

# $^{100}\text{Mo}(^{28}\text{Si}, xnyp)$ with the LBNL Total Absorption Spectrometer (TAS)

Richard B. Firestone

Isotopes Project

Lawrence Berkeley National Laboratory



**Workshop on "Decay Spectroscopy at CARIBU: Advanced Fuel Cycle Applications, Nuclear Structure and Astrophysics"**  
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# Prelude

The LBNL Total Absorption Spectrometer (TAS) was constructed by Mike Nitschke's research group in 1989. The data presented here were briefly described in the 1989-1990 LBNL Nuclear Science Division Annual Report [1] and have languished in my computer for over 20 years.

In 1989 Mike proposed a national radioactive beam facility at the *Workshop on Future Perspectives for Nuclei Far from Stability for the Long Range Plan for Nuclear Science* at Argonne [2]. He turned his attention to radioactive beams until his death in 1995. TAS did one experiment in Berkeley and when the SuperHILAC closed it was moved to GSI where it was coupled their on-line mass separator [3].

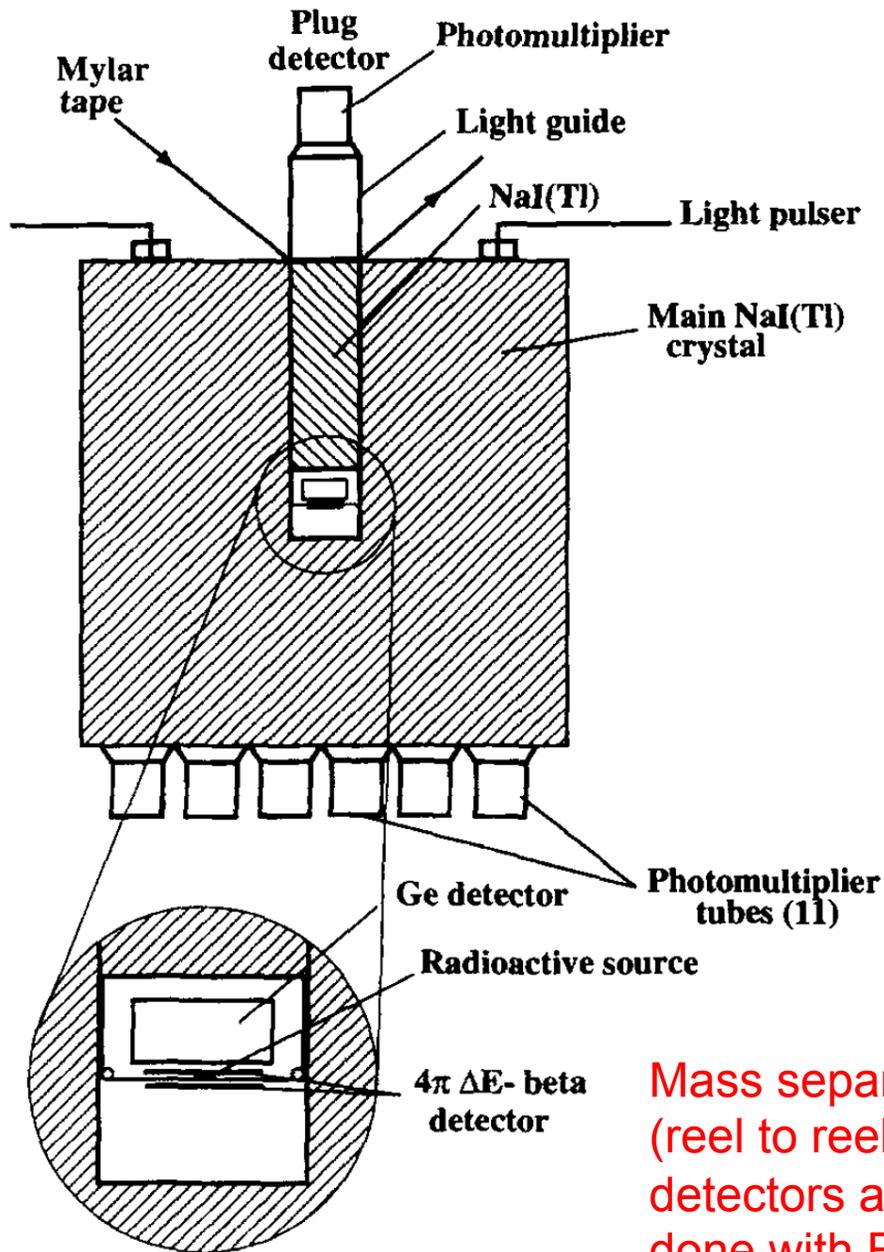
[1] J.M. Nitschke, P.A. Wilmarth, and R.B. Firestone, 1989-1990 LBNL Nuclear Science Division Annual Report (LBL-31855).

[2] M. Nitschke, "Workshop on Future Perspectives for Nuclei Far from Stability for the Long Range Plan for Nuclear Science," Argonne National Laboratory, April 9-10, 1989, unpublished; and "Town Meeting on Low Energy Nuclear Physics," Argonne National Laboratory, April 17-18, 1989, unpublished.

[3] M. Karny, J.M. Nitschke, L.F. Archambaul, et al, Nucl. Instrum. Meth. Phys. Res. **B** 126, 411-415 (1997).

*This talk is dedicated to the memory of Mike Nitschke.*

# TAS Spectrometer



## Detectors

- 356 mm×356 mm(14"×14") NaI(Tl)
- 51 mm×203 mm well
- 43 mm×150 mm plug NaI(Tl)
- 16 mm×10 mm Ge x-ray detector
- Two 18 mm×0.5,1mm Si β detectors

## Efficiency

- >66% peak @ 0.3-1.5 MeV
- >95% total detection @ 0.3-1.5 MeV
- >55% peak @ 5 MeV
- >89% total detection @ 5 MeV

Mass separated source is collected on mylar tape (reel to reel tape drive) and transported between β detectors at TAS center. Isotopic identification is done with EC decay x-ray coincidences.

# OASIS Mass Separator

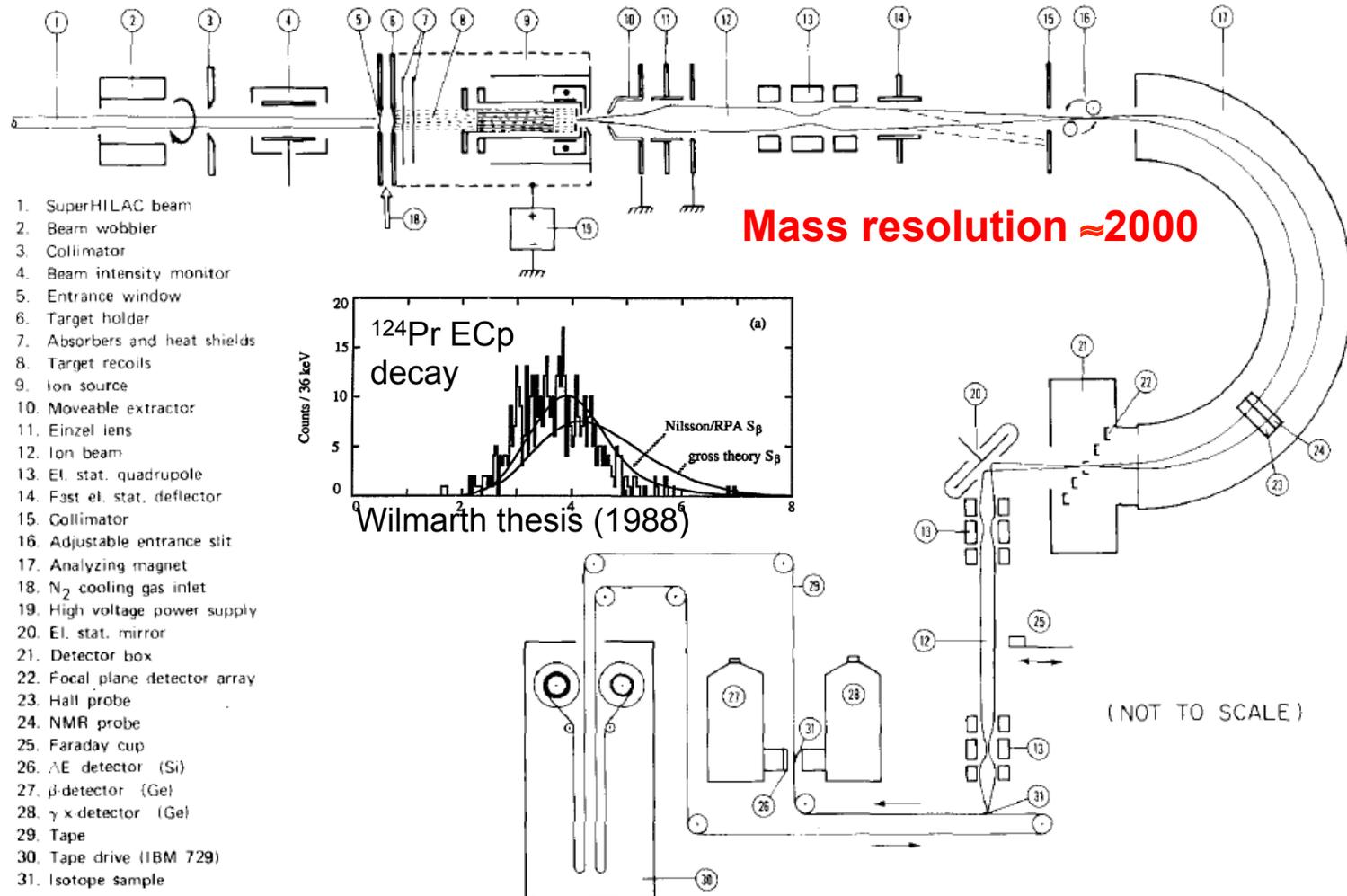


Fig. 2. Schematic representation of OASIS showing its main components. The electrostatic mirror (20) deflects the beam vertically (shown turned  $90^\circ$ ) to the next floor of the laboratory.

J.M. Nitschke, Nuclear Instruments and Methods 206 (1983) 341-351.

# Measurement Summary

For the Isotopes  $^{117-124}\text{Cs}$ ,  $^{117-121}\text{Xe}$ , and  $^{121-124}\text{Ba}$  I have preserved the TAS data from our only experiment that measure

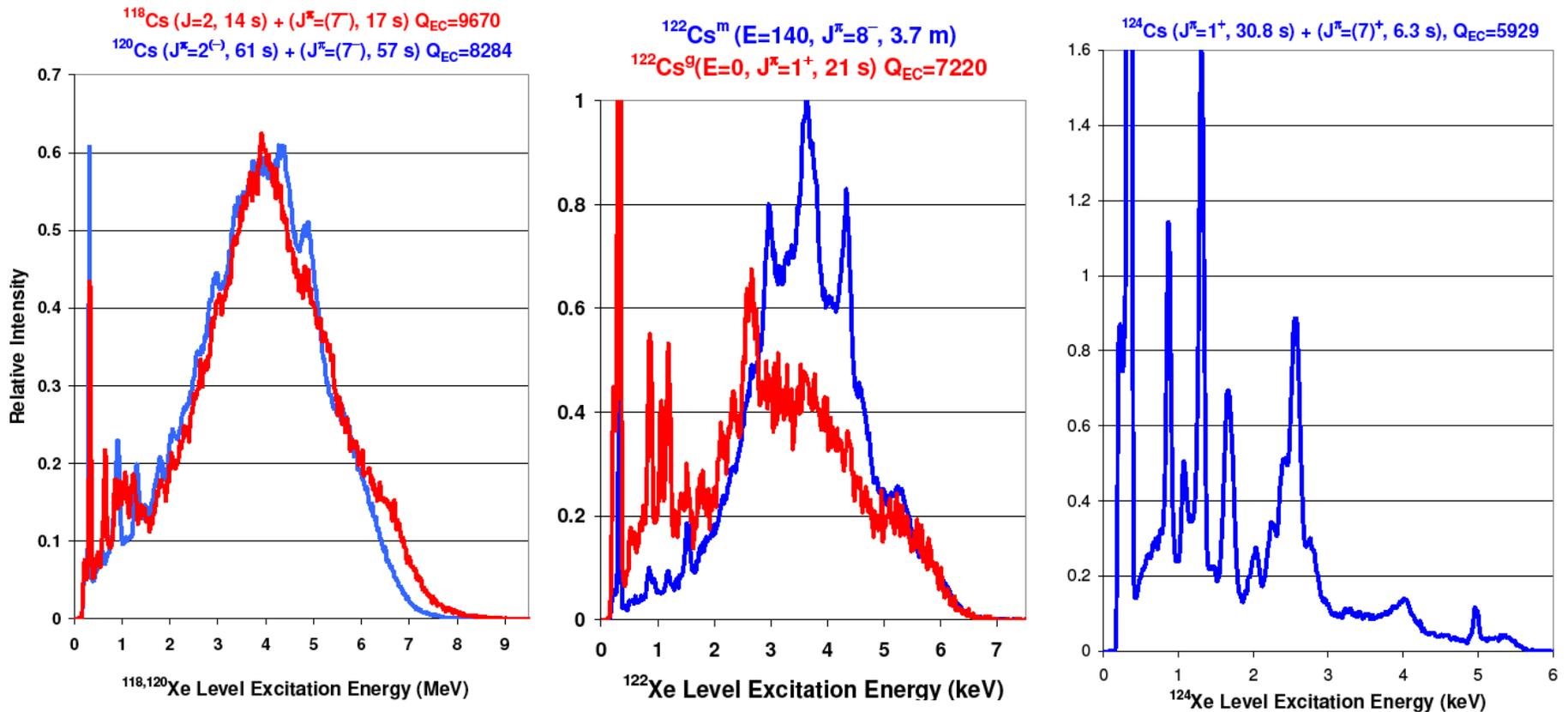
Complete  $I_\beta$  spectra,  $Q_{\text{EC}}$  values, and  $S_\beta$  strengths

For  $^{124}\text{Cs}$  plug detector coincidence data survive and  $\gamma$ -ray strengths will be discussed.

Implications of these data to statistical models (Gross Theory of  $\beta$ -decay) will be discussed.

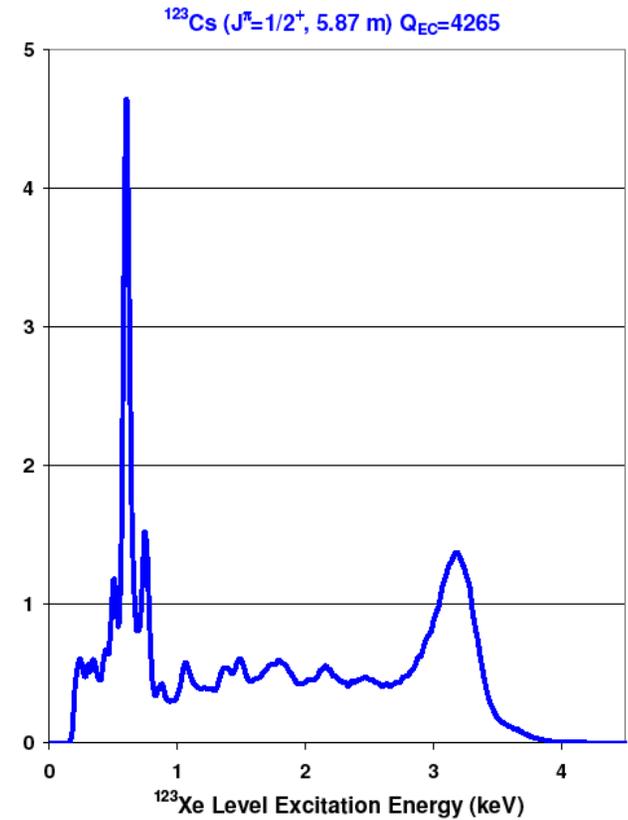
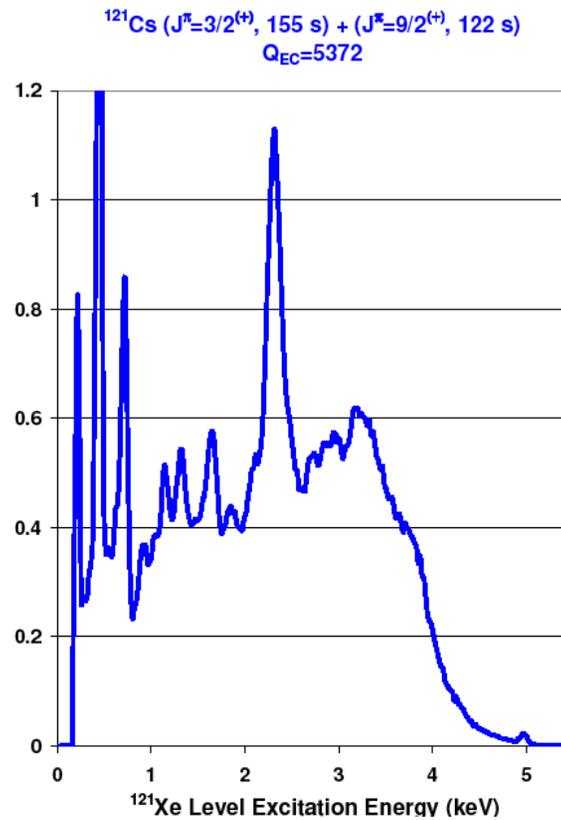
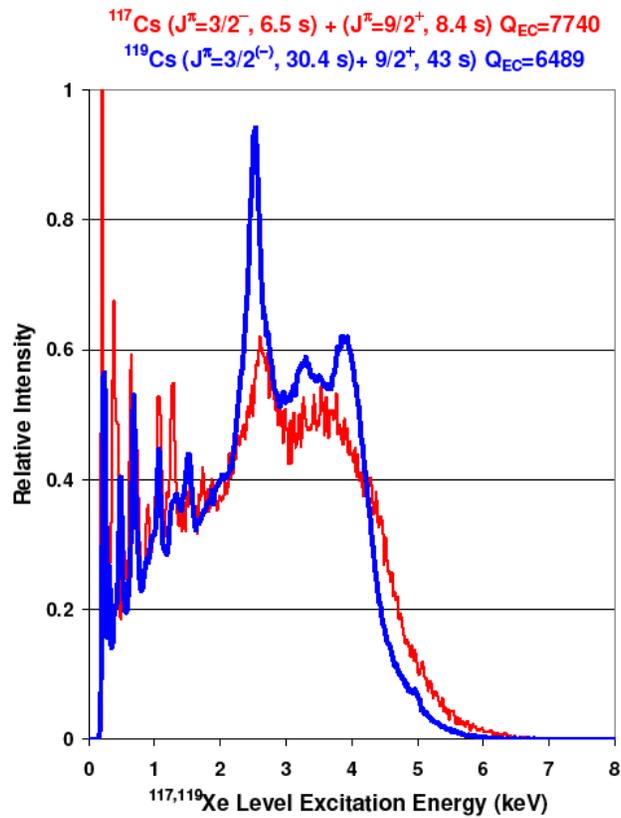
No other data from these experiments survives!

# Even A Cs Isotopes

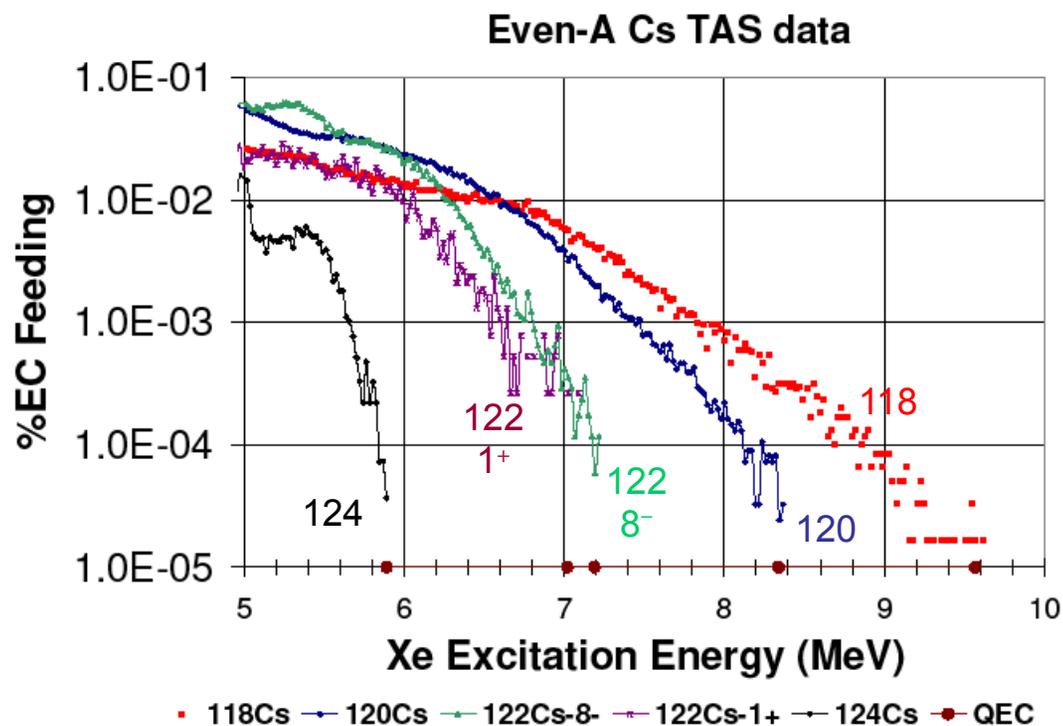


Note: These spectra have not been corrected for the TAS response function.

# Odd-A Cs Isotopes



# $Q_{EC}$ Determination – Even A Cs



The  $^{122}\text{Cs}$   $Q_{EC}$  value is consistent with the  $8^-$  isomer not the  $1^+$  GS decay. The excitation energy  $E(8^-)=170\pm 100$  keV from this work is consistent with  $E(8^-)=140\pm 30$  keV from AME.

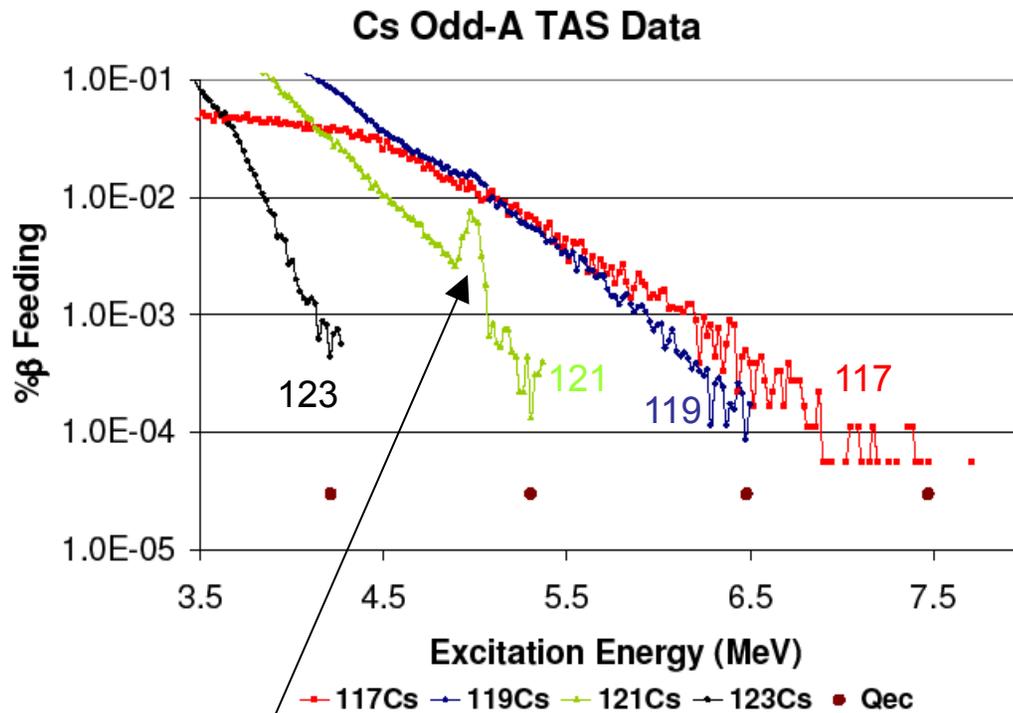
$Q_{EC}$  can be determined by the endpoint of the  $\gamma$ -ray sum spectrum.

Here  $Q_{EC}$  has been estimated by visual inspection with the aide of French curve.

Isotope	AME (Audi)		TAS
	E	$Q_{EC}$	
$^{118}\text{Cs}(2^-)$	0	9670(16)	9570(100)
$^{118}\text{Cs}(7^-)$	100(60)		
$^{120}\text{Cs}(2^-)$	0	8284(15)	8340(100)
$^{120}\text{Cs}(7^-)$	100(60)		
$^{122}\text{Cs}(1^+)$	0	7220(30)	7020(100)
$^{122}\text{Cs}(8^-)$	140(30)		7190(100)
$^{124}\text{Cs}(1^+)$	0	5929(9)	5890(100)

TAS uncertainties are estimated

# $Q_{EC}$ Determination – Odd A Cs



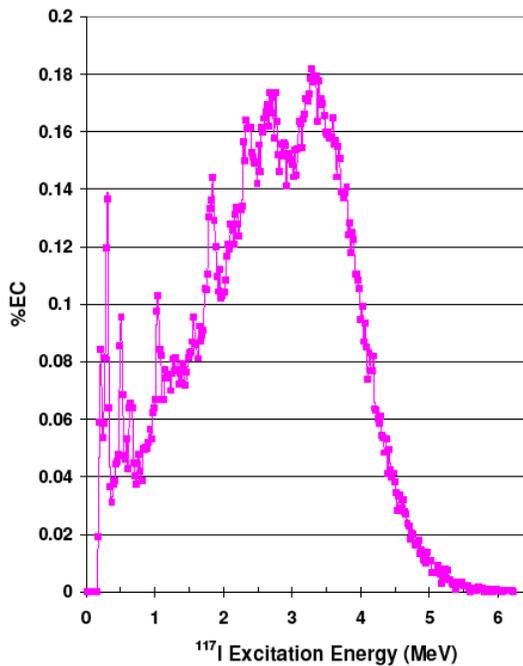
Note the high energy resonance with  $E=5.0$  MeV fed in  $^{121}\text{Cs}$  decay

Agreement between Audi and TAS data is excellent except for  $^{117}\text{Cs}$  where a large discrepancy exists.

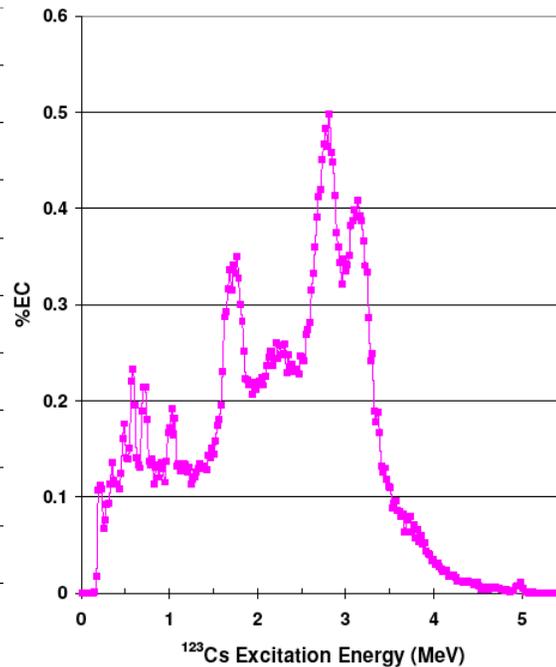
Isotope	AME (Audi)		TAS
	E	$Q_{EC}$	
$^{117}\text{Cs}(9/2^+)$	0	7740(60)	7470(100)
$^{117}\text{Cs}(3/2^-)$	150(80)		
$^{119}\text{Cs}(9/2^+)$	0	6489(17)	6480(100)
$^{119}\text{Cs}(3/2^+)$	50(30)		
$^{121}\text{Cs}(9/2^+)$	0	5372(18)	5300(100)
$^{121}\text{Cs}(3/2^+)$	68.5(3)		
$^{123}\text{Cs}(1/2^+)$	0	4205(15)	4210(100)

# Xe and Ba $Q_{EC}$ values

$^{117}\text{Xe}$  ( $J^\pi=5/2^+$ ,  $t_{1/2}=61$  s,  $Q_{EC}=6250$ )

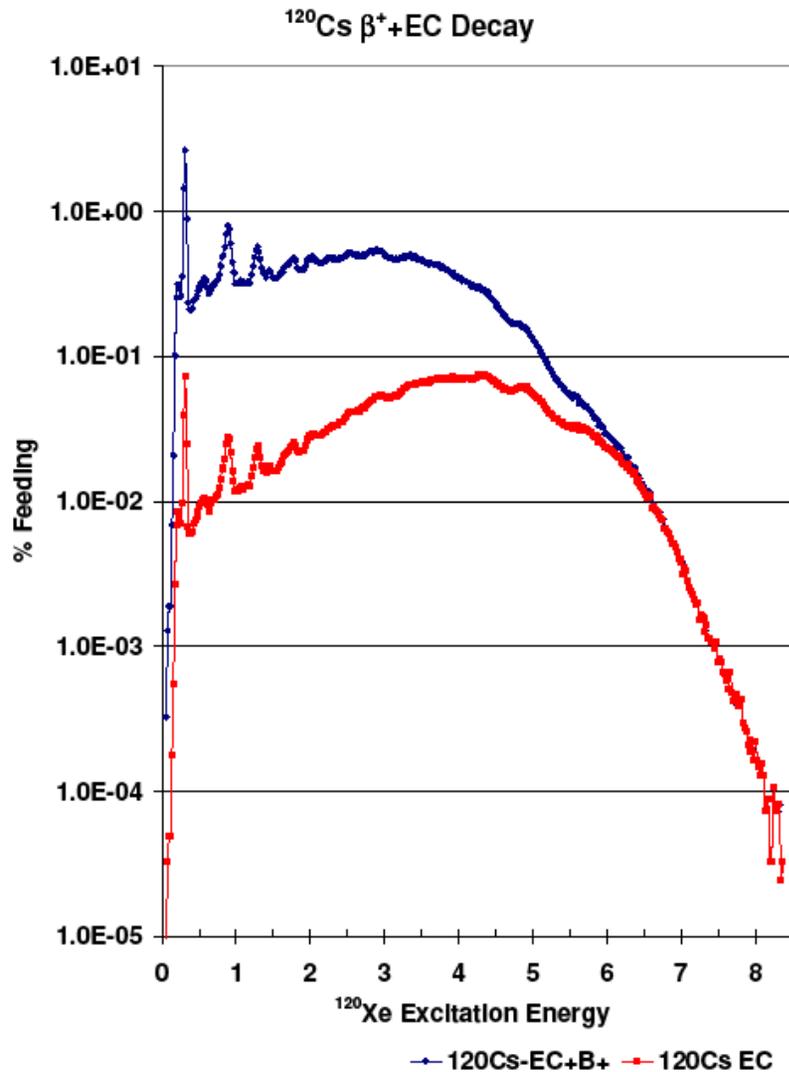


$^{123}\text{Ba}$  ( $J^\pi=5/2^+$ ,  $t_{1/2}=2.7$  m,  $Q_{EC}=5340$ )



Isotope	$Q_{EC}$ (keV)	
	AME Audi	TAS
$^{117}\text{Xe}$ ( $5/2^+$ )	6250(30)	6220(100)
$^{118}\text{Xe}$ ( $0^+$ )	2892(22)	2880(100)
$^{119}\text{Xe}$ ( $5/2^+$ )	4970(30)	4930(100)
$^{120}\text{Xe}$ ( $0^+$ )	1617(21)	1610(100)
$^{121}\text{Xe}$ ( $5/2^+$ )	3814(15)	3820(100)
$^{121}\text{Ba}$ ( $5/2^+$ )	6360(140)	6160(100)
$^{122}\text{Ba}$ ( $0^+$ )	3530(40)	3530(100)
$^{123}\text{Ba}$ ( $5/2^+$ )	5389(17)	5340(100)
$^{124}\text{Ba}$ ( $0^+$ )	2542(15)	2650(100)

# Absolute EC+ $\beta^+$ Feedings



TAS measures relative electron capture feedings. To get total EC+ $\beta^+$  feedings

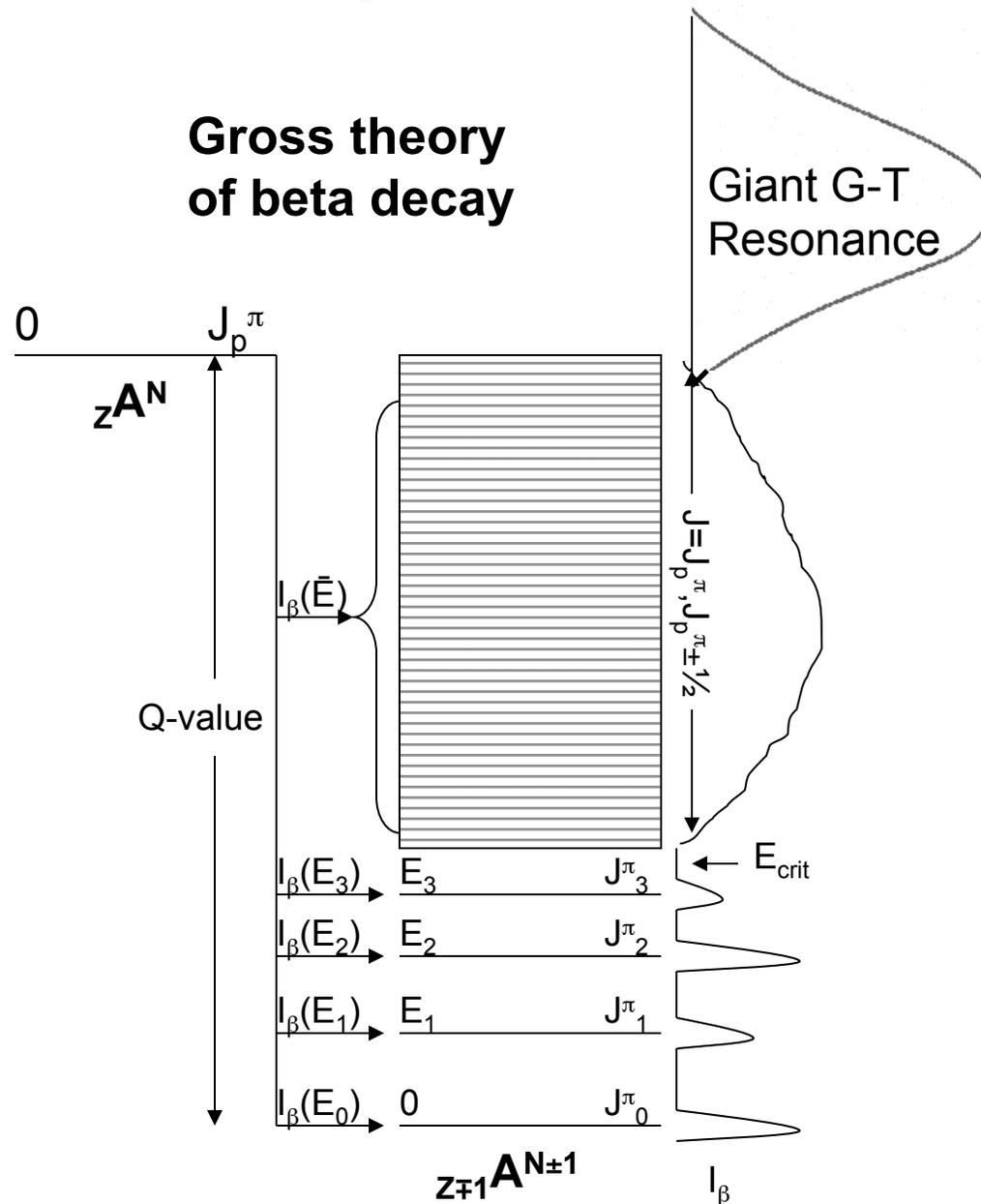
$$I(\text{EC} + \beta^+)_i = I(\gamma)_i \left(1 + \frac{f_{\beta^+}}{f_{\text{EC}}}\right)$$

$$\%(\text{EC} + \beta^+)_i = 100 \times \sum_i I(\text{EC} + \beta^+)_i$$

The spectrum should be corrected for the detector response function which is not known because the  $\gamma$ -ray spectrum is not known as a function of excitation energy.

Preliminary attempts to estimate this correction indicate that this only qualitatively affects the following results.

# $\beta$ -Strength Function



The  $\beta$ -strength  $S_\beta(E)$  to levels above  $E_{crit}$  is proportional to the level density  $\rho(E)$  with an average  $ft$  value derived from the tail of the proposed giant Gamow-Teller resonance near the IAS.

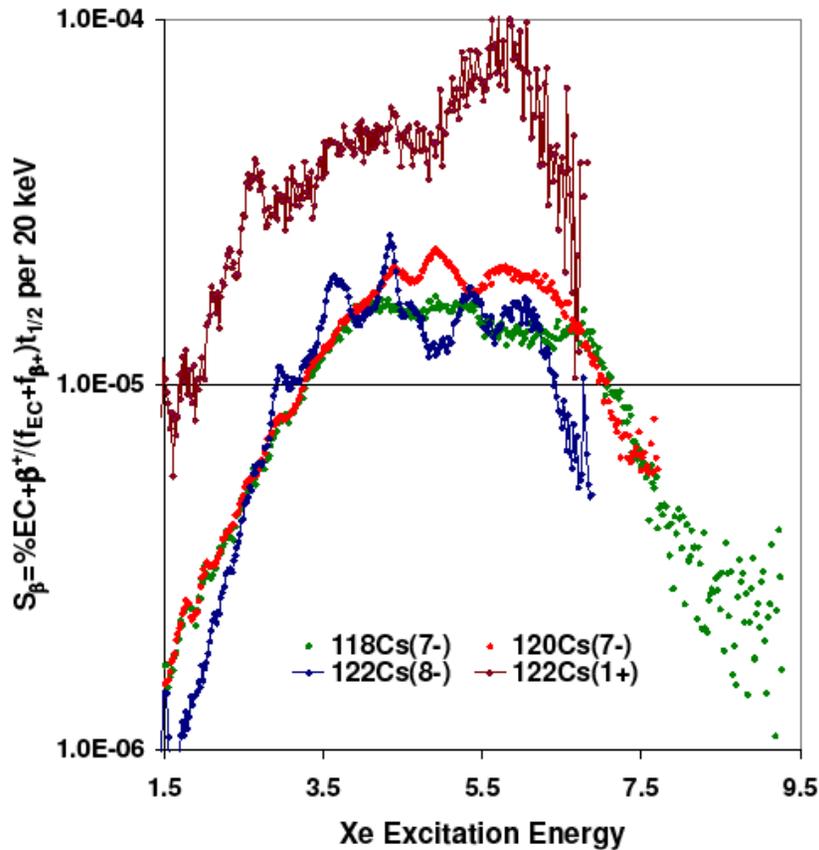
$$S_\beta(E) = \frac{I_\beta(E)}{f(Q_\beta - E)t_{1/2}} \quad (\text{individual levels})$$

$$S_\beta(E) = \frac{\rho(E)}{f(Q_\beta - E)t_{Ave}} \quad (\text{continuum levels})$$

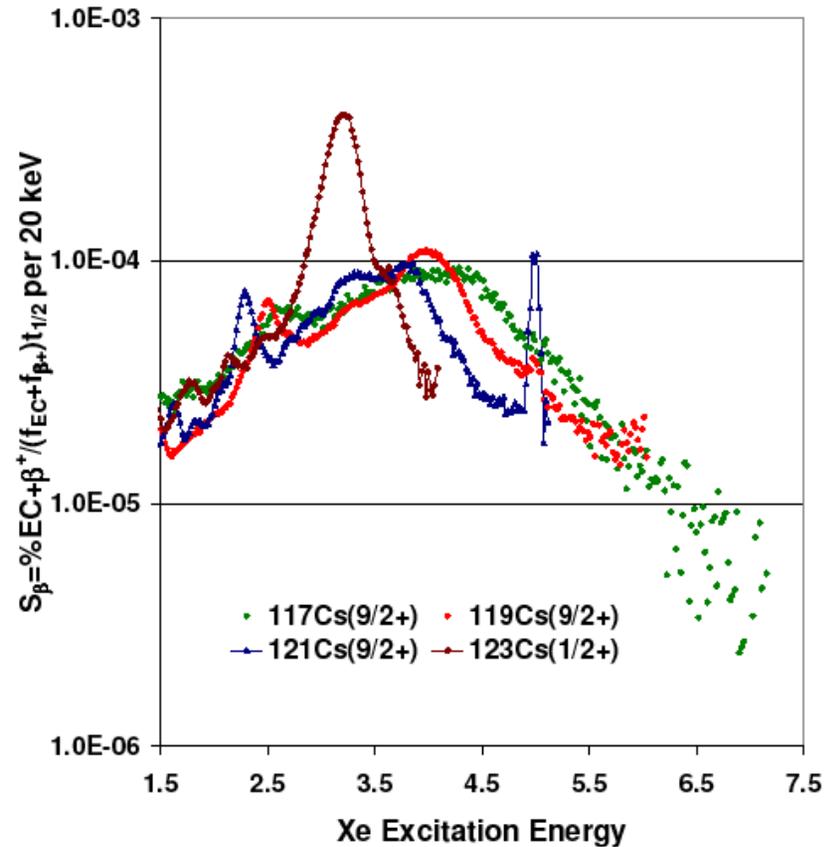
This model is similar to the statistical models used in the analysis of neutron reactions.

# Cs Beta Strength

Beta Strength - Even A Cs



Beta Strength - Odd A Cs



Cs beta strength per 20 keV,  $S_\beta = (\%EC + \beta^+) / (f_{EC} + f_{\beta^+}) t_{1/2}$  increases exponentially up to  $\approx 4$  MeV as expected if it were proportional to level density but falls off dramatically at higher energies. **This is inconsistent with the statistical model of beta decay.**

# Nuclear Structure in the $\beta$ -strength of the Cs isotopes

Strong  $\beta$ -strength is expected for  $\pi g_{9/2} \rightarrow \nu g_{7/2}$  spin-flip transition.

The Cs isotopes have  $\beta_2 = 0.2 - 0.3$  so a fast spin-flip  $\beta$ -decay transition

$$\pi g_{9/2+}[404] \rightarrow \nu g_{7/2+}[404]$$

is expected near  $\approx 4$  MeV.

Configuration mixing spreads this  $\beta$ -strength of a wide excitation range.

Shell model effects appear to dominate these decays.

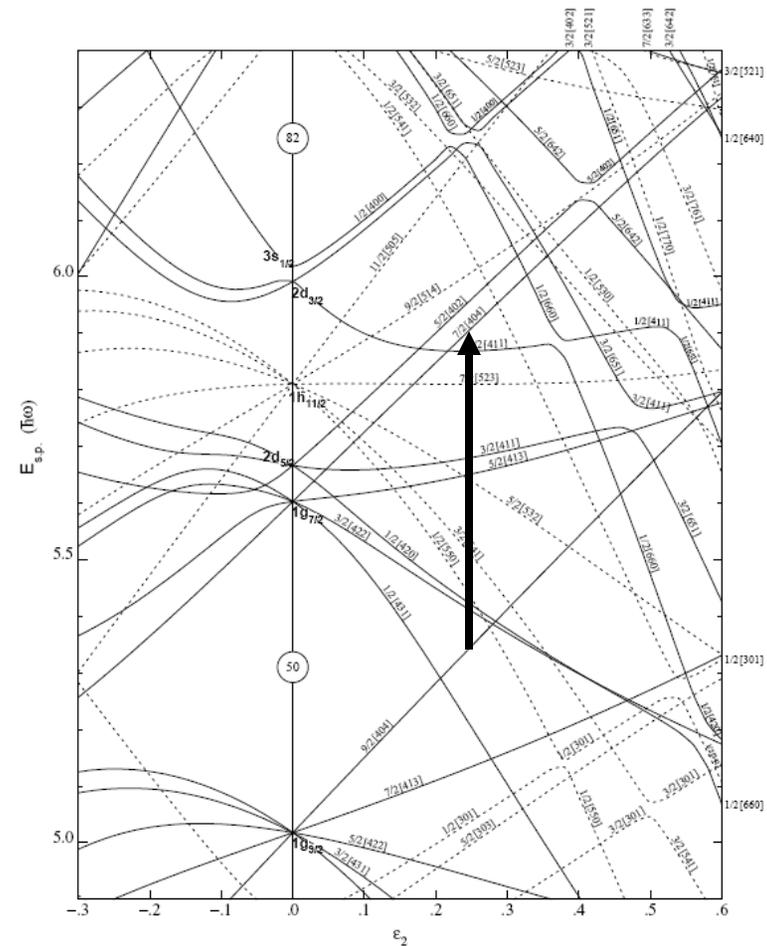
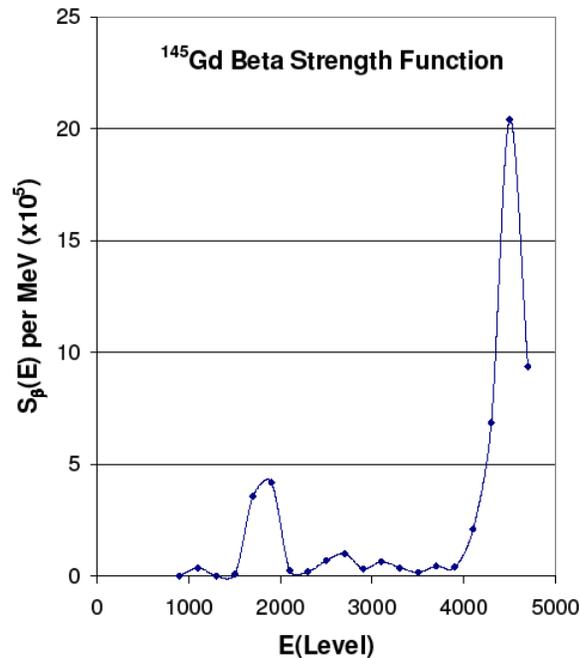
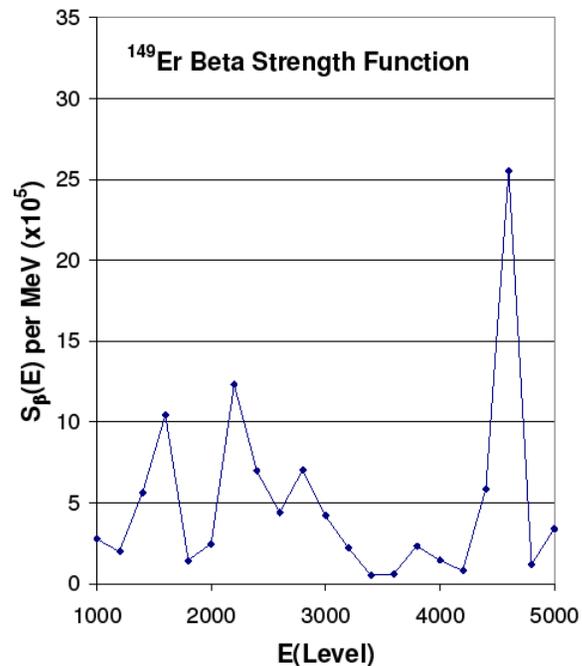


Figure 12. Nilsson diagram for protons,  $50 \leq Z \leq 82$  ( $\epsilon_4 = -\epsilon_2^2/6$ ).

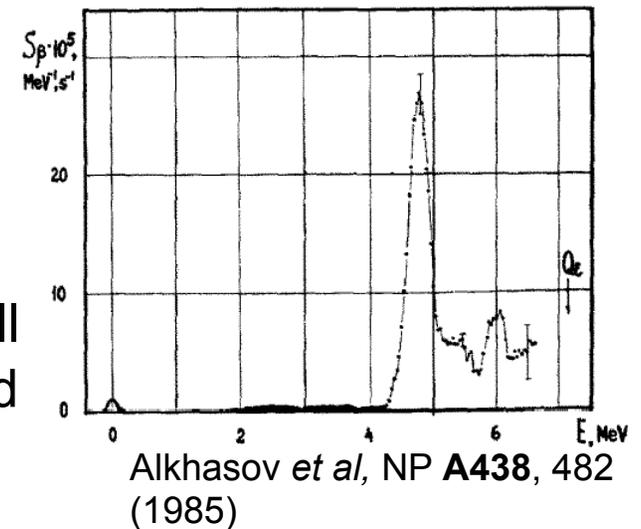
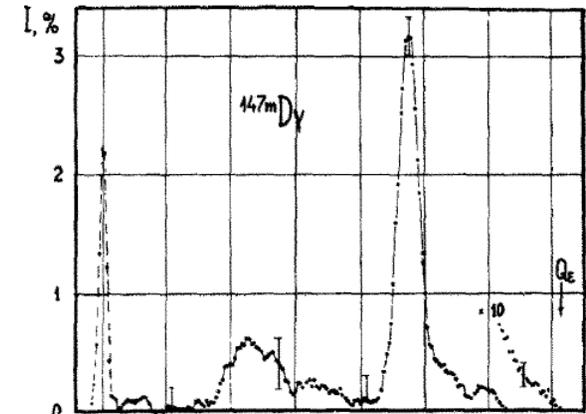
# Nuclear structure in N=81 decay $\beta$ -strength



R.B. Firestone *et al*,  
PRC**25**, 527(1982)

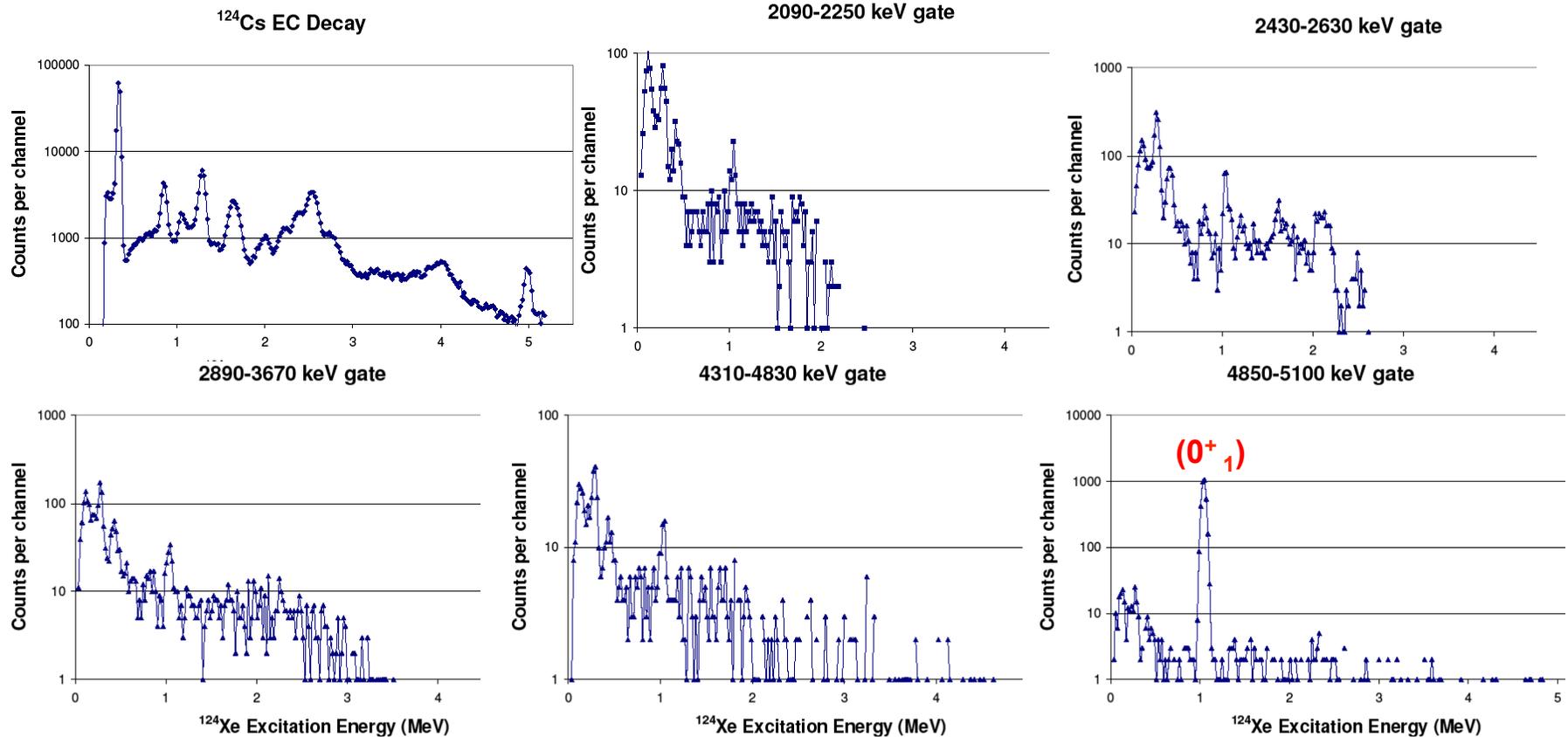


R.B. Firestone *et al*,  
PRC**39**, 219(1988)



For the N=81  $^{145}\text{Gd}$ ,  $^{147}\text{Dy}$ , and  $^{149}\text{Er}$  decays the shell model effects are even more pronounced dominated by the  $\pi h_{11/2-} \rightarrow \nu h_{9/2-}$  transition.

# $\gamma$ -ray Strength Function



Gating on the Nai plug detector in coincidence with the TAS sum spectrum gives the  $\gamma$ -ray spectrum de-exciting the excitation region corresponding to the sum.

For  $^{124}\text{Cs}(1^+)$ ,  $Q_{\text{EC}}=5929$  keV decay the strong population of the 5 MeV resonance gives a very different  $\gamma$ -ray spectrum than for other excitations.

# Future Considerations

- The LBNL TAS spectrometer has returned to Berkeley. No reasonable offer will be refused.
- For use in the study of fission products the x-ray coincidences will not be useful for isotope identification.

But, replacement of the plug detector with an external HPGe detector would allow the use of  $\gamma$ -rays for isotopic identification.

And, the TAS  $\gamma$ -ray endpoint could allow determination of both  $S_N$ ,  $Q_{EC}$ , and the parent spin if the neutron emission probability above  $S_N$  can be modeled properly.

**If I am invited back to Argonne in 20 years I' ll be happy to report on the research that I am currently doing.**

Thank you for your attention