NSSC 8
NUCLEAR SCIENCE and SECURITY CONSORTIUM

Nuclear Science and Security Consortium

September Workshop and Advisory Board Meeting

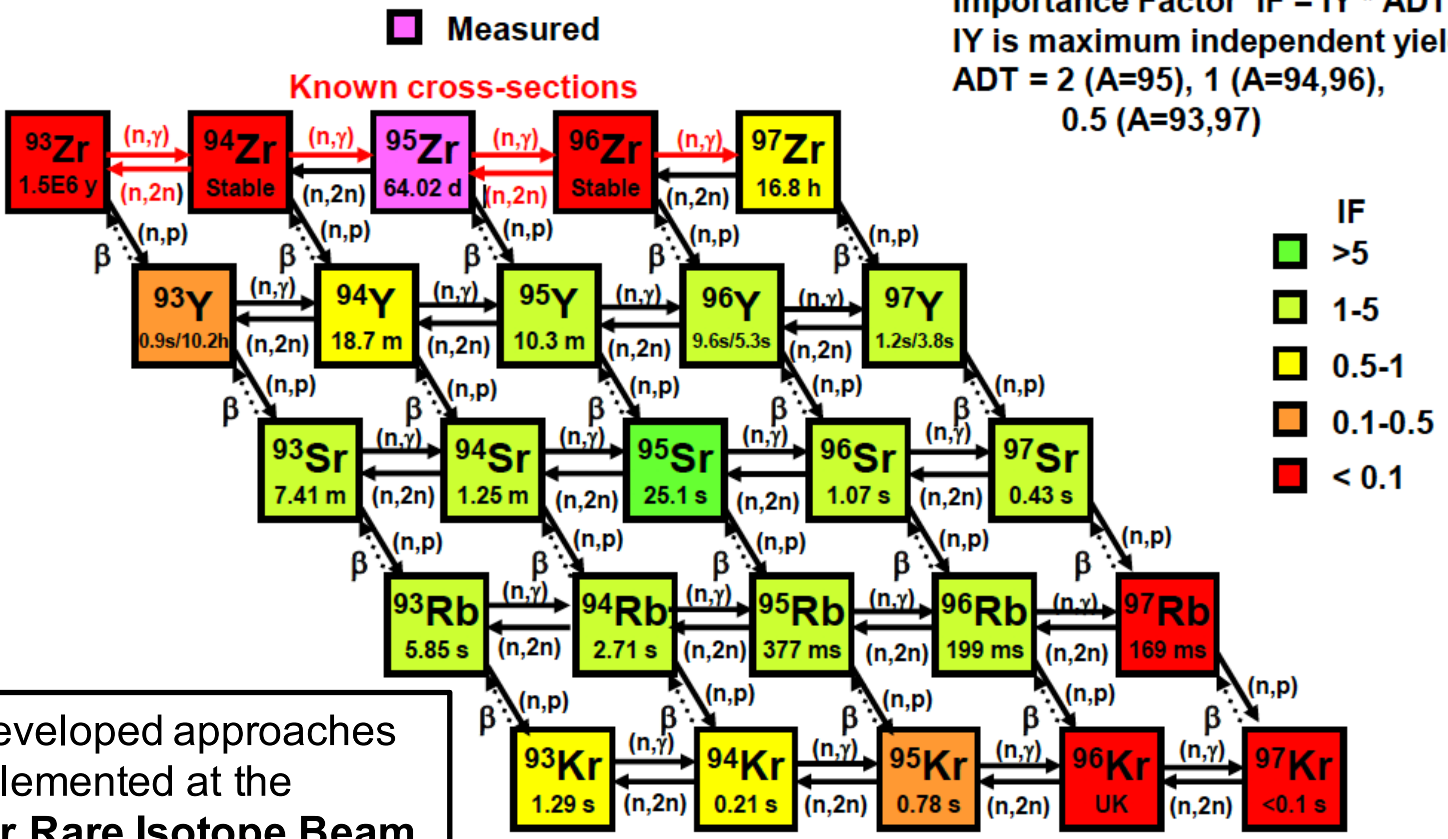
Statistical Properties of Nuclei Far from Stability for National Security Applications

September 11, 2017

Adriana Ureche
UC Berkeley
Nuclear Data

Fission products in a fission environment

Importance Factor IF = IY * ADT
IY is maximum independent yield
ADT = 2 (A=95), 1 (A=94,96),
0.5 (A=93,97)



Future: Developed approaches will be implemented at the **Facility for Rare Isotope Beam (FRIB)** to explore the limits of the known nuclides.

Meeting Isotope Needs and Capturing Opportunities for the Future: The 2015 Long Range Plan for the DOE-NP Isotope Program, *NSAC Isotopes Subcommittee,* July 20, 2015

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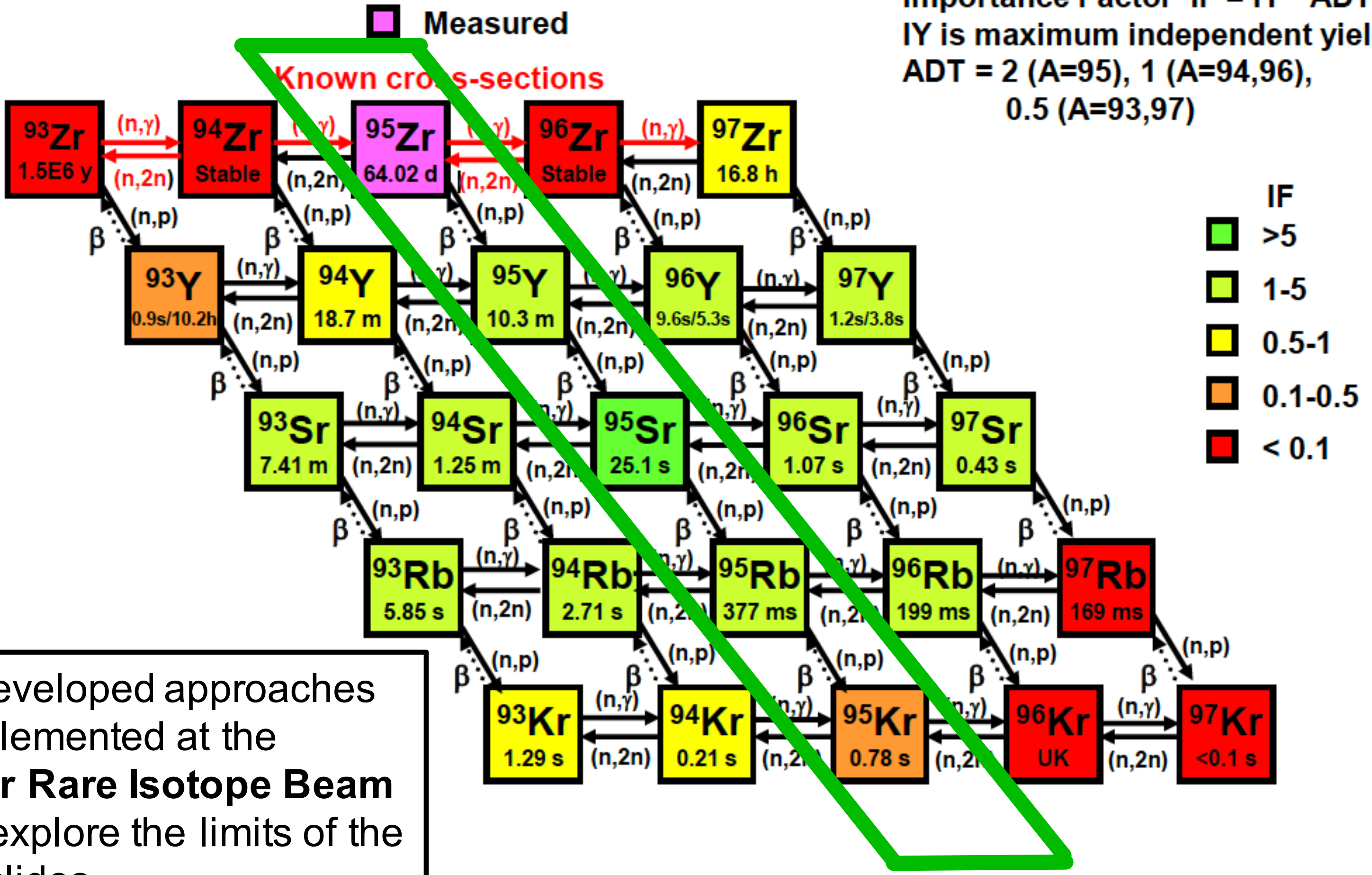

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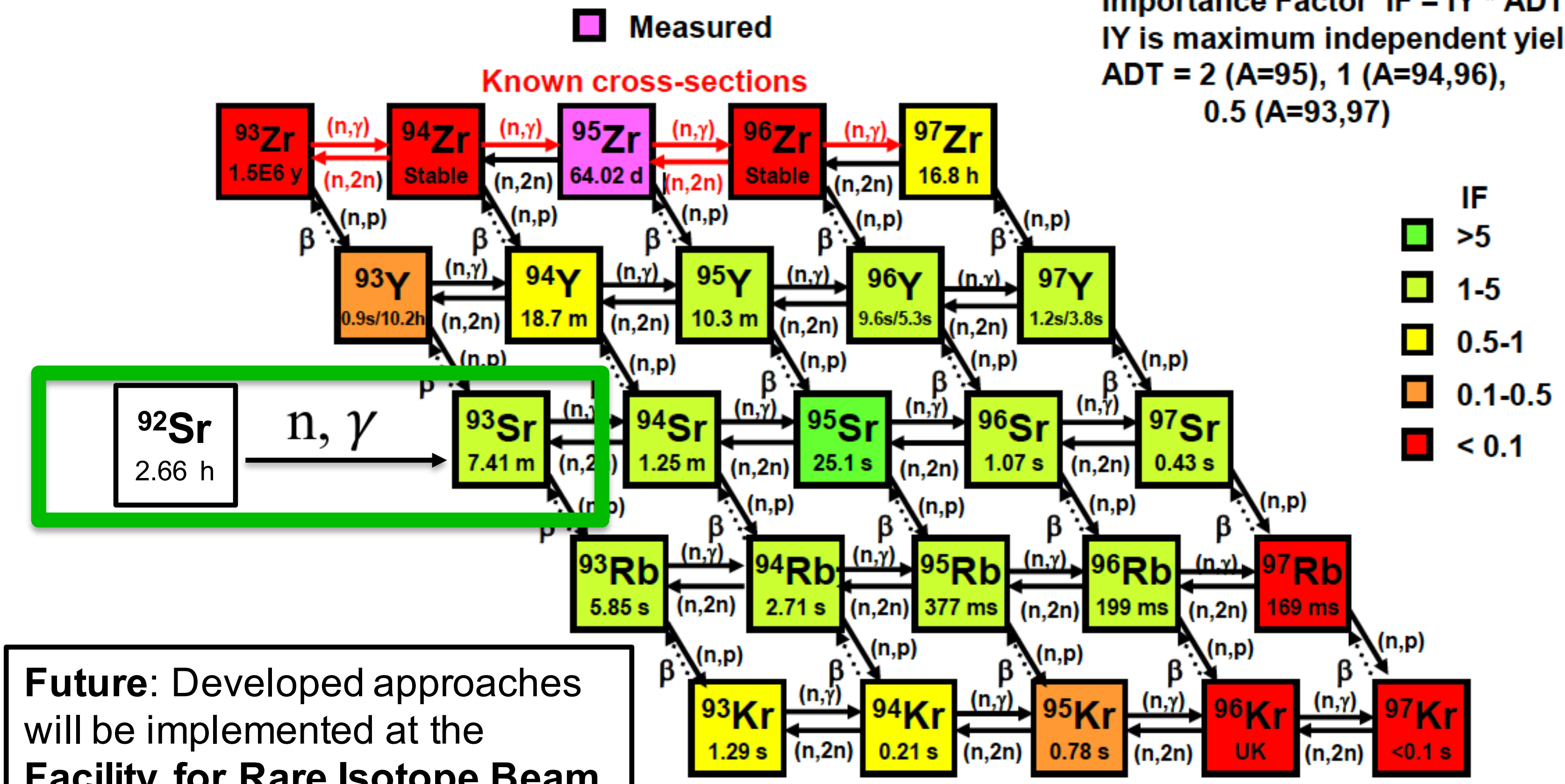

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NSSC Institutes

NNSA
National Nuclear Security Administration

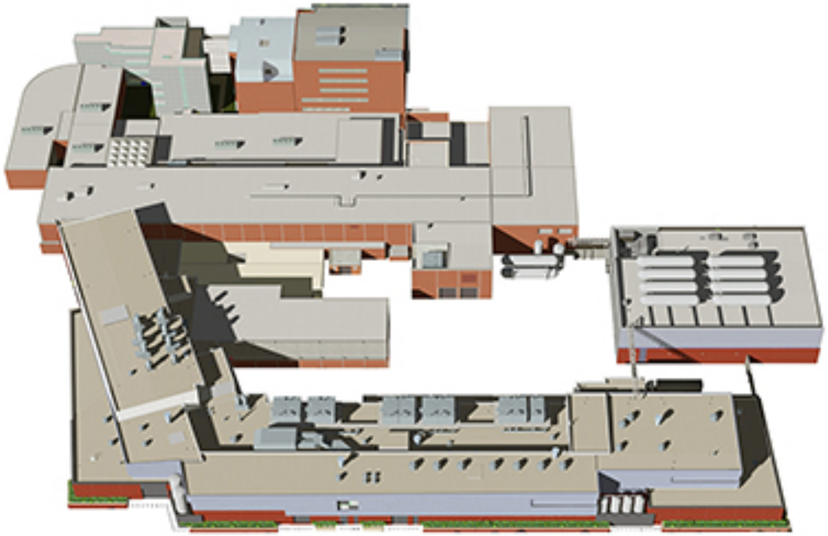
FRIB

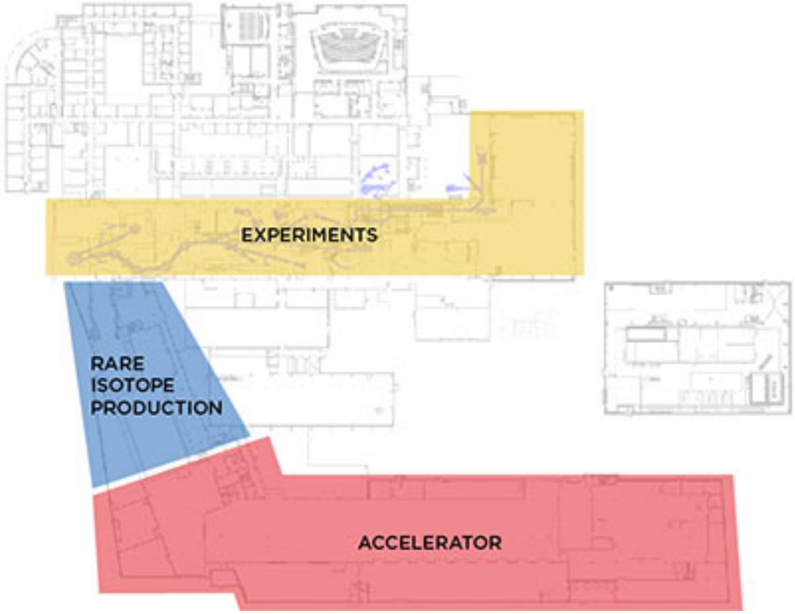
The flagship U.S. facility in low-energy nuclear science that started civil construction March 2014! By 2022, we will have the tools and techniques to use it to it's full capability!

Isotopes Harvesting

Reaction measurements in inverse kinematics

Predictive reaction theory for heavy nuclei





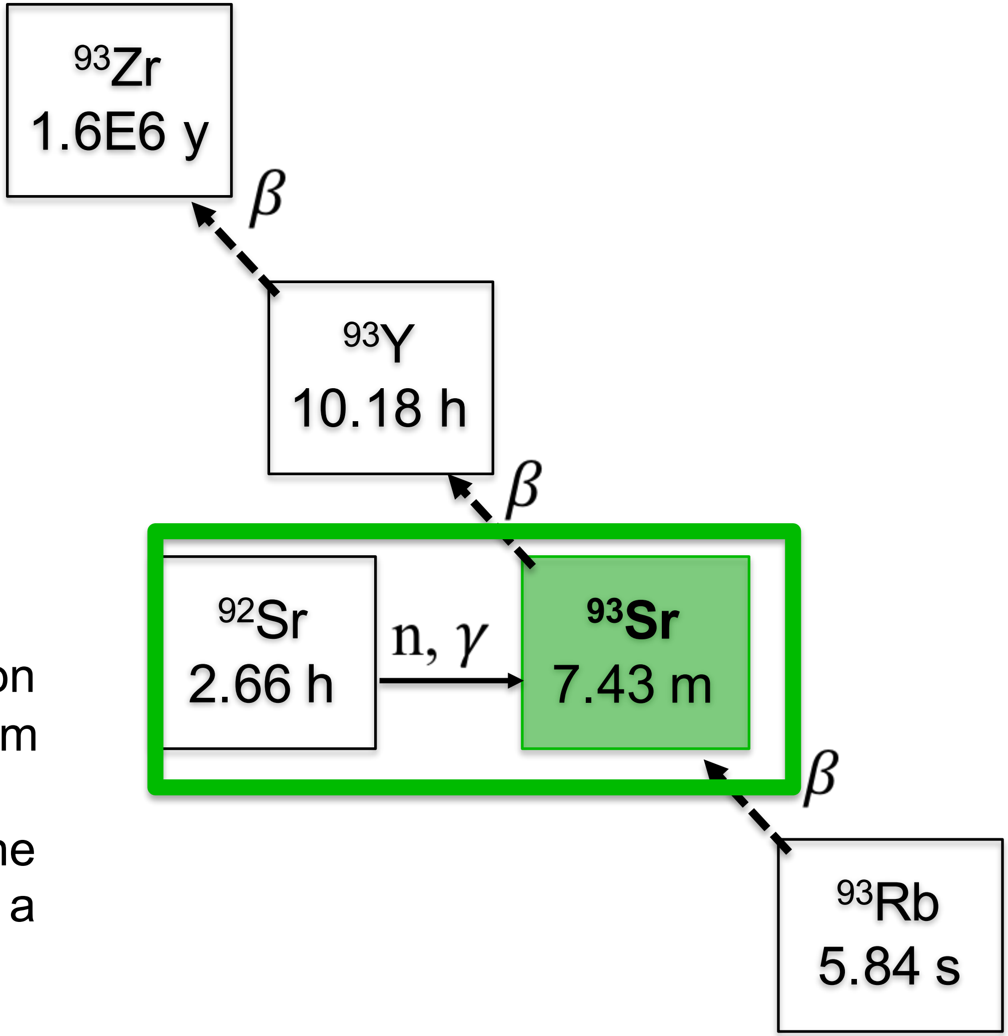
Determining the ^{92}Sr(n,γ) Cross Section

Challenges:

- Compound nucleus ^{93}Sr cannot be formed through neutron capture due to the short half life of ^{92}Sr
- β-decay is a *very selective* decay, populating levels with spin of $0 \leq \Delta J \leq 1$ and no change in parity

Experiment Spring 2018:

- National Superconducting Cyclotron Lab will provide a thermal beam of ^{93}Rb
- Coincidence measurements with the Summing NaI (SuN) detector & a plastic β-particle scintillator



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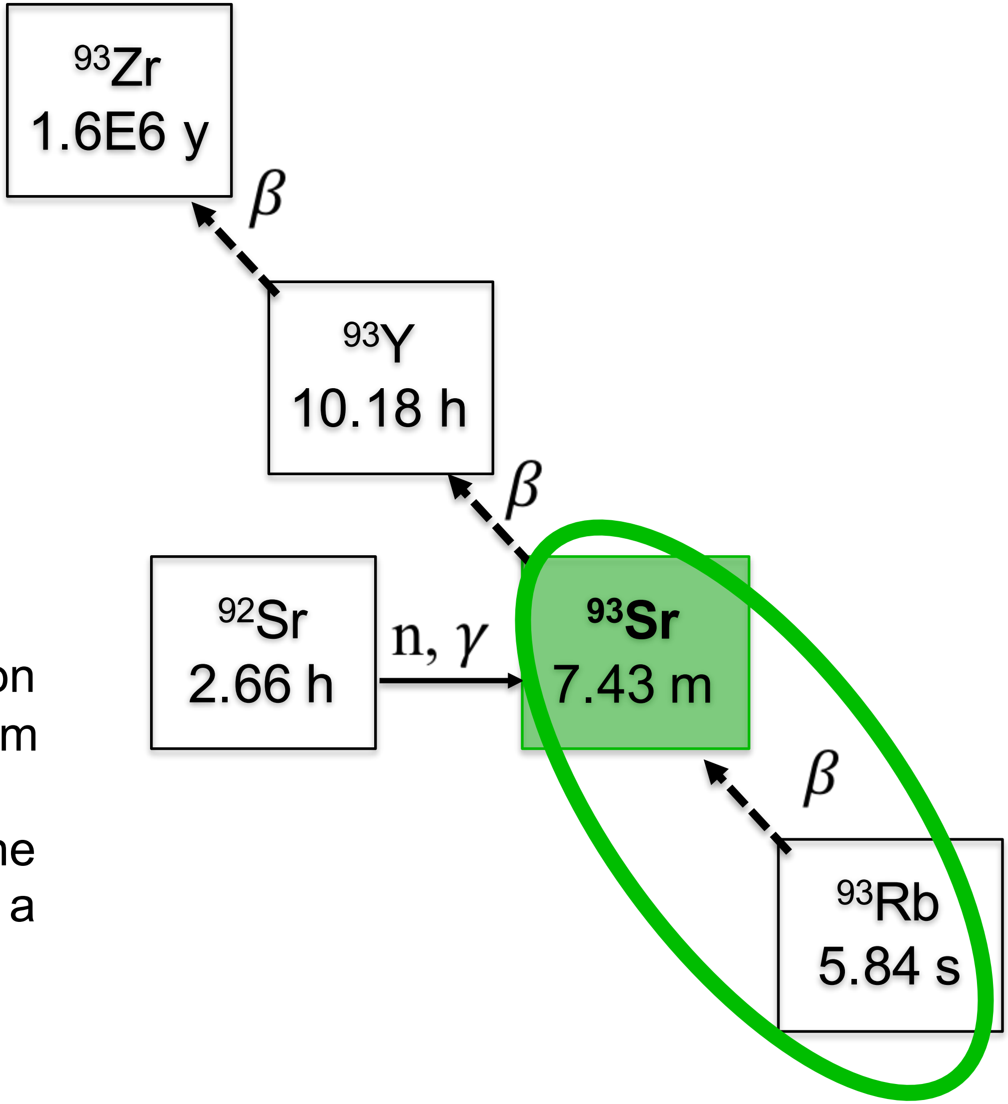
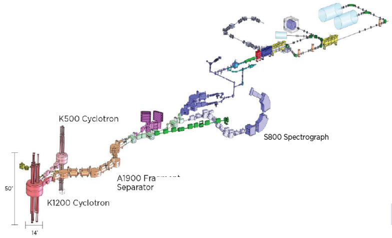
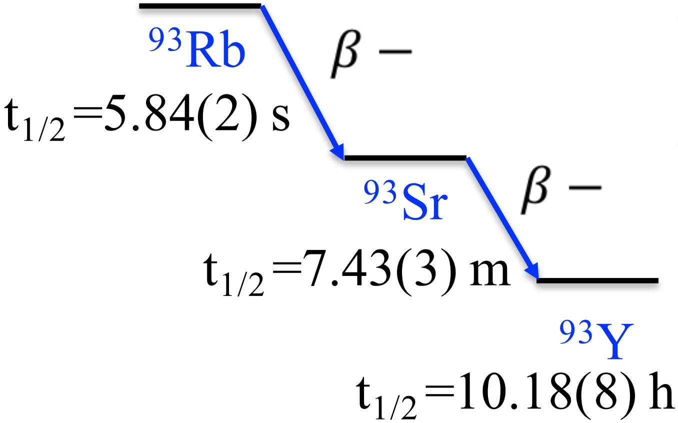




Radioactive Beam: ^{93}Rb



^{93}Rb

$t_{1/2}$=5.84(2) s

$\beta-$

^{93}Sr

$t_{1/2}$=7.43(3) m

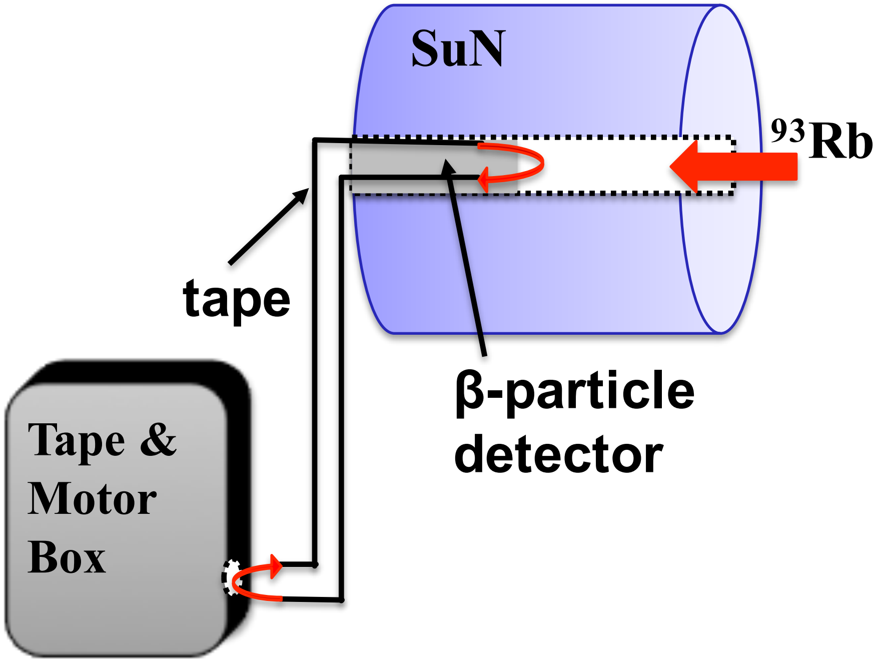
$\beta-$

^{93}Y

$t_{1/2}$=10.18(8) h

- Count rate seen by detector system: R = 2 s^{-1}
- ~10% of the β-decays will populate highly-excited states of ^{93}Sr within 1 MeV of the neutron separation energy, S_n = 5.29 MeV

Removal Time (s)	Contamination (%)	Event Rate (s^{-1})
300	16.39	1.94
120	7.61	1.86
60	3.85	1.72
30	1.84	1.45
20	1.18	1.24
10	0.56	0.83



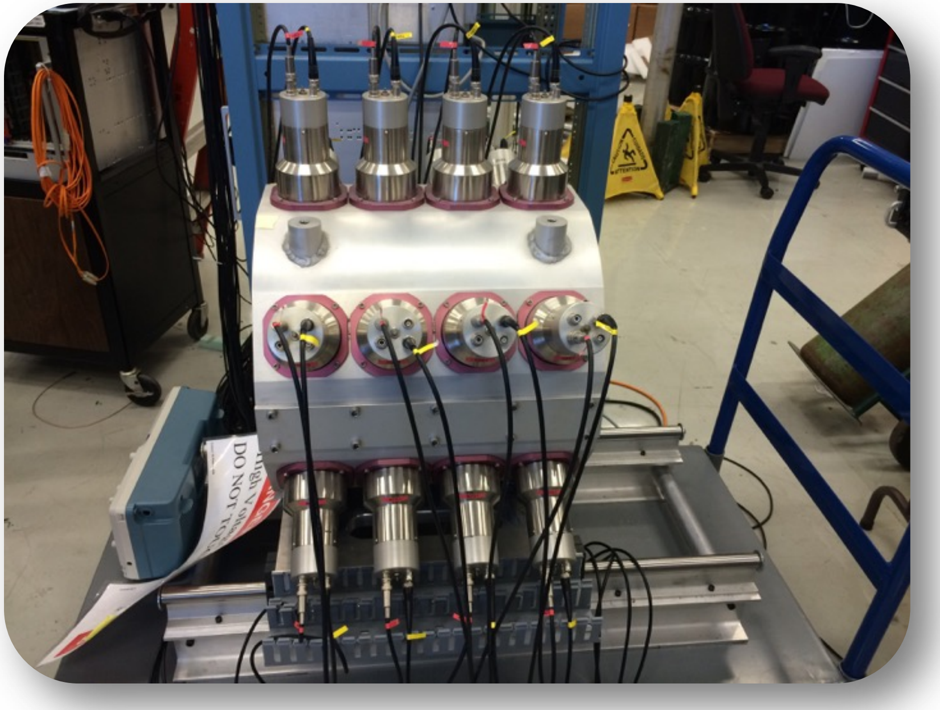
Experimental Set-up

Summing Sodium Iodine (NaI) Detector

- 85% efficiency for a ^{137}Cs source (E_γ = 661 keV)
- High efficiency for γ rays
- 16-in diameter x 16-in length
- 8 optically isolated NaI segments
- Photomultiplier tubes (3 per NaI segment)
- Bore hole (45 mm in diameter)

Plastic β-particle scintillator

- 30% total efficiency
- Length of 8-in
- Located at center of SuN



Summing NaI(Tl) (SuN) Detector

Michigan State University

[A. Simon, S. J. Quinn, A. Spyrou, et al., NIM A703 (2013) 16-21]

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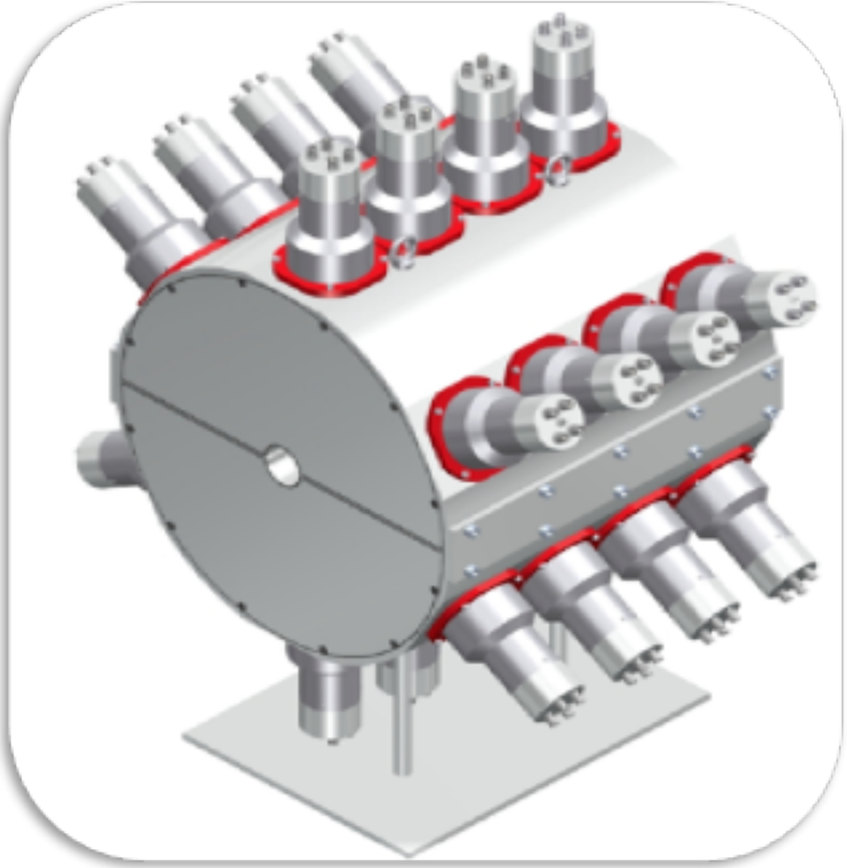

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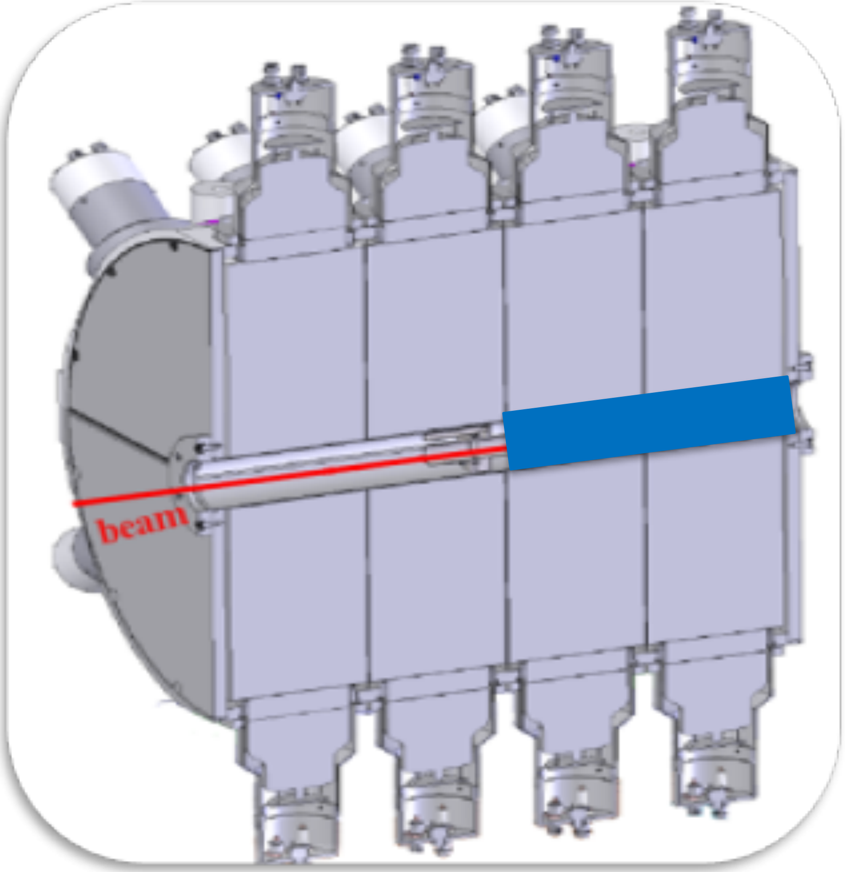

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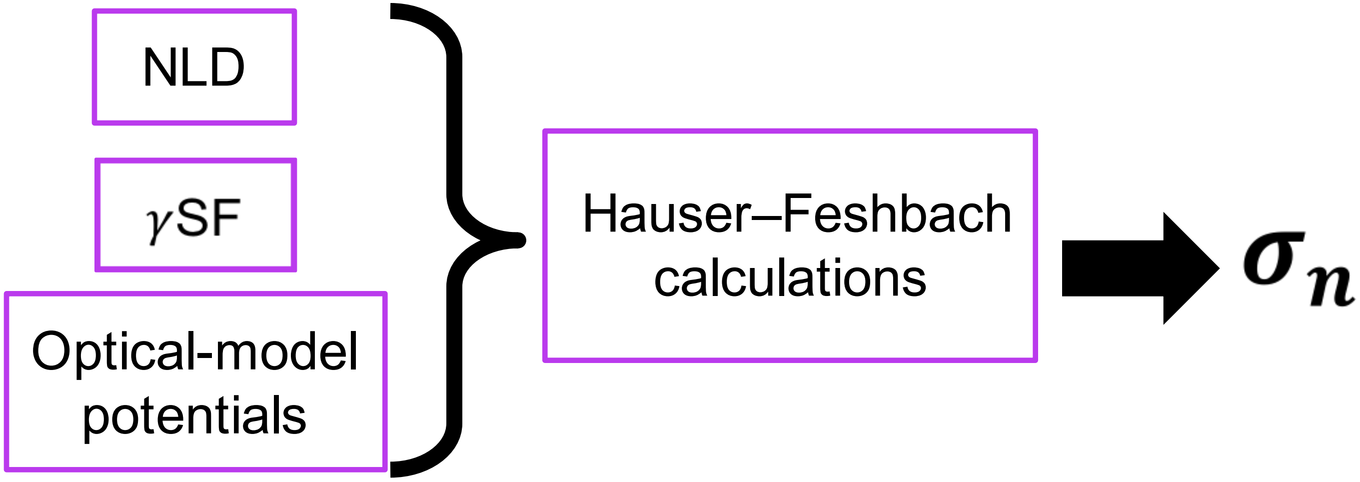
Experimental Set-up

Methodology

β-Oslo Method: a set of methods and techniques for the simulations extraction of the nuclear level density (NLD) and γ-strength function (γSF) from the measured γ energies as a function of excitation energy.

$$P(E_i, E_\gamma) \propto \rho(E_i - E_\gamma)\mathcal{T}(E_\gamma)$$



NLD

γSF

Optical-model potentials

Hauser–Feshbach calculations

$\boldsymbol{\sigma_n}$

Success Stories: ^{75}Ge(n,γ) [A. Spyrou *et al*., Phys. Rev. Lett. 113, 232502 (2014)]
^{69}Ni(n, γ) [S. N. Liddick *et. al.*, Phys. Rev. Lett. 116, 242502 (2016)]

Simulation Space

DICEBOX: Monte Carlo code was used to simulate γ decay

Emitted γ-rays (**DICEBOX**) + Detector response (**GEANT4**) → Extract NLD and γSF (**β-Oslo**)

Nuclear data libraries contain **no** experimentally determined:

- Nuclear Level Density ← Constant Temperature (CT) Formula
- Giant Dipole Resonance ← RIPL-3
- Neutron Resonance parameters ← Level density at S_n & regional systematics

Simulation Space

1. Unfold the detector response

2. First generation extracted

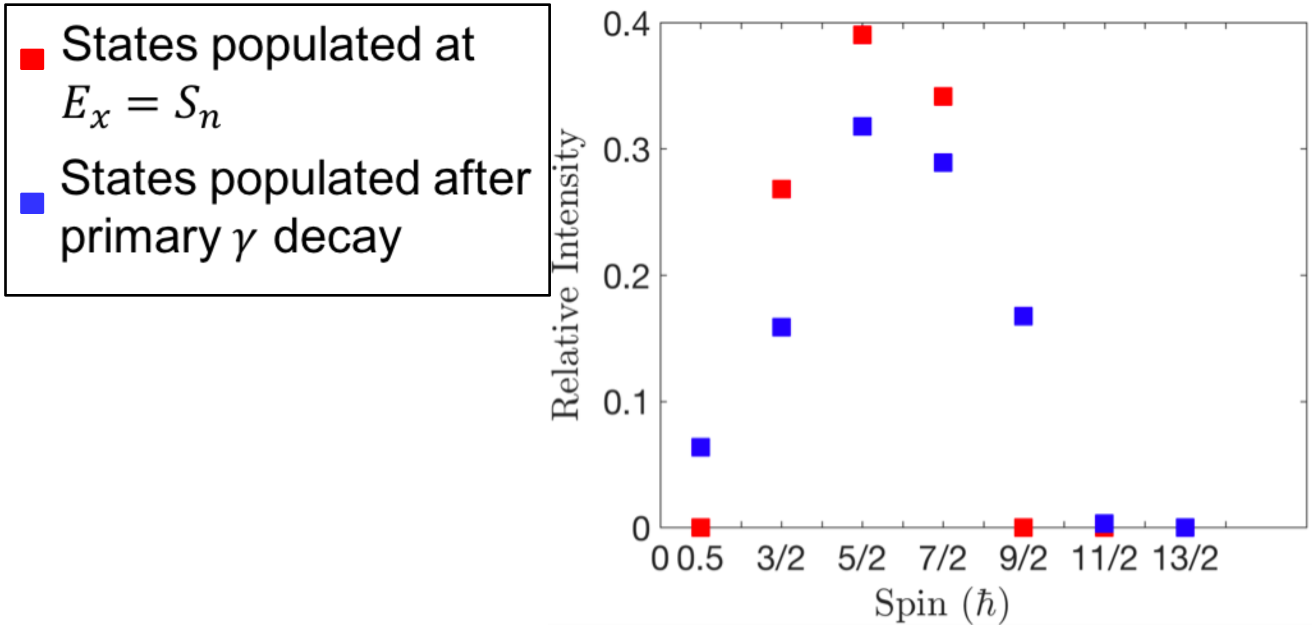
3. NLD & γSF extracted

4. Normalize NLD & γSF

Challenges:

- **β-decay** as described by **Gamow-Teller Allowed Decays** restricts the spin J range and parity π of initial excitation-energy levels

- Discrete states in ^{93}Sr below 2MeV (**14 levels**) are outside $\frac{3}{2} \leq J \leq \frac{7}{2}$, $\pi = 1$



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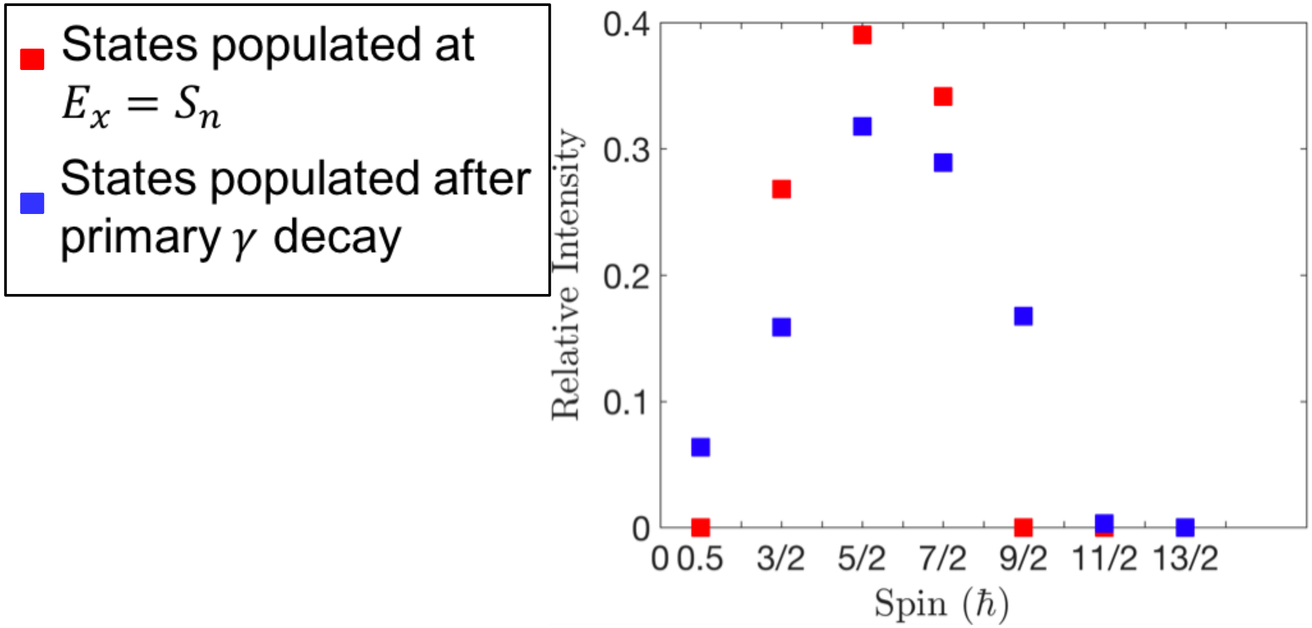
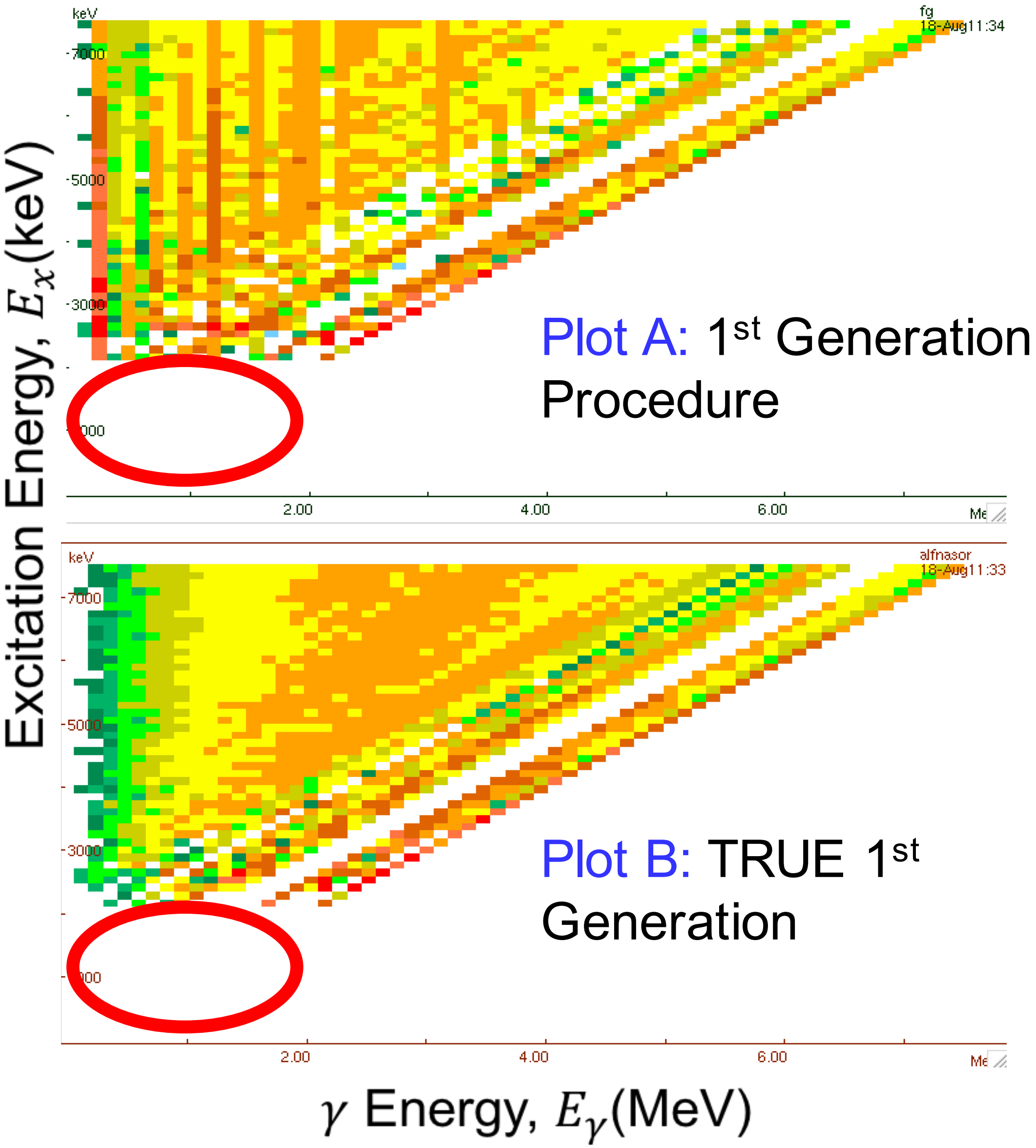


First generation extracted



Plot A: 1^{st} Generation Procedure

Plot B: TRUE 1^{st} Generation

- Plot A: 1st generation γ's obtained by Oslo Method from simulated data set
- Plot B: true 1st generation γ's from simulated data set
- Excitation bins from 0 to 2MeV are not initially populated by β decay, so there are no primary γ transitions from these bins.

So you can't trust your results below E_γ = 2 MeV!

Extracted & Normalized NLD

Nuclear Level Density

Does the extracted NLD match input parameters?

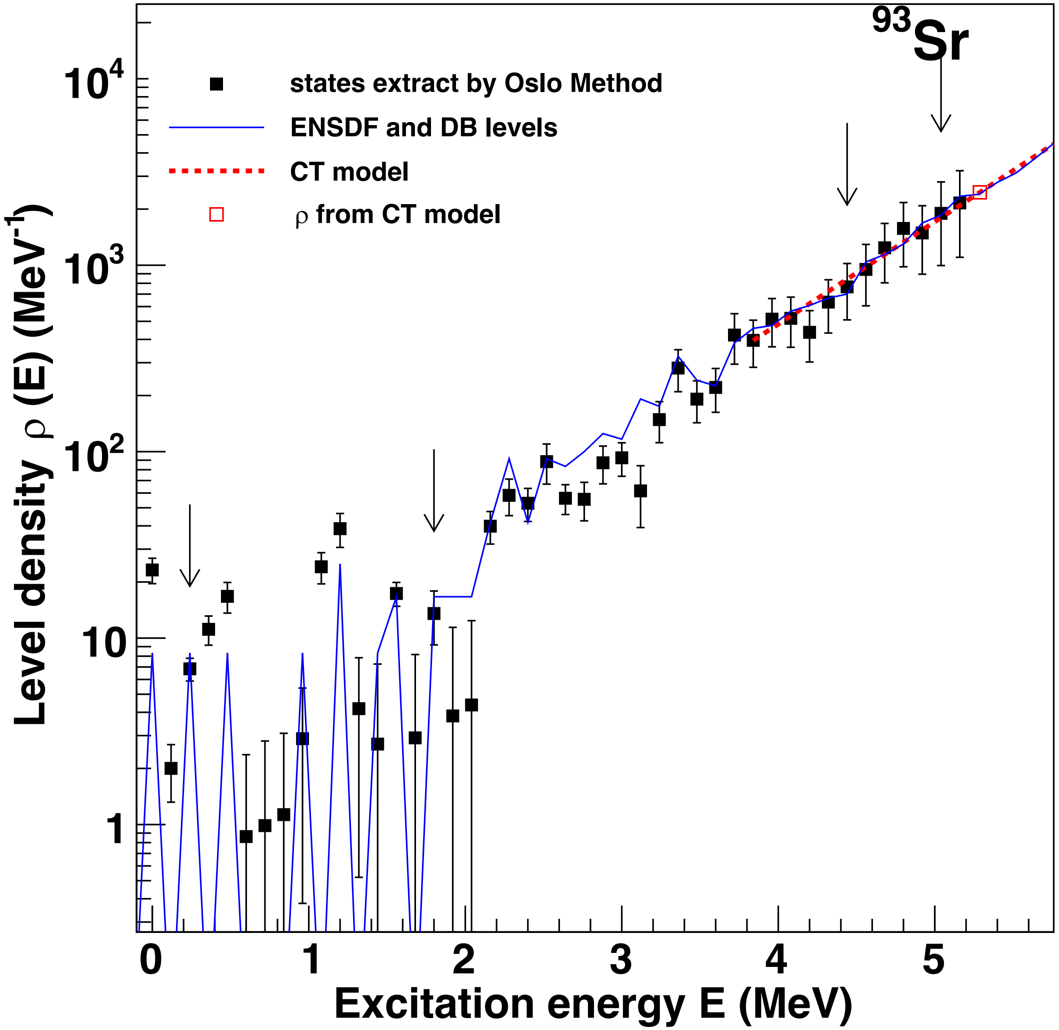
Constant Temperature Formula:

$$\rho_{CT} = \frac{e^{(E_x - E_0)/T}}{T}$$

von Egidy & Bucurescu [PRC 80, 054310 (2009)]

Next Step: γSF normalization

- Shape is determined by the normalization of the NLD.
- Absolute normalization is determined by total mean radiative width at the neutron separation energy.



Summary & Future Work

- Analyzed a simulated data set of γ rays emitted by ^{93}Sr to predict the experimentally-observed behavior
- Fold in the response function of the SuN detector to the simulated emitted γ rays
- First generation γ's are incorrectly extracted—develop a method to overcome challenge of incomplete population of excitation energies from 0 MeV to S_n
- Improve the absolute normalization of the γSF by anchoring it to available data
- Motor and tape box is completed. Commissioning run: **Dec. 8th at MSU**
- Experiment: **SPRING 2018!**

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Disclaimer

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