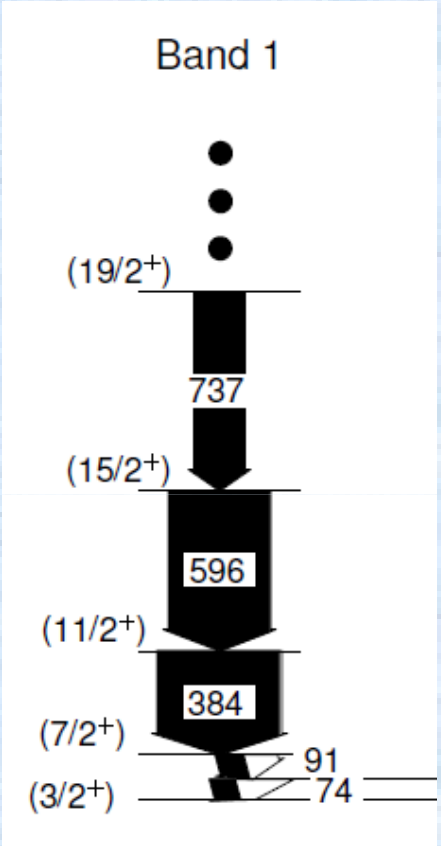
Electromagnetic Transition Rates:
using one set of wave functions.



$$T_\gamma = \frac{2\pi}{\hbar}\left[\left\langle \psi_f^* \middle| M(\sigma L) \middle| \psi_i \right\rangle\right]^2 \rho(E)dE$$

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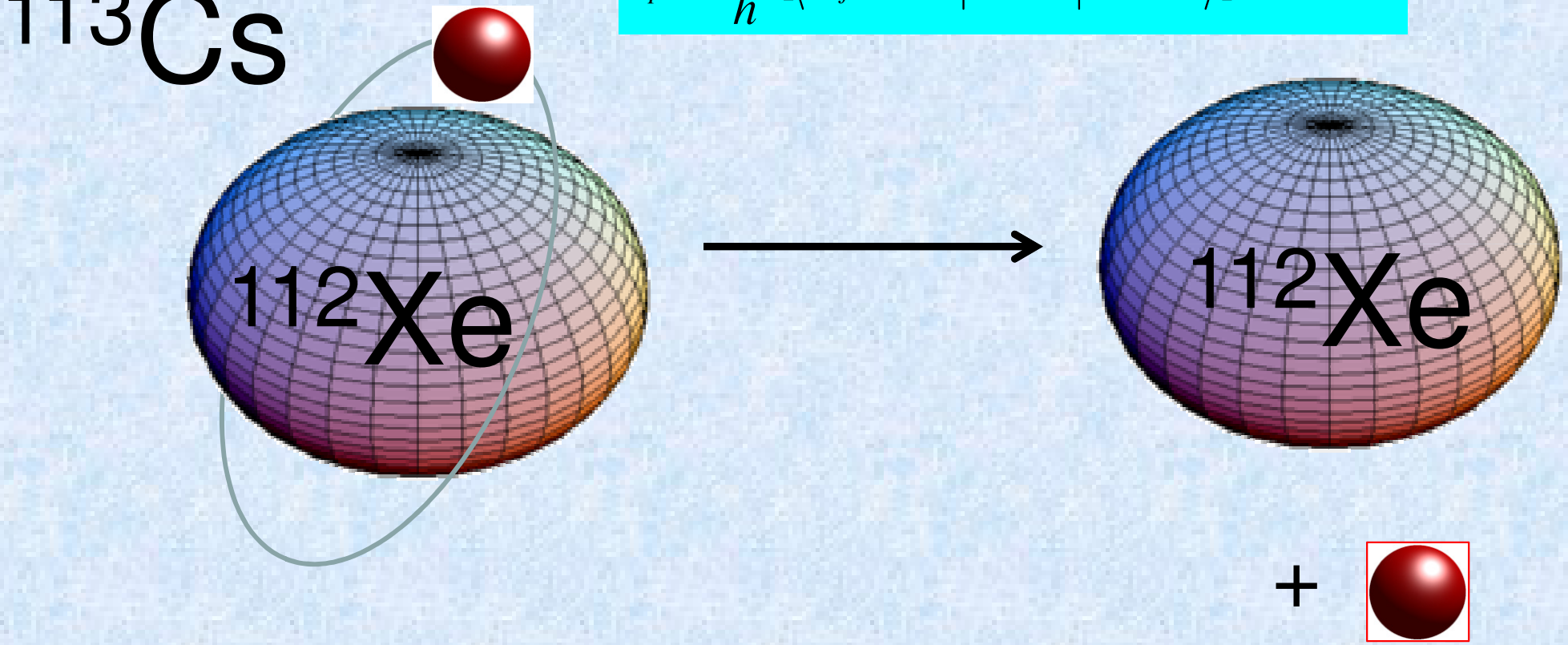
Proton decay Transition Rates:
using one set of wave functions.

$$T_p = \frac{2\pi}{\hbar}\left[\left\langle \psi_f^{*daughter} \middle| M(p) \middle| \psi_i^{parent} \right\rangle\right]^2 \rho(E)dE$$



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^{113}Cs deformed proton emitter?

State	Measurement type	β_2
$(11/2^+)$	Excitation energy	~ 0.18
$(11/2^+)$	B(E2) calculation	$0.22 - 0.26$
$(15/2^+)$	Excitation energy	~ 0.15
$(15/2^+)$	B(E2) calculation	> 0.19
$(3/2^+)$	Proton Emission calculation	~ 0.22

Both particle and gamma decay rates fit best with experimental deformation of β_2 =0.2, which compares well with Möller-Nix β_2 =0.207.

^{113}Cs really seems to be a deformed proto emitter.

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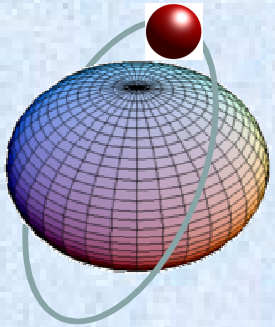
Conclusions

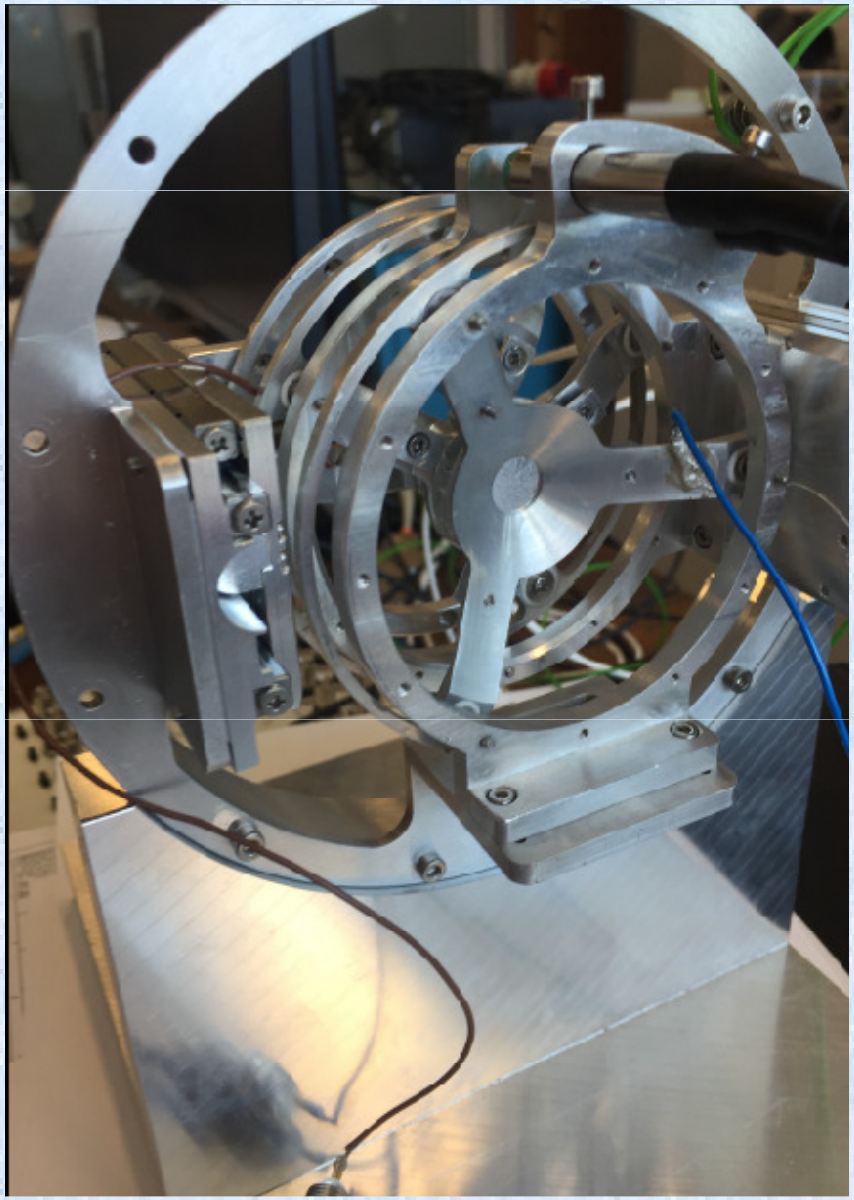


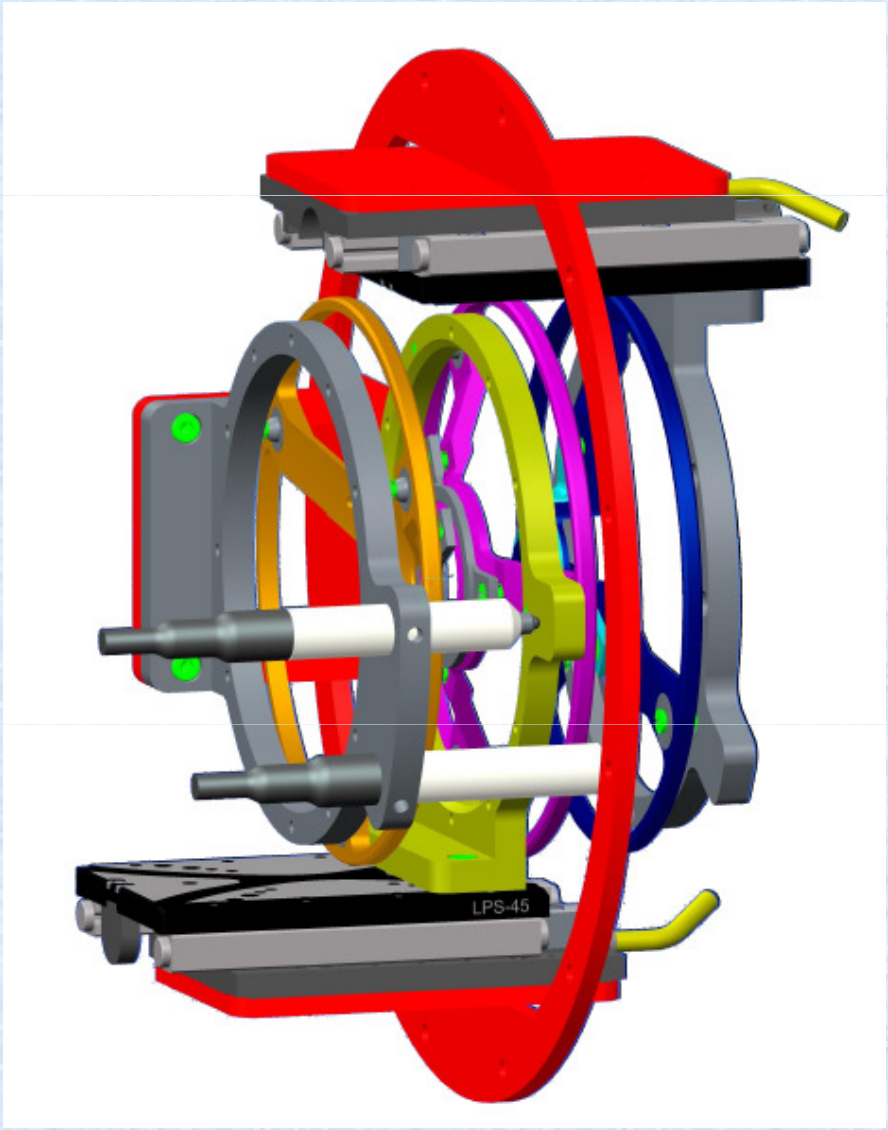
1. *Measurement of experimental lifetimes of nuclear states at and beyond the proton drip line has helped define deformation in new non-adiabatic theoretical nuclear code.*

2. *Computation of nuclear wave functions at these experimental deformations have allowed a better approach to understanding both proton and gamma decay rates in a somewhat self-consistent way.*

3. *Future radioactive + stable beam facilities + MARA with new TPEN will allow us to go further...*

Triple-Foil Plunger for Exotic Nuclear States (TPEN)





Commission at JYFL in not too distant future...

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