The future of nuclear structure: at ATLAS

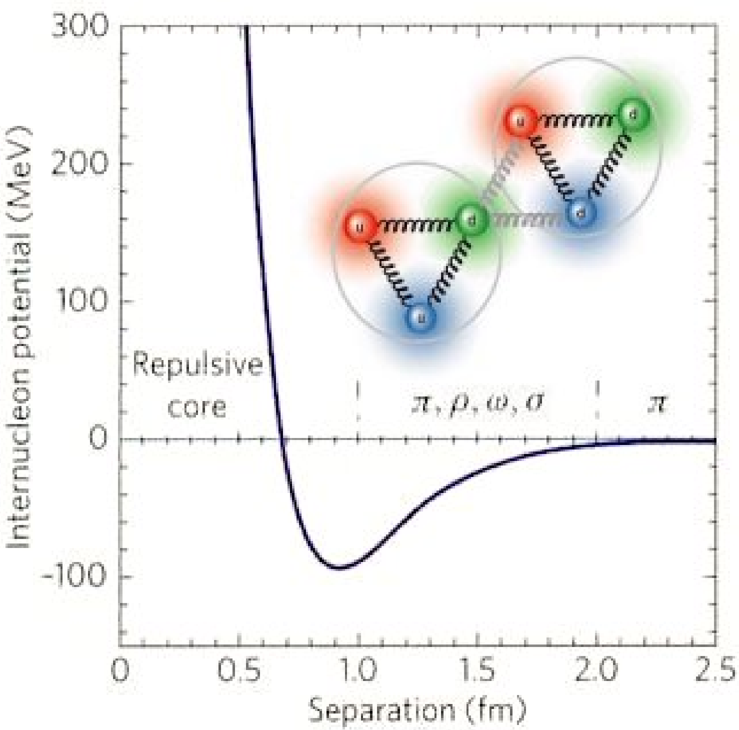
Will γ-rays be useful tools?

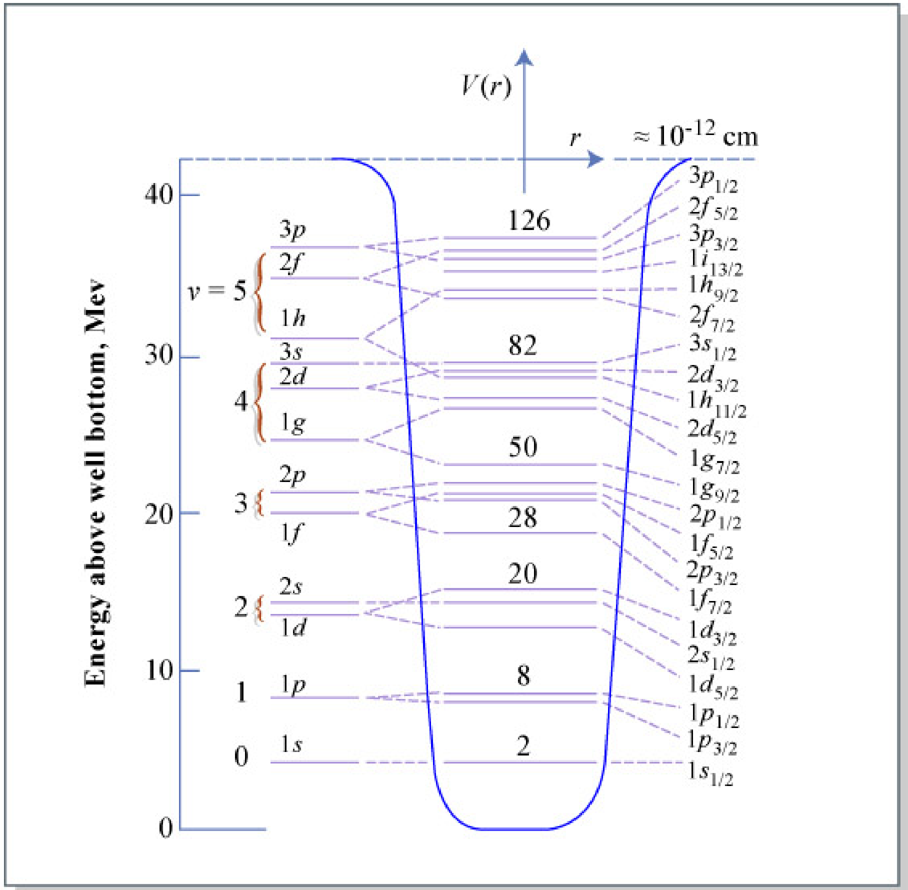
C.J. (Kim) Lister

Argonne Physics

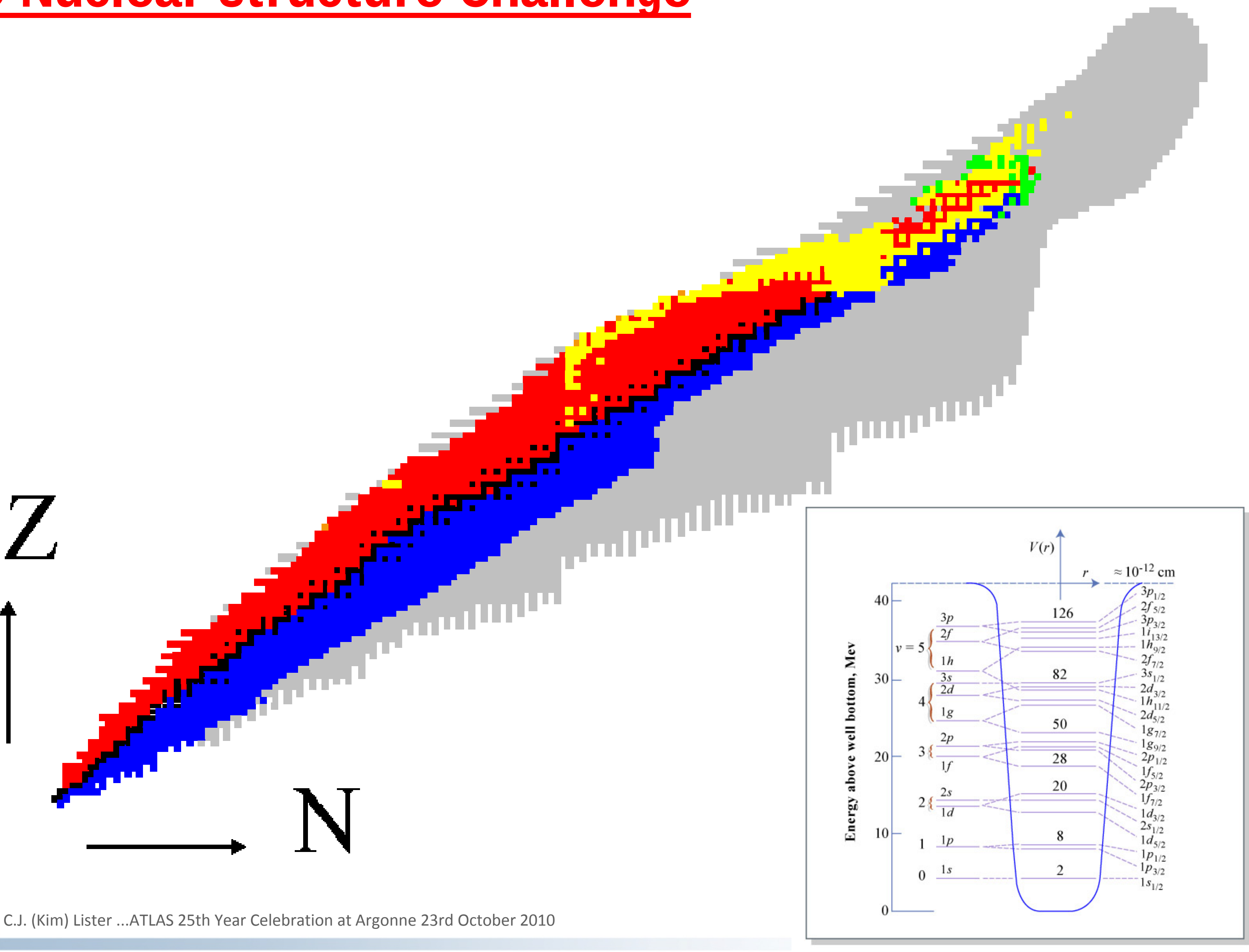
10-23-2010

The Nuclear Structure Challenge

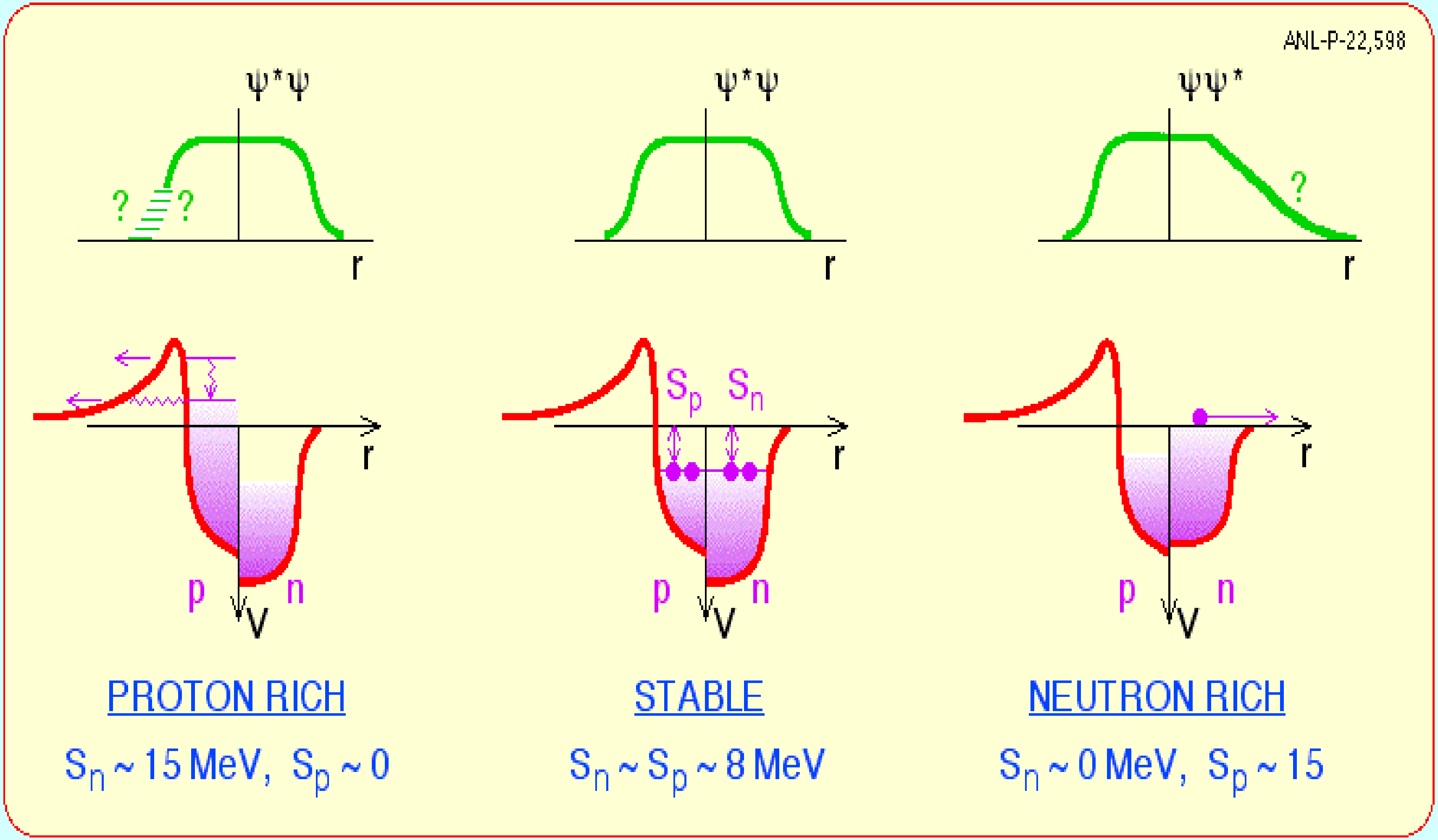




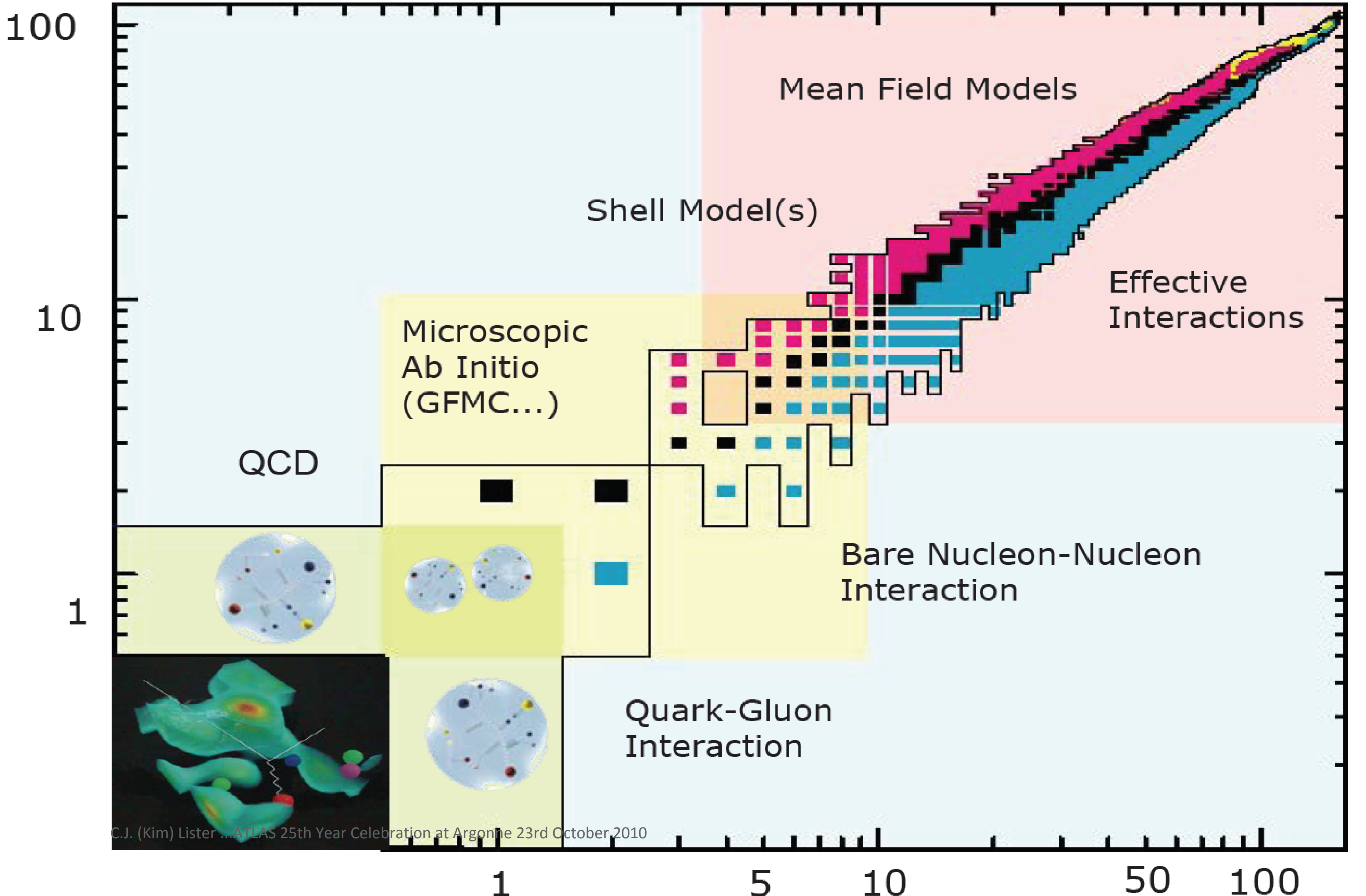
The Nuclear Structure Challenge



Schematic Nuclear Potentials



Where to start?



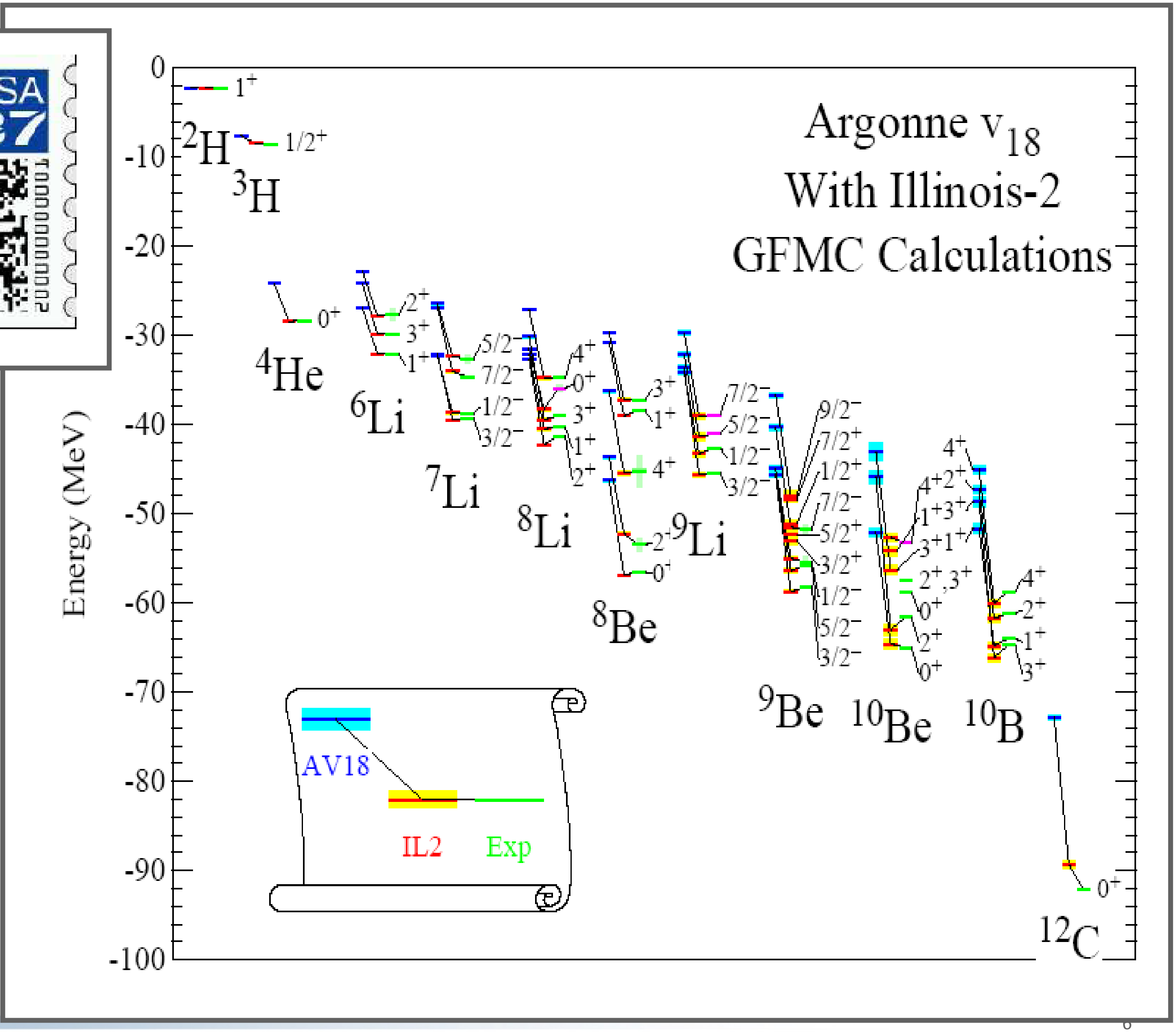
Ab-initio Greens Functional Monte Carlo Calculations

Pieper and Wiringa (ANL)

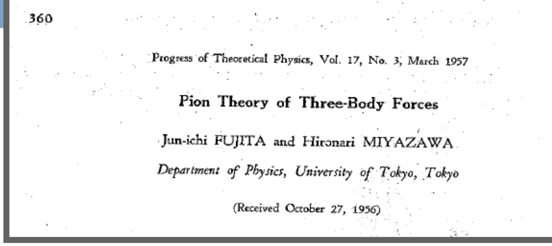
Described in

NP A751 516c (2005)

Bonner Prize 2010



Three body forces in nuclei


360

Progress of Theoretical Physics, Vol. 17, No. 3, March 1957

Pion Theory of Three-Body Forces

Jun-ichi FUJITA and Hironari MIYAZAWA

Department of Physics, University of Tokyo, Tokyo

(Received October 27, 1956)

From Fujita and Miyazawa (1956).

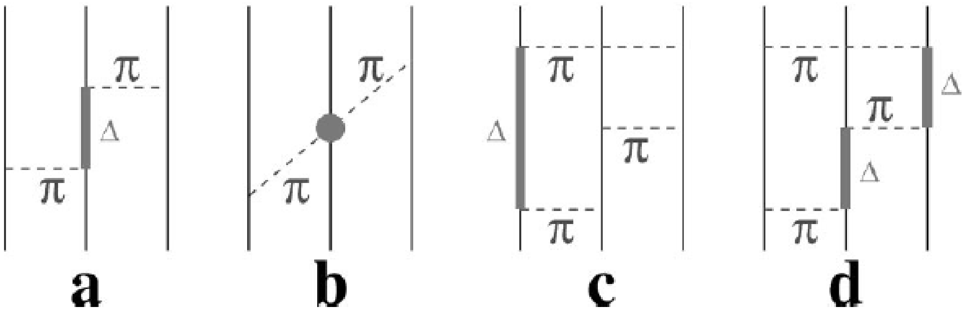
But now the potentials are being refined..... A real "work in progress"

Urbana Potentials:

$$V_{ijk} = V_{ijk}^{2\pi} + V_{ijk}^{R.C.}$$

Illinois Potentials:

$$V_{ijk} = V_{ijk}^{2\pi} + V_{ijk}^{3\pi} + V_{ijk}^{R.C.}$$



Fujita-Miyazawa Dominant Term

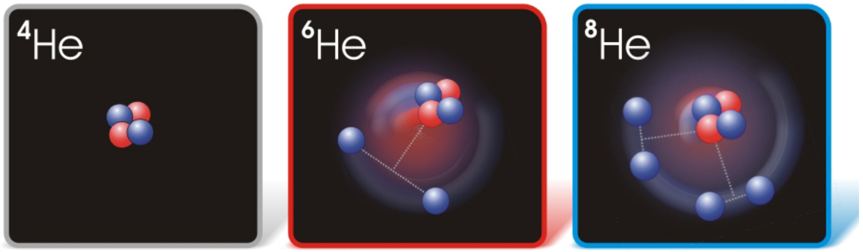
Steven C. Pieper *et al.*, Phys. Rev. C **64**, 014001 (2001).

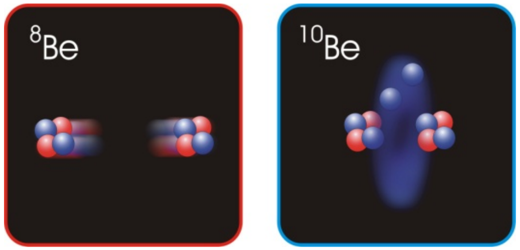
Coupling constants are currently fit to binding energies of a few light nuclei… ~4 parameters

What can experimentalists do to "help" with the theoretical developments?

- Discuss what measurements will make a difference.
- Make really good precise measurements.
- Ask lots of dumb questions.
- Be persistent.

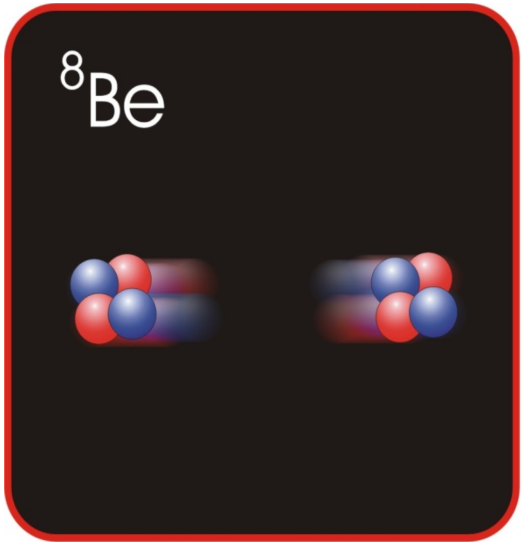
For refinement of the ab-initio calculations "alpha clustered" nuclei… like He, Be and C isotopes are especially important.

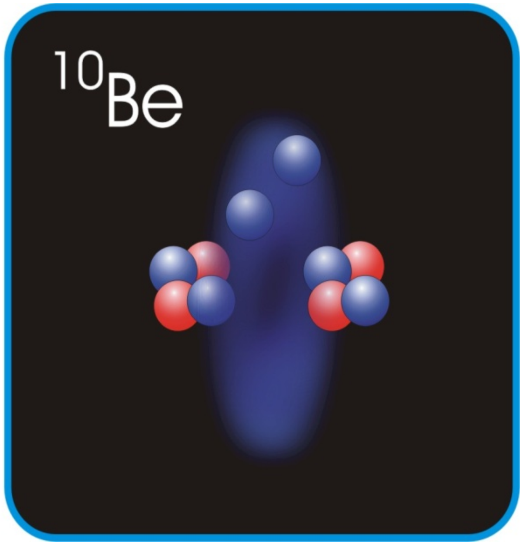




The Special Case of A=10

By mass 10, the nuclei have several bound states (^{10}C has 1, ^{10}Be has 6) and so probing the wavefunctions through investigating electromagnetic transitions becomes relevant.



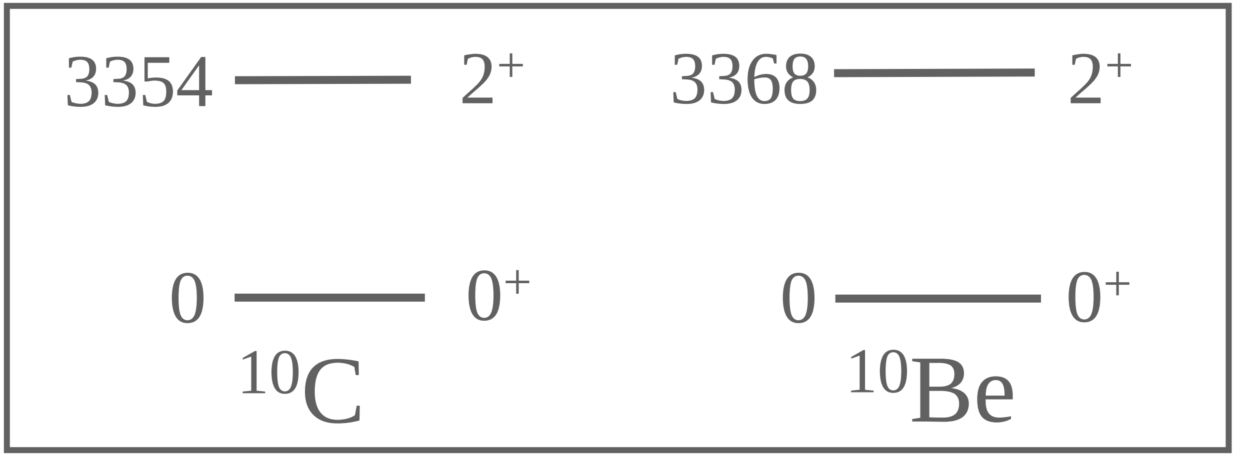


What is the role of the neutrons?

Why did Kurath (1957) need to use an anomalously large spin-orbit splitting?

Is the role of protons in ^{10}C the same as the neutrons in ^{10}Be?

^{10}C and ^{10}Be: What do we know?

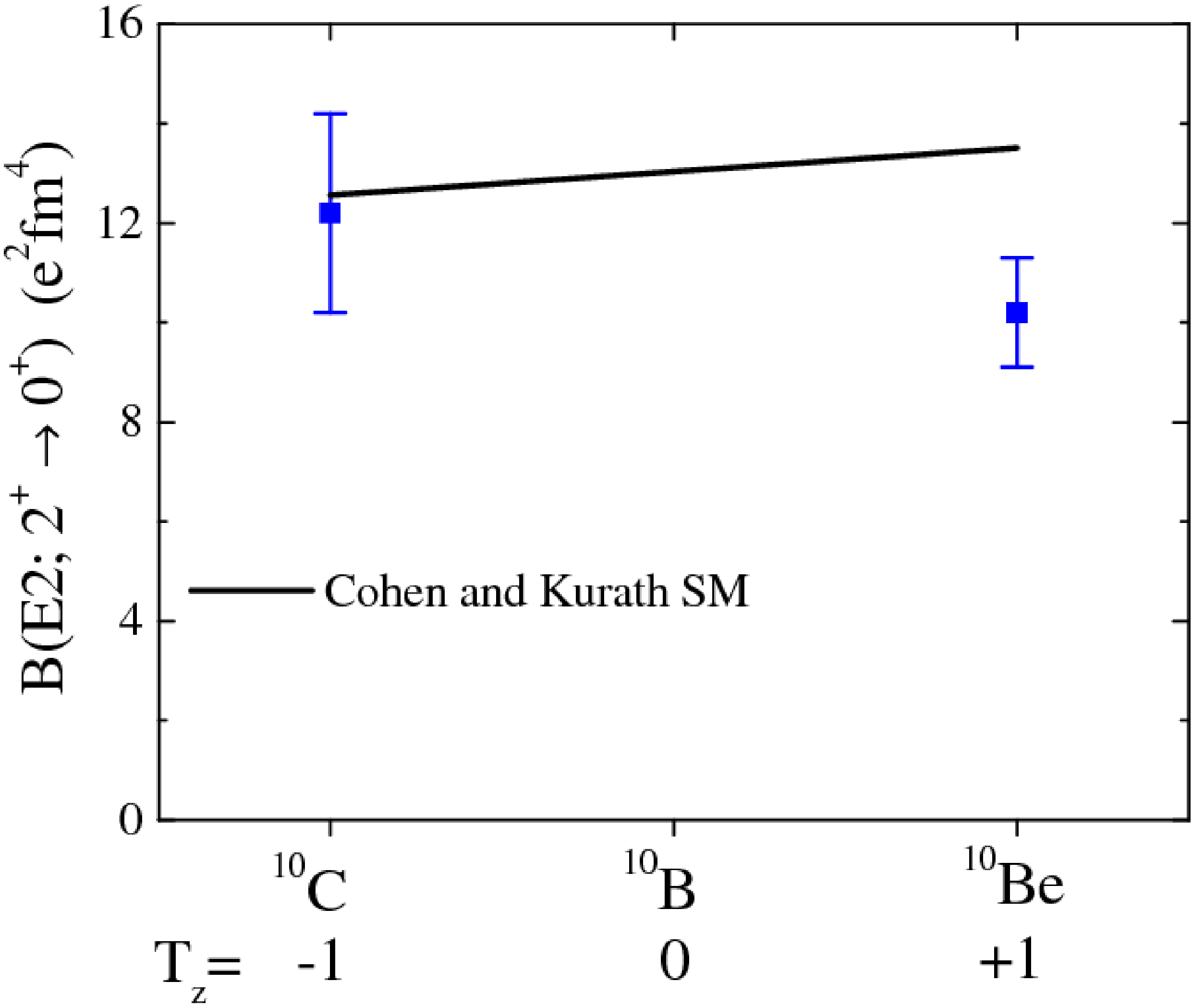


Lifetimes of Levels in $A=10$ Nuclei*

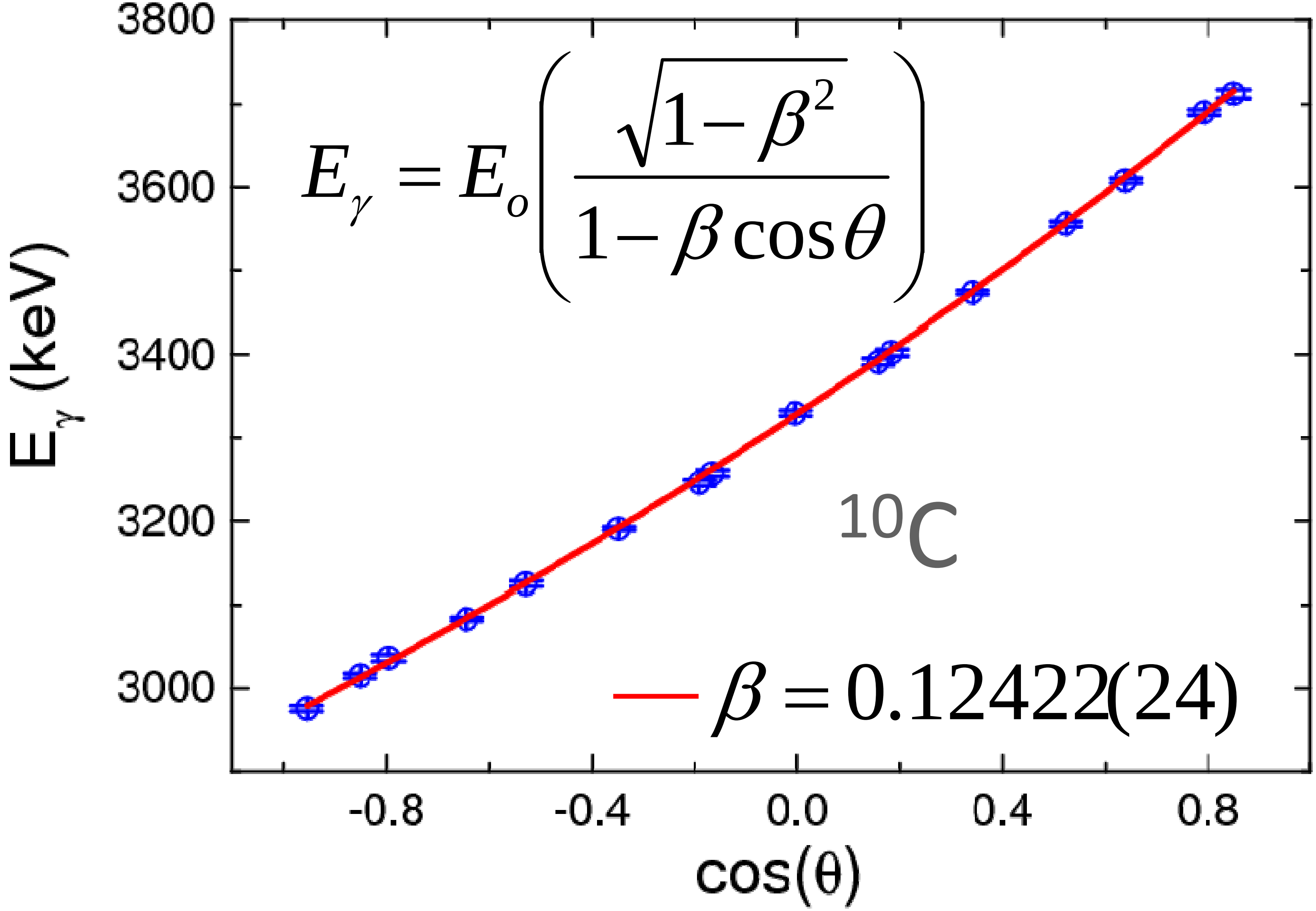
T. R. Fisher, S. S. Hanna, D. C. Healey, and P. Paul†
Department of Physics, Stanford University, Stanford, California 94305
(Received 6 June 1968)

The Doppler-shift attenuation method was used to obtain the following mean lifetimes (in psec) for the indicated nuclear levels: ^{10}C(3.36), $\tau=0.155\pm0.025$; ^{10}B(3.59), $\tau=0.150\pm0.015$; ^{10}Be(3.37), $\tau=0.189\pm0.020$; ^{10}B(2.15), $\tau=2.7_{-0.4}^{+0.5}$. A limit of $\tau<30$ fsec is obtained for ^{10}B(1.74), which is a factor of 8 greater

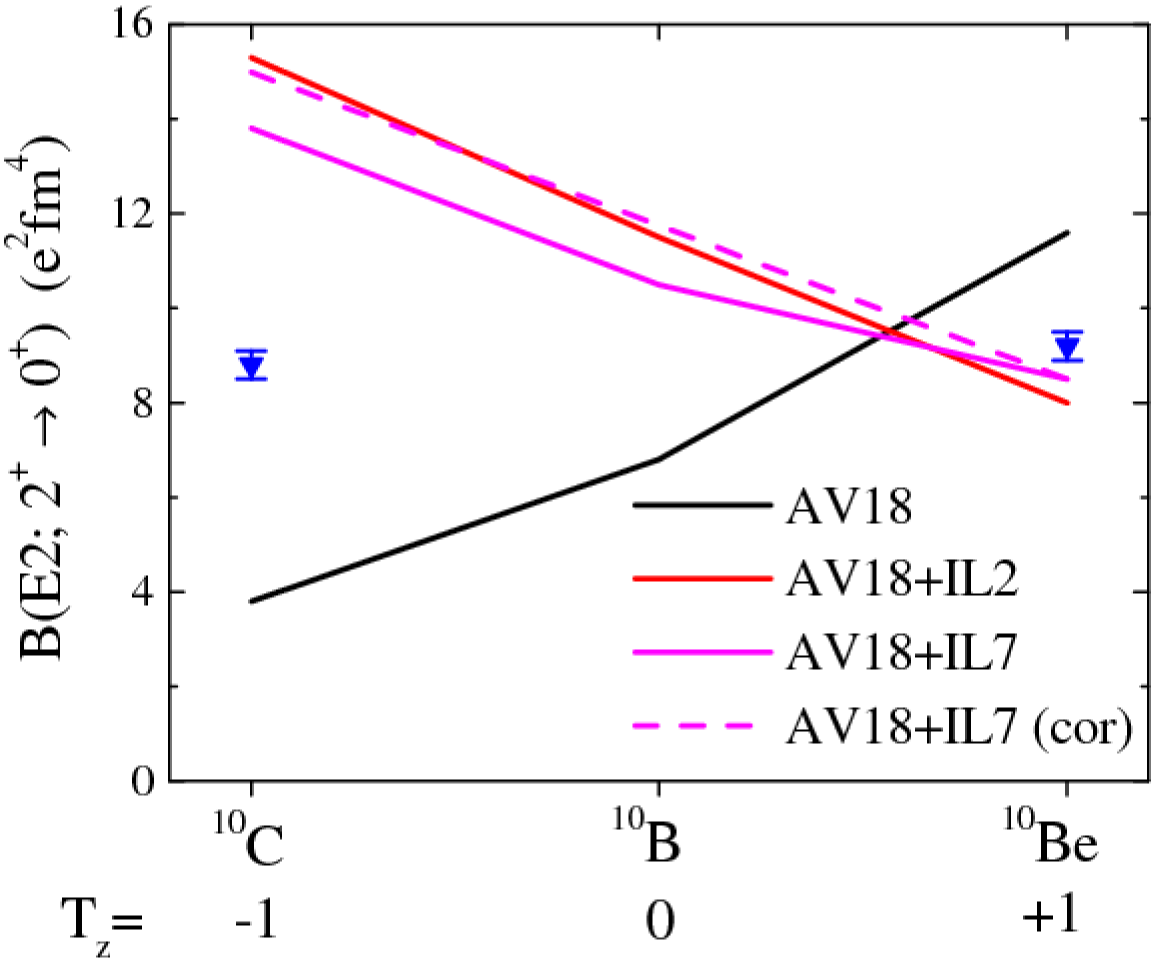
The situation in 1968

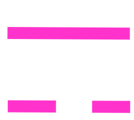


And the Doppler Shift is …



Current situation in A=10




^{10}Be wavefunctions, exchange n for p in B(E2) calculation

Separate GFMC minimization of wavefunctions for ^{10}C

Light Nuclei

We are in a new domain of theory….more microscopic and parameter free. We need a new generation of experiments to match.

For the A=10 puzzle …. We need a high quality measurement of ^{10}B

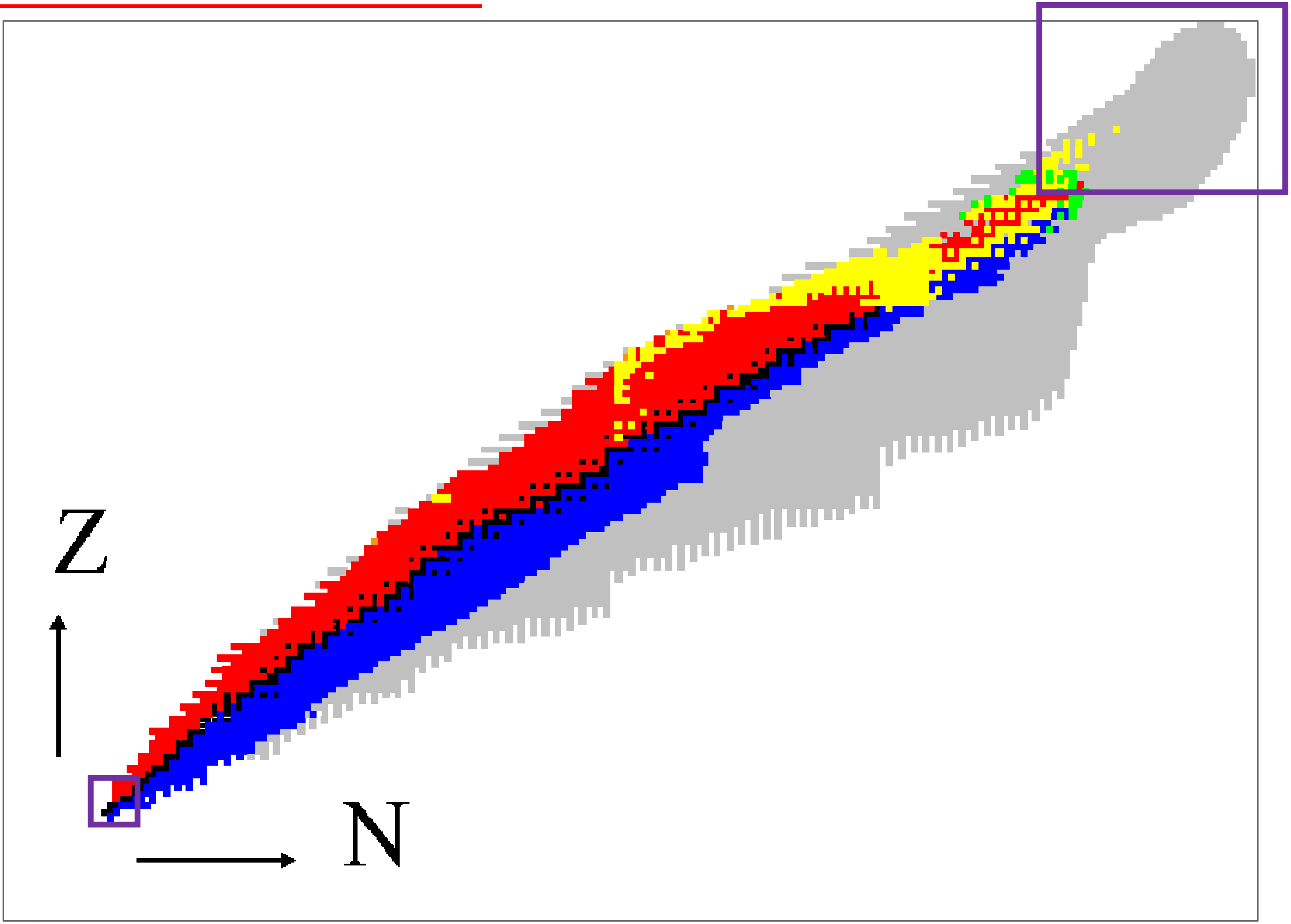
Electromagnetic transitions are very sensitive probes of nuclear wavefunctions.

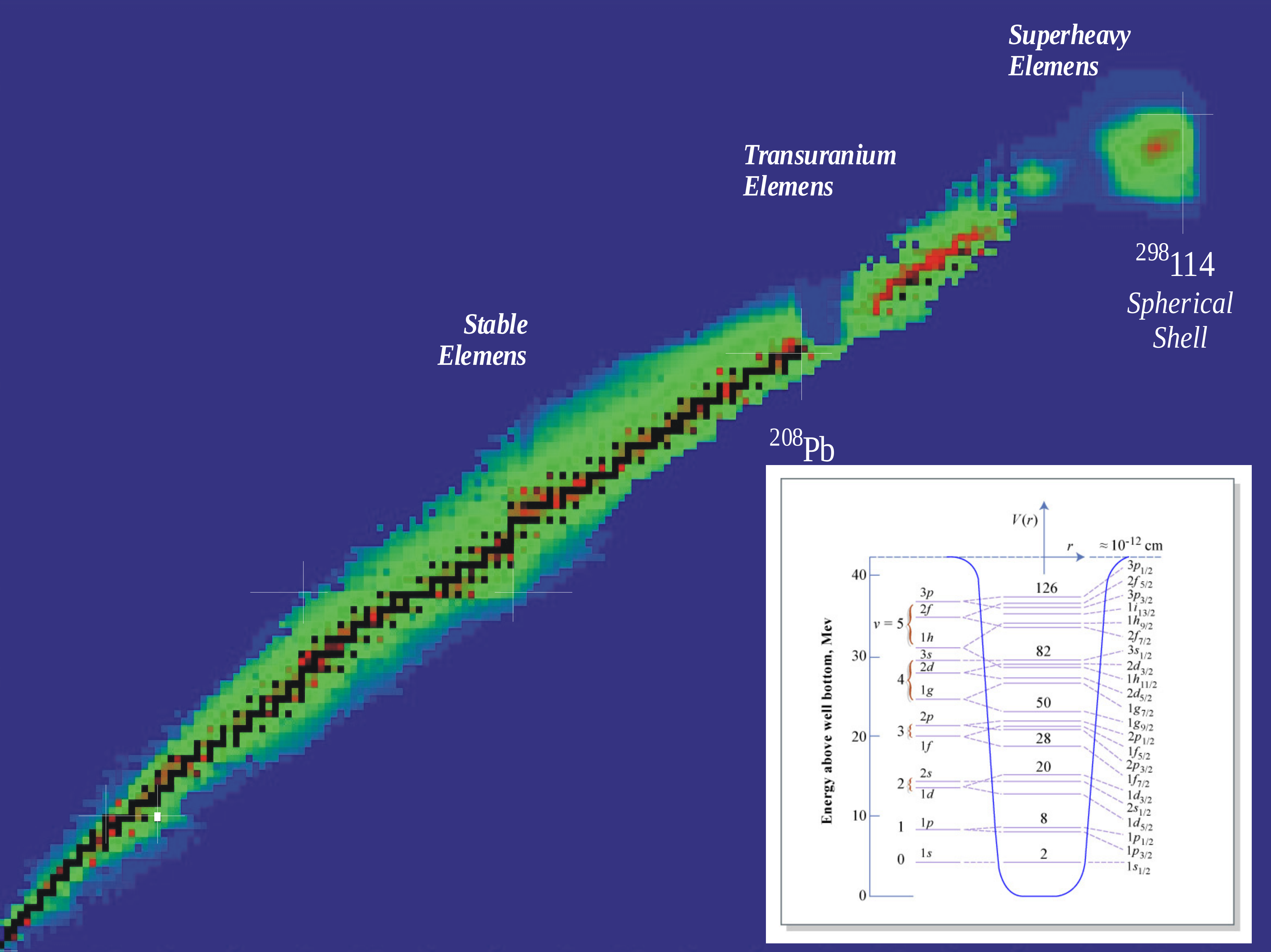
PRECISION is good….. Always. (<5%)

Experimental challenges:
Leading systematic error lies in targetry ….. Need to nano-fabricate
Apply new technique to other problems across mass surface.

Theory challenges:
Better convergence issues, better 3-body interactions.
"Export" of Ab-Initio wisdom to Shell Model and beyond.

The Heaviest Elements




Superheavy Elemens
Transuranium Elemens
Stable Elemens
208Pb
298114
Spherical Shell
V(r)
r
≈ 10-12 cm
Energy above well bottom, Mev
0
10
20
30
40
1s
1p
2s
1d
2p
1f
3s
2d
1g
3p
2f
1h
v = 5
4
3
2
1
0
2
8
20
28
50
82
126
3p1/2
2f5/2
3p3/2
1i13/2
1h9/2
2f7/2
3s1/2
2d3/2
1h11/2
2d5/2
1g7/2
1g9/2
2p1/2
1f5/2
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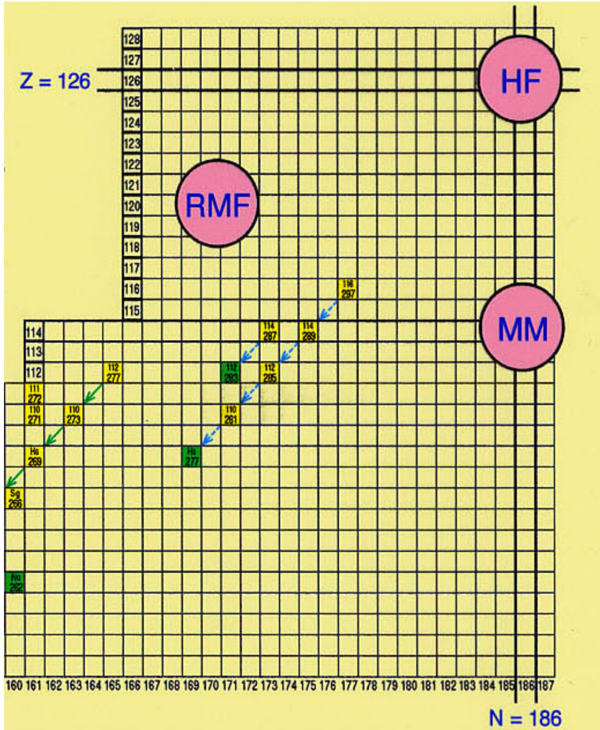
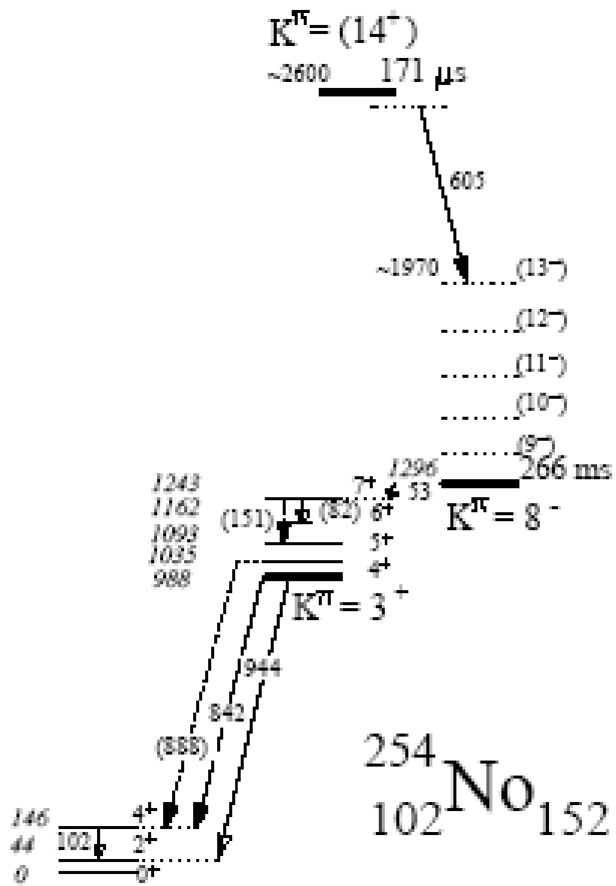
1p3/2
1s1/2

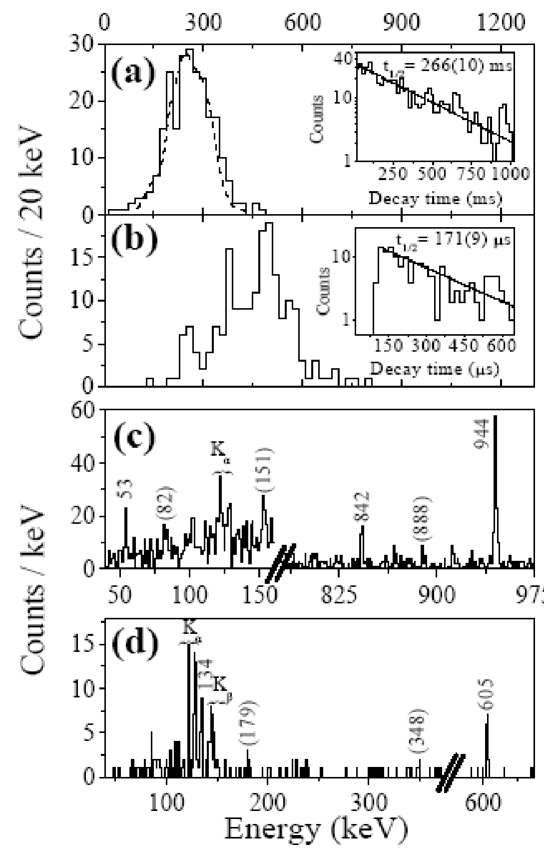


Spectroscopy of the Heaviest Nuclei

Key Questions: Where are the single particle gaps?

What are the Nilsson-like states near the Fermi surface?



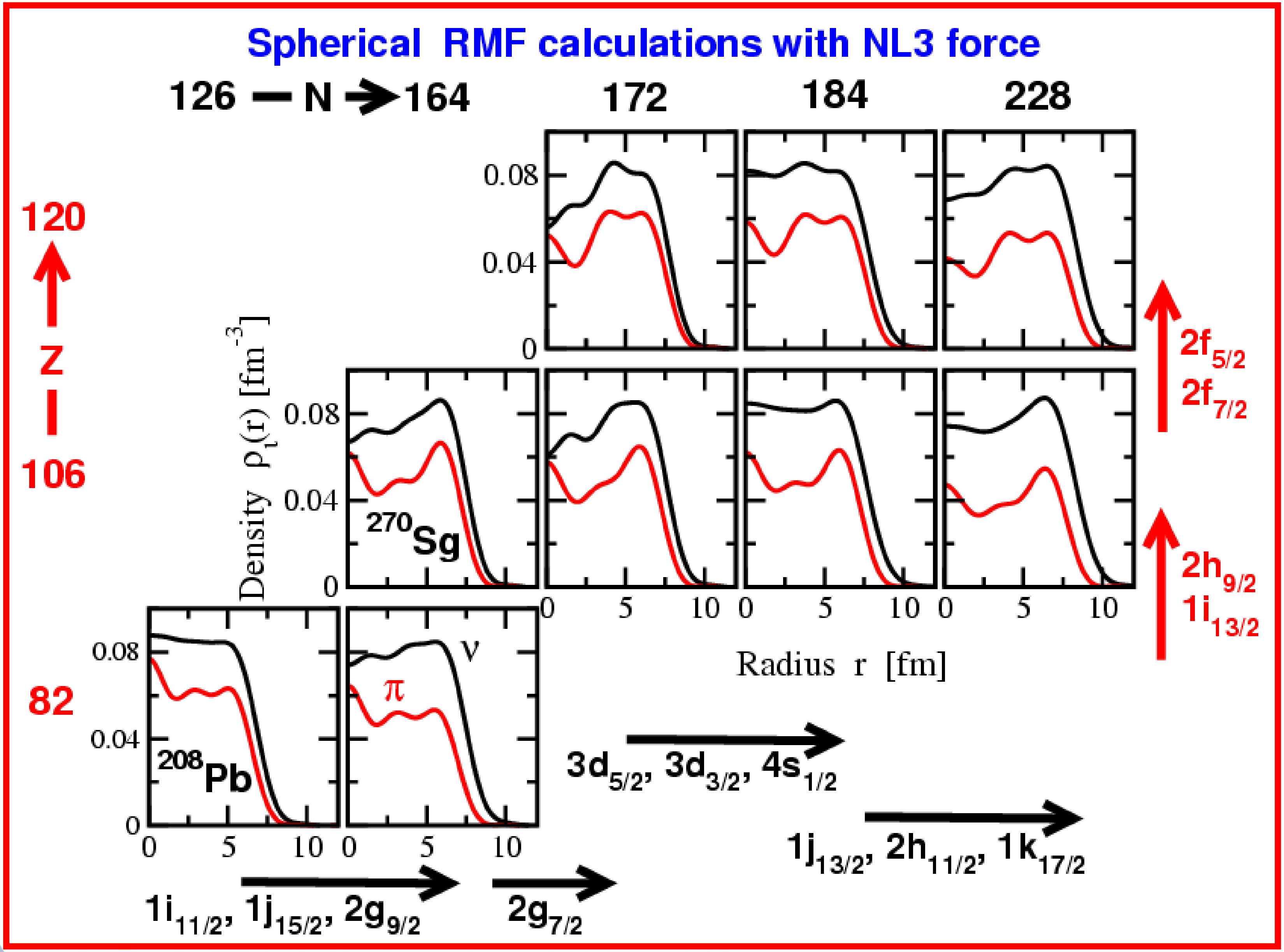


Do the answers lie at Z=118 or Z=104?

Is spectroscopy more informative than existence?

$\sigma \sim < 300$nb

A Self-Consistency Effect

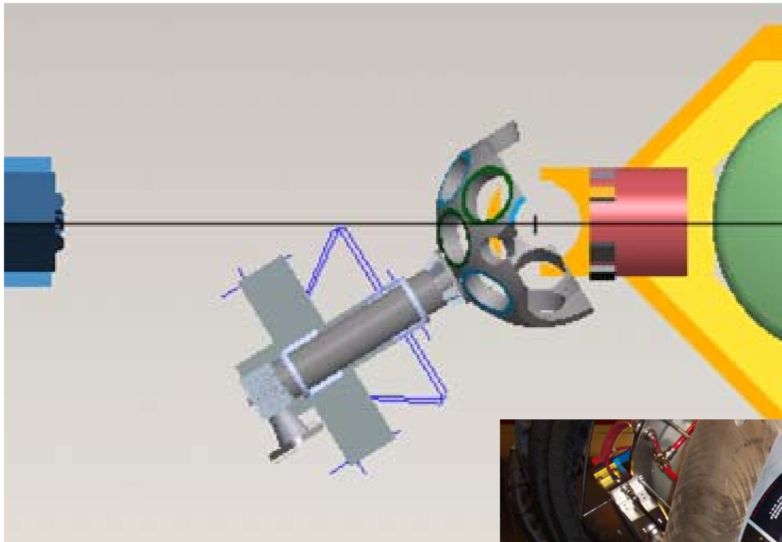


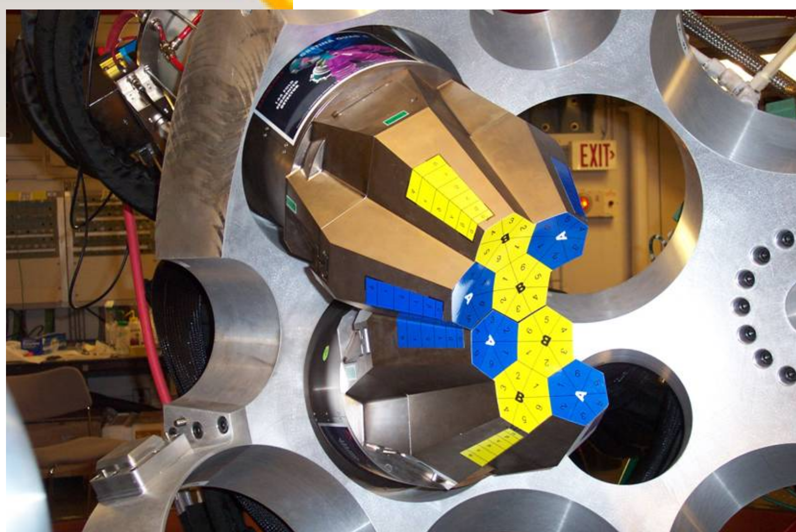
GRETINA@ATLAS

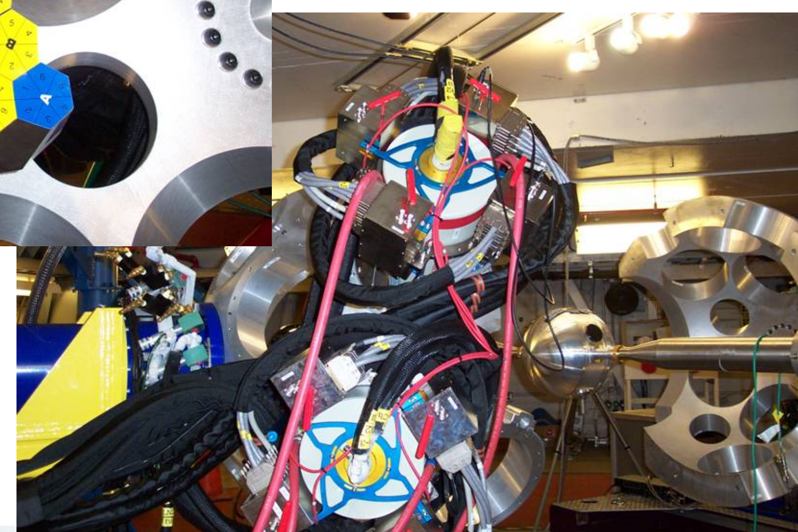
Coming in 2013

Ideal for very heavy element spectroscopy

Ideal for ^{100}Sn

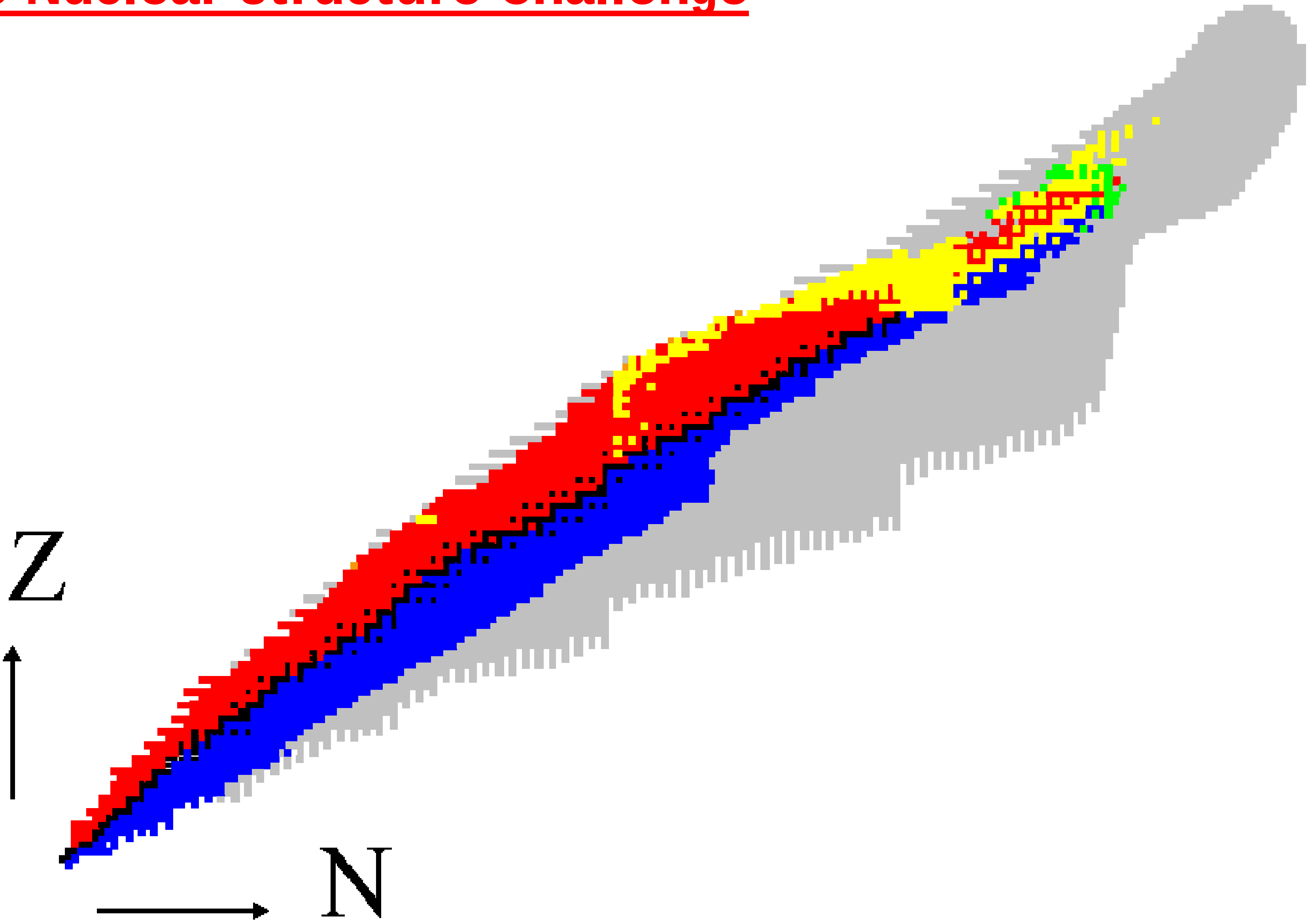






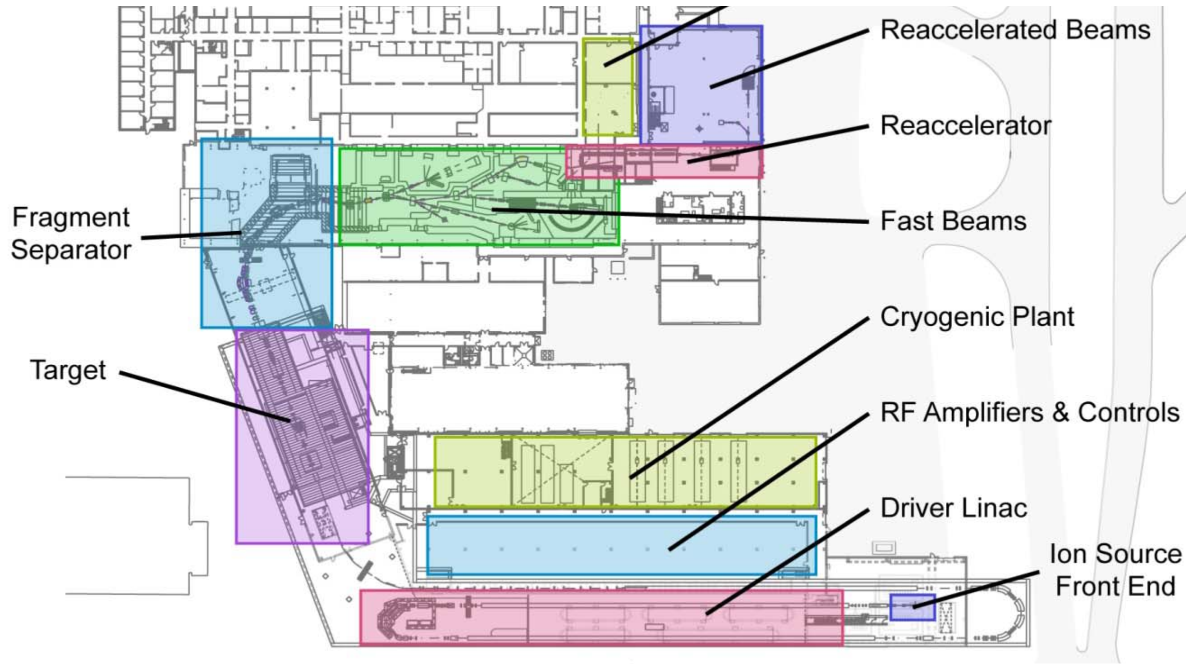
Efficient and fast-counting

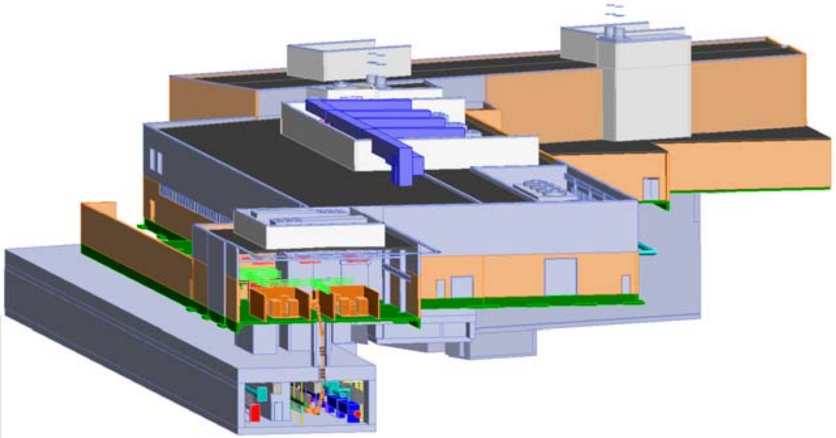
The Nuclear Structure Challenge



FRIB Conceptual Overview

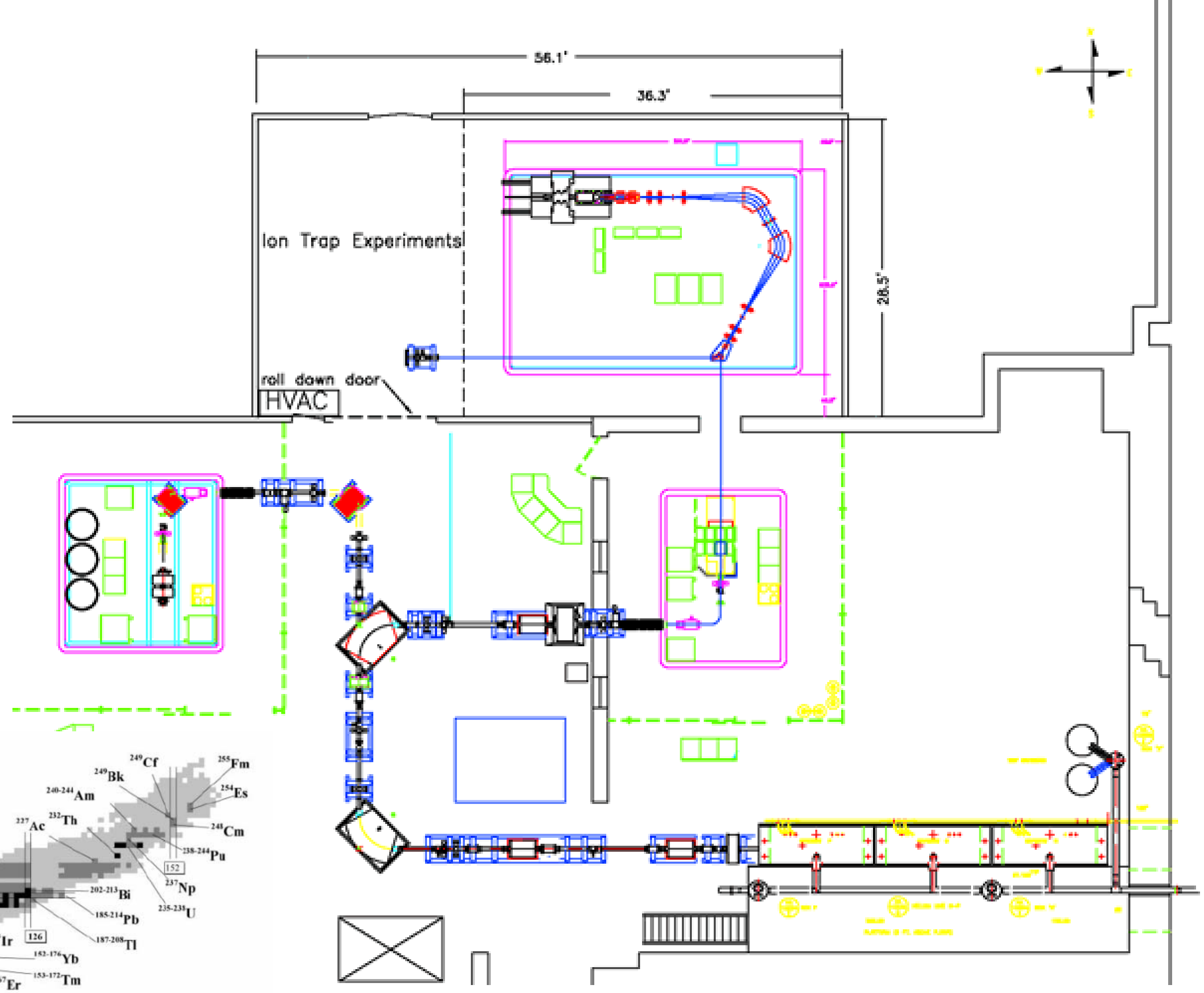
- Rare isotope production with primary beams up to 400 kW, 200 MeV/u uranium
- Fast, stopped and reaccelerated beam capability
- Experimental areas and scientific instrumentation for fast, stopped and reaccelerated beams
- Beam power ramps from 10 kW in year 1 to 400 kW in year 4

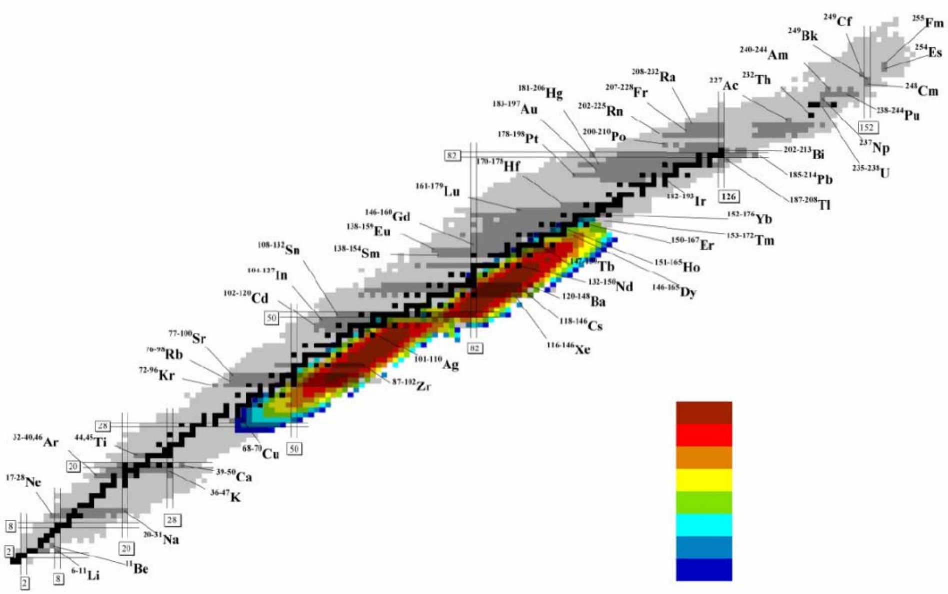




CARIBU

Gives ATLAS real "reach" into the neutron-rich world of nuclei



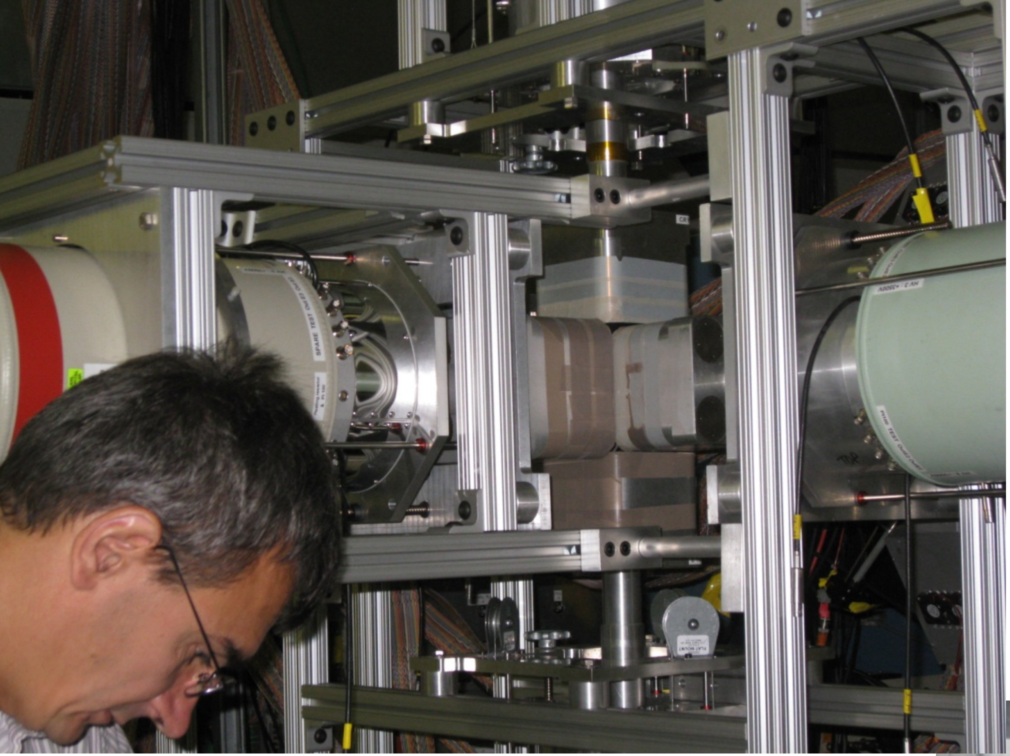


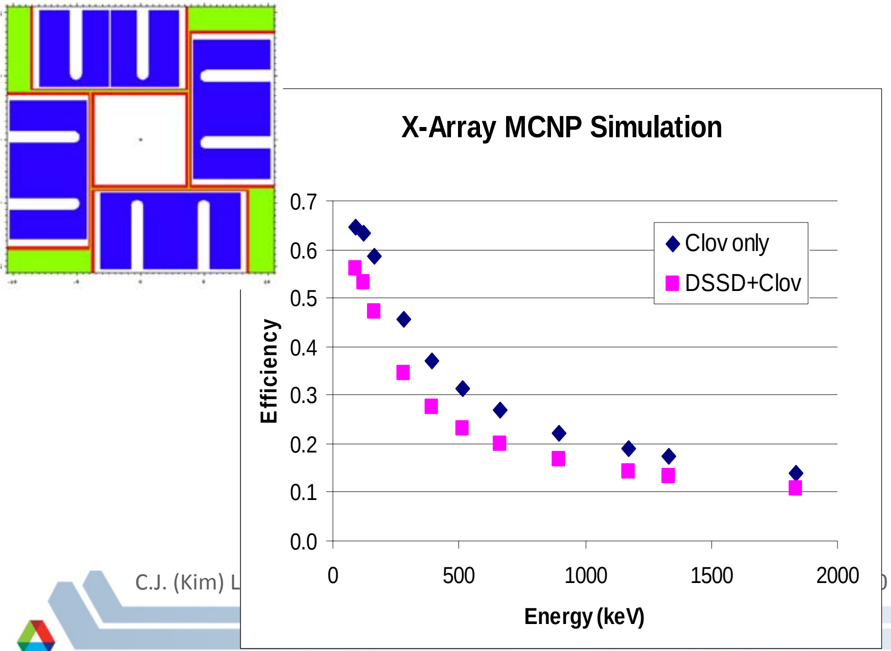
New Physics
New Techniques
New Generation

The X-Array

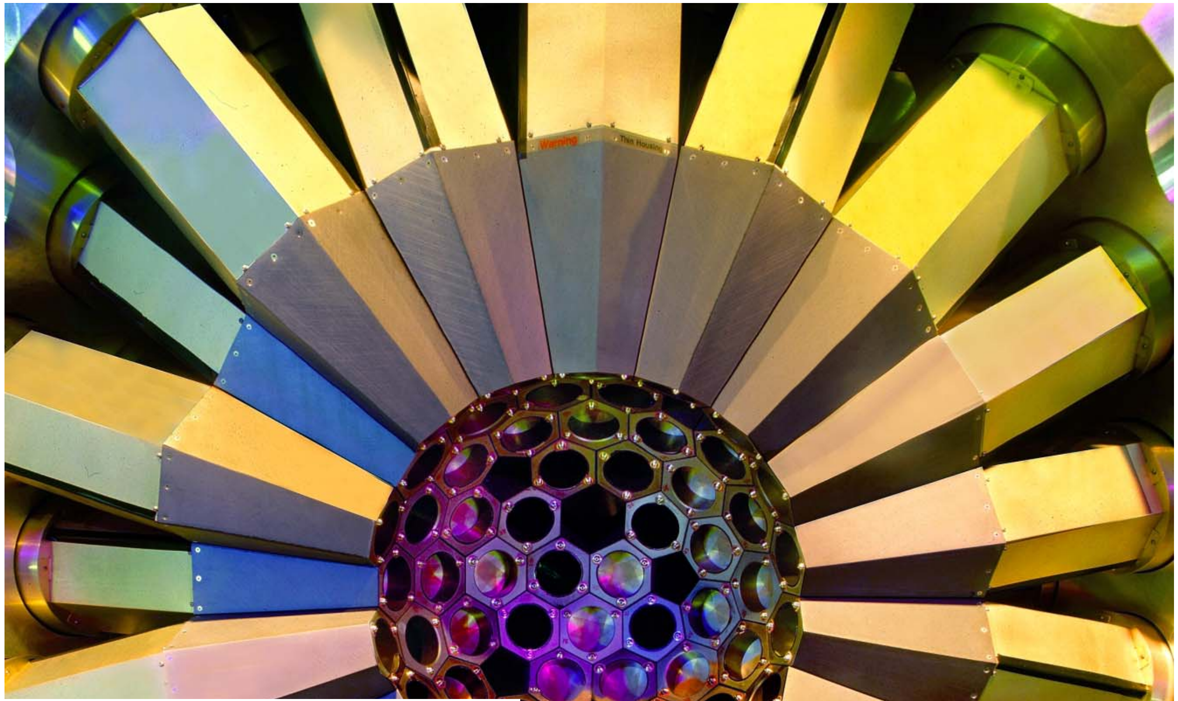
For spectroscopy when cross-sections are low and every count counts.

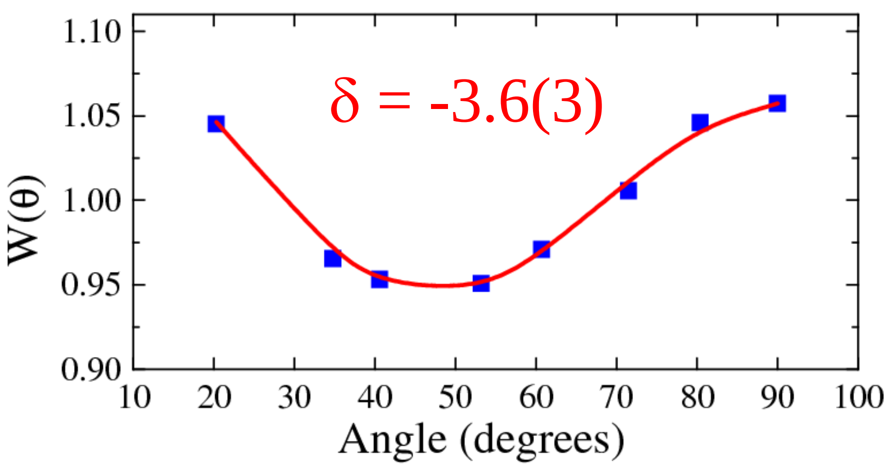
TWICE the efficiency of Gammasphere

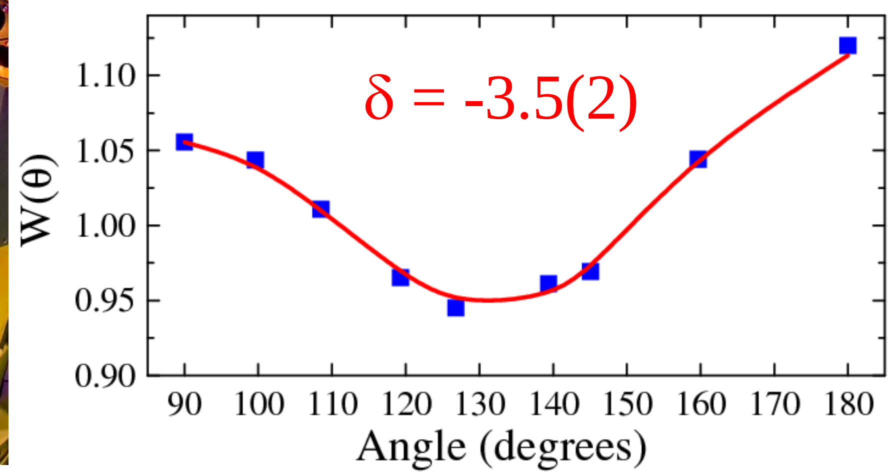




Gammasphere







Deep Inelastic Transfer as a tool for structure studies

PHYSICAL REVIEW C **79**, 034319 (2009)

Levels above the 19/2$^-$ isomer in ^{71}Cu: Persistence of the $N = 40$ neutron shell gap

I. Stefanescu,[1,2,3] W. B. Walters,[1] R. V. F. Janssens,[2] N. Hoteling,[1,2] R. Broda,[4] M. P. Carpenter,[2] B. Fornal,[4] A. A. Hecht,[1,2] W. Krolas,[4,5] T. Lauritsen,[2] T. Pawlat,[4] D. Seweryniak,[2] J. R. Stone,[1,6] X. Wang,[2,7] A. Wöhr,[1,2] J. Wrzesinski,[4] and S. Zhu[2]

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **79**, 061303(R) (2009)

Lifetime of the $K^\pi = 8^-$ isomer in the neutron-rich nucleus ^{174}Er, and $N = 106$ $E1$ systematics

G. D. Dracoulis,[1,*] G. J. Lane,[1] F. G. Kondev,[2] H. Watanabe,[3] D. Seweryniak,[4] S. Zhu,[4] M. P. Carpenter,[4] C. J. Chiara,[2,†] R. V. F. Janssens,[4] T. Lauritsen,[4] C. J. Lister,[4] E. A. McCutchan,[4] and I. Stefanescu[4,5]

Conclusions

An upgraded ATLAS will be relevant for nuclear structure studies:

Intense stable beams for the proton dripline and heavy nuclei

Intense stable beams for Multi-Nucleon transfer reactions

Intense stable beams for “in-flight” production of exotic nuclei.

Accelerated fission-fragment beams

A new generation of experimental techniques.

A new generation of experimenters.

Argonne NATIONAL LABORATORY

Unfinished business:
Nuclear Structure at Argonne