FLORIDA STATE UNIVERSITY

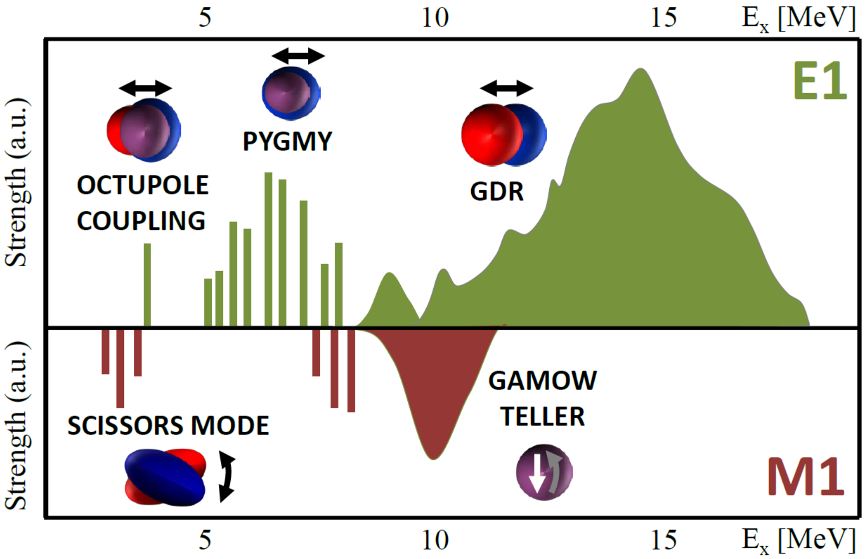
# Opportunities for studying the Pygmy Dipole Resonance at FRIB

M. Spieker

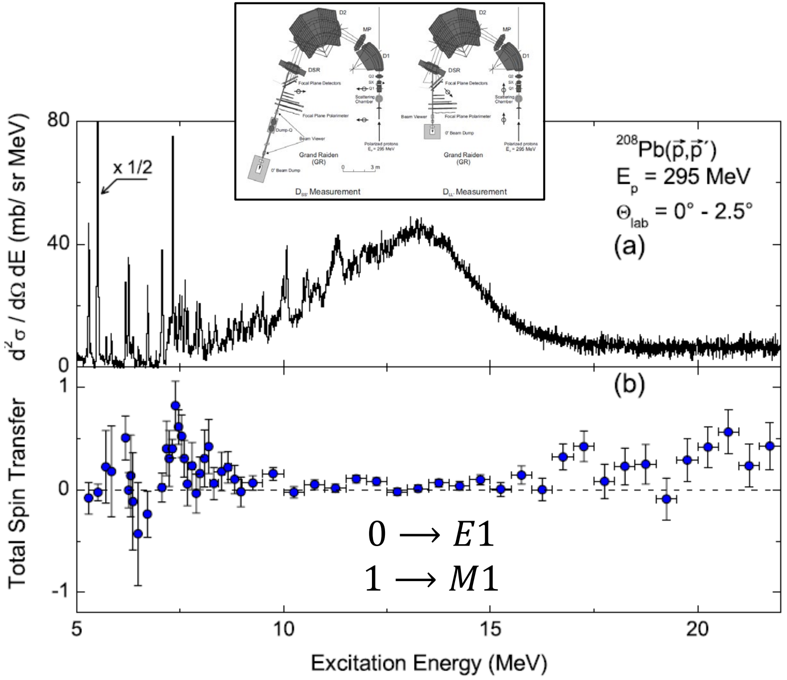
Theoretical Justifications and Motivations
for Early High-Profile FRIB Experiments, FRIB-TA, May 2023

# Dipole strength distribution in nearly spherical atomic nuclei

## Cartoon vs. Reality




Courtesy of A. Zilges (University of Cologne);
see older version in FRIB400 white book

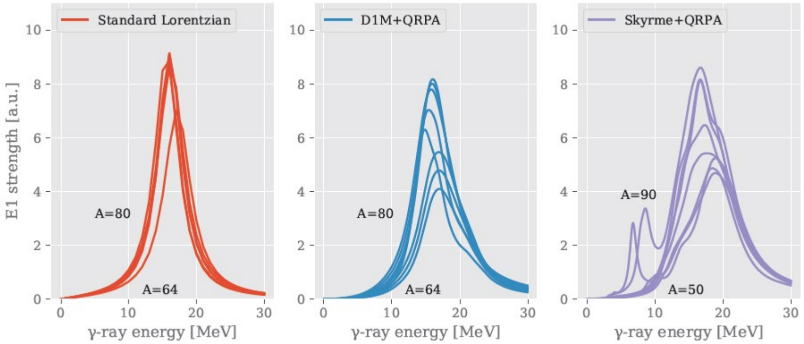



A. Tamii et al., PRL **107**, 062502 (2011)

# Existence of PDR can influence (n,γ) rates of nuclei involved in the *r* process

## Different theoretical γSF for Zn isotopes

Implemented in TALYS code

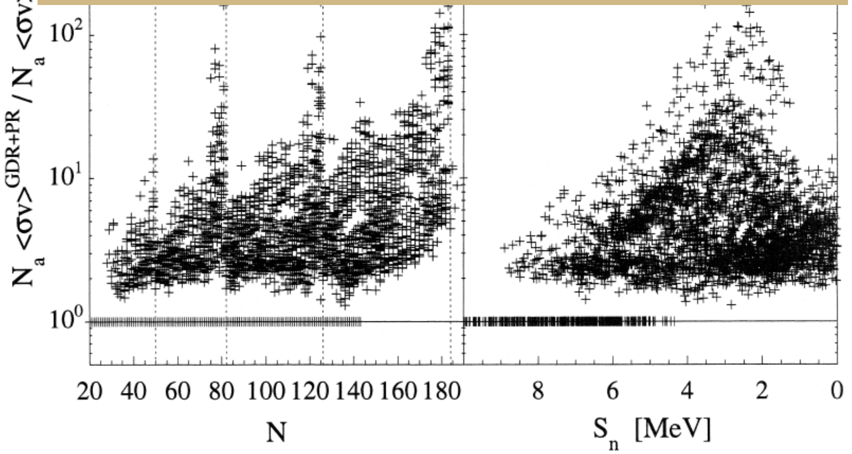



... Some γSFs have no low-lying E1 or M1 component, only a “tail” of the IVGDR.

[**Figure 1:** P. Scholz, PhD thesis, University of Cologne (2019)]
[**Figure 2**: S. Goriely, PLB **436** (1998) 10]
[**Review article:** A.C. Larsen *et al.*, PPNP **107**, 69 (2019)]

## Variations of up to a factor of 100!

Influence of the γ-ray strength function

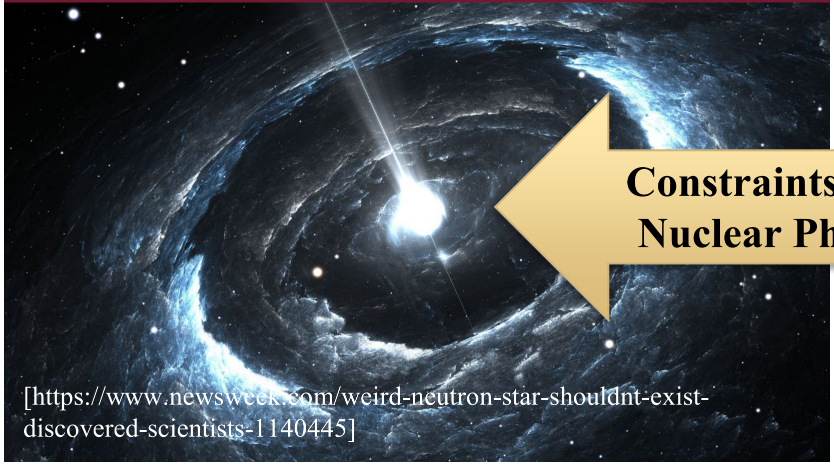



**Nuclear physics input:**

- Masses
- β-decay: $T_{1/2}$, $P_n$
- **(n,γ) rates**
- Fission rates/yields

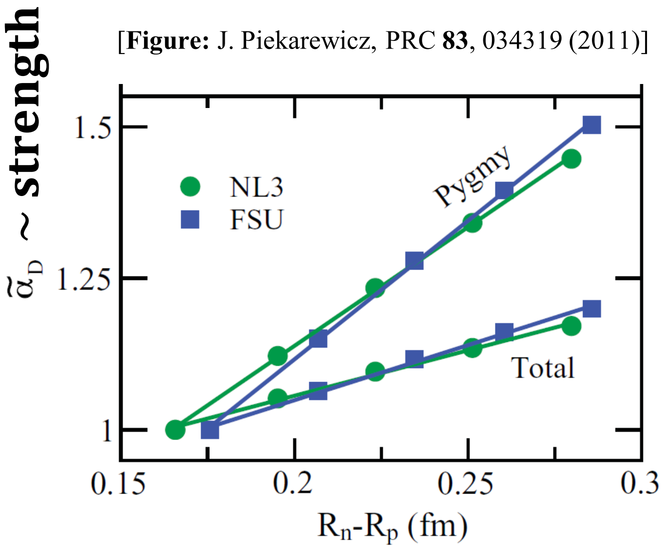
# Neutron-star radii and properties – Insights from Nuclear Physics

## How big is this thing?




**Constraints from Nuclear Physics**

[**Figure:** J. Piekarewicz, PRC **83**, 034319 (2011)]




**= neutron – skin thickness**

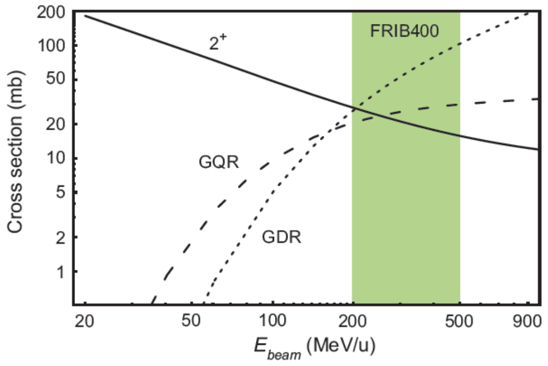
Measure the neutron skin ($10^{-16}$ m) and constrain possible neutron-star radii ($10^{4}$ m)

20 orders of magnitude difference

# Studying the low-lying E1 strength at FRIB? (Isovector and isoscalar strength)

## CoulEx after 400 MeV/u upgrade

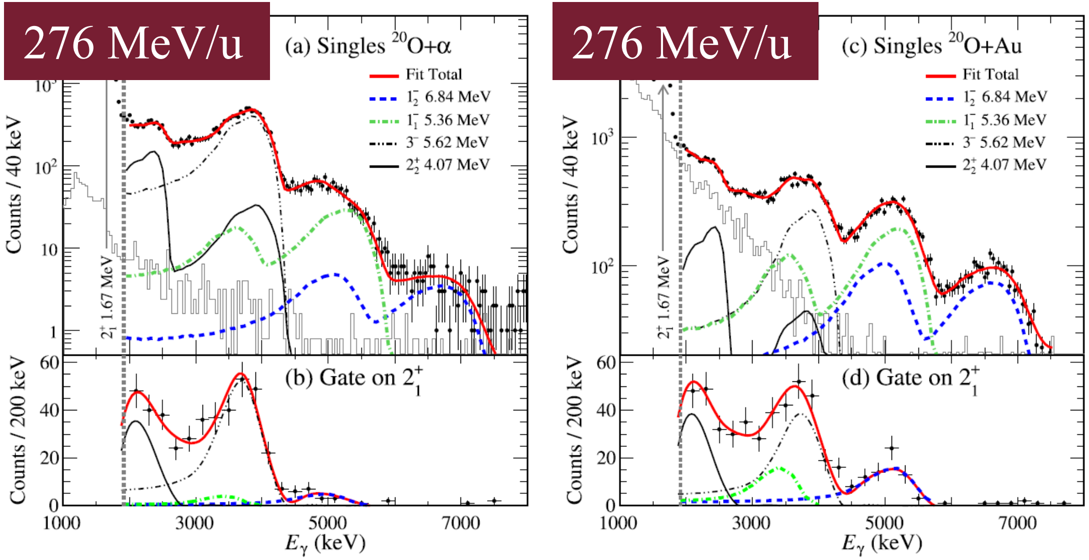
[FRIB400 White Paper]




We might need to wait until the FRIB400 upgrade but with GRETA we should get quite a boost in resolution!

PDR?

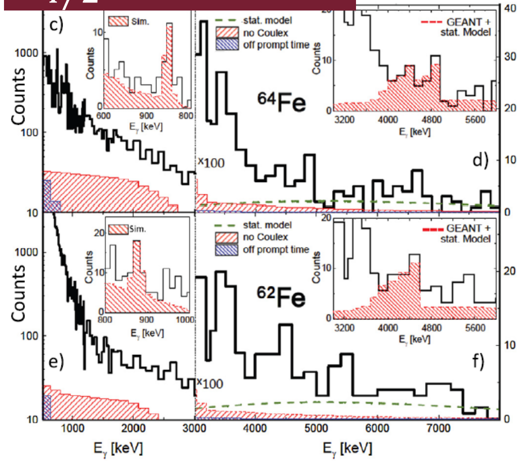
Two lowest 1⁻ states in $^{20}$O @ RIKEN



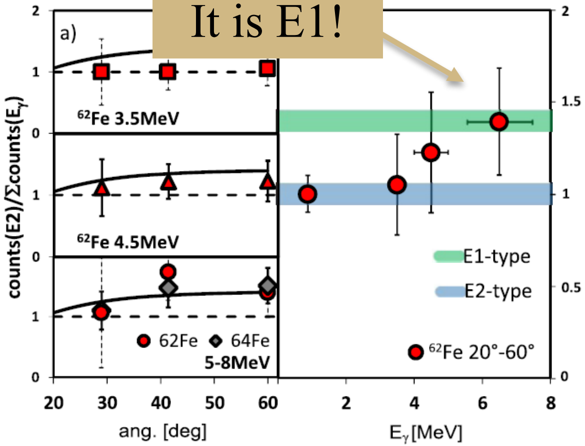

[N. Nakatsuka *et al.*, PLB **768**, 387 (2017)]

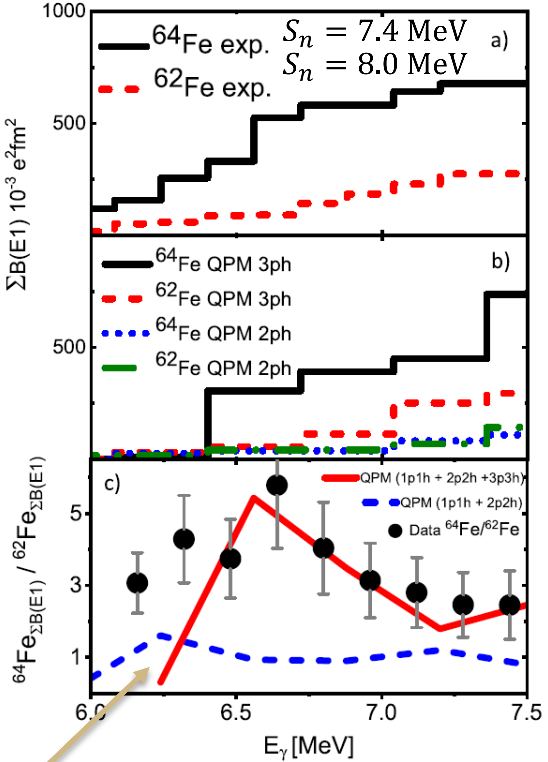
# In search of statistics: Future PDR studies at RIB facilities

$R_{4/2} = 2.4 - 2.5$




It is E1!




With AGATA@GSI (5 triple and 3 double clusters)

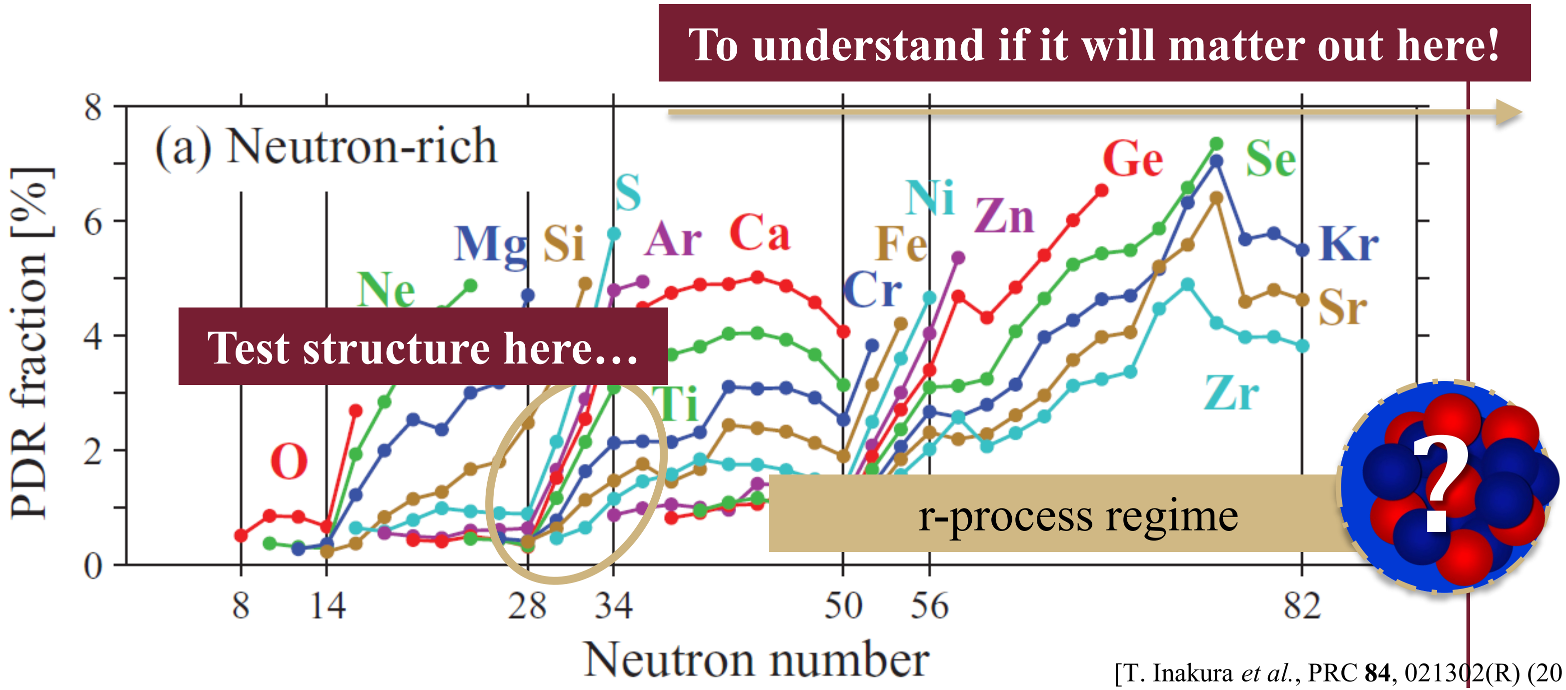
Complex analysis to estimate background & continuum analysis

[R. Avigo et al., PLB **811**, 135951 (2020)]

$^{86}$Kr primary beam up to $8 \times 10^9$ pps. Total of $1.4 \times 10^5$ for $^{64}$Fe and $1.8 \times 10^6$ for $^{62}$Fe detected. $E_{beam}$ = 700-900 MeV/u.

**Up to 3p-3h excitations needed to describe low-lying E1 strength!**

# Strength of PDR might be connected to occupation of low-*l* single-particle orbits



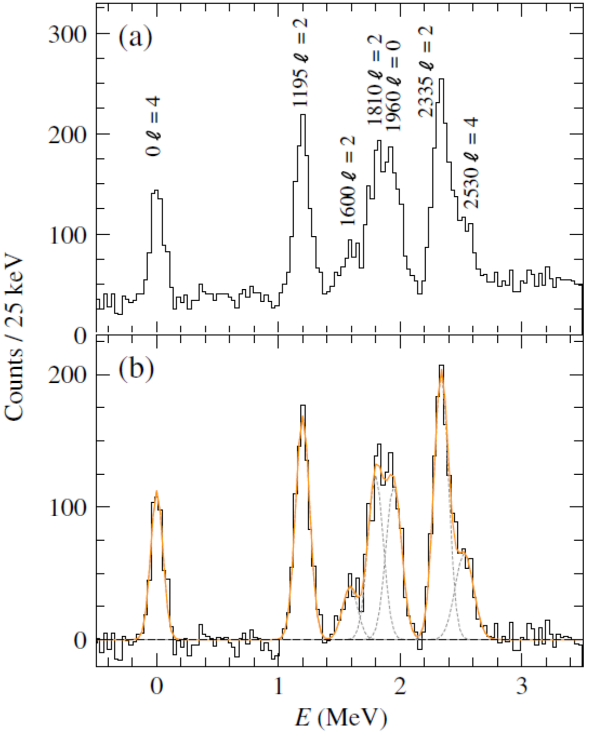

[T. Inakura *et al.*, PRC **84**, 021302(R) (2011)]

So, how do we test that? How about we start "easy" and not too exotic?
We will probably need to make a good case to convince the PAC.

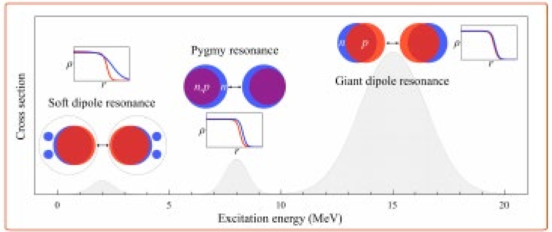
# Single-particle structure studies of PDR with solenoidal spectrometers?

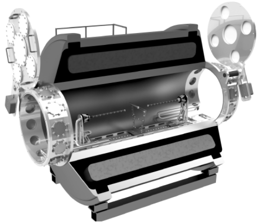
A proposal

$^{206}$Hg(d,p)$^{207}$Hg with ISS@CERN
(inverse kinematics; $^{206}$Hg is beam; ~ 7 MeV/u)



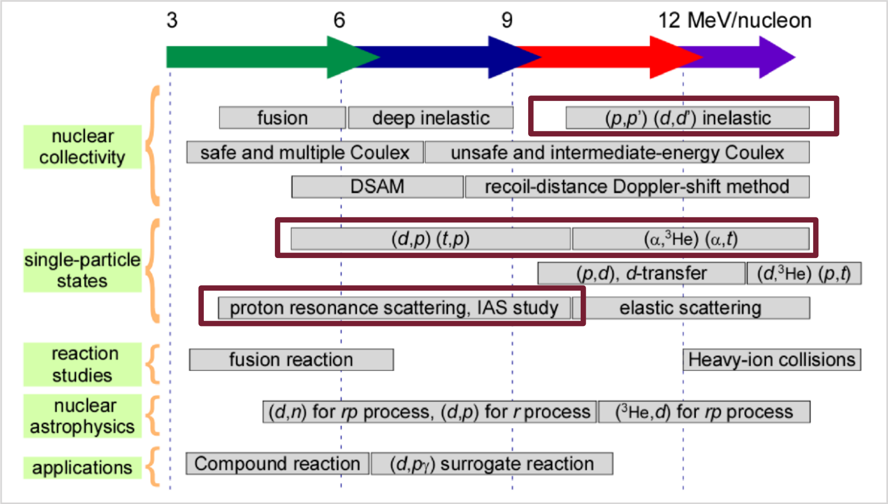

[T.L. Tang, B.P. Kay, C.R. Hofmann, *et al.*, PRL **124**, 062502 (2020)]



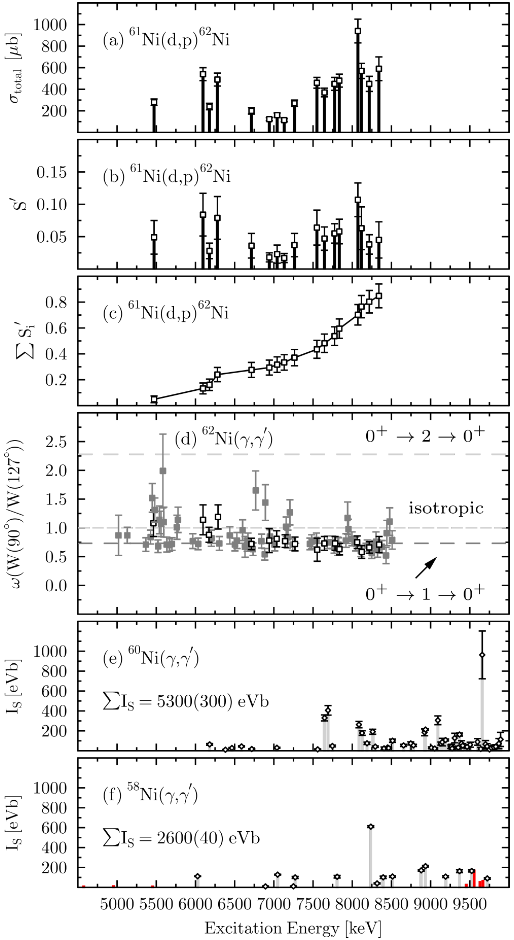
## ReA stages @ FRIB

[SOLARIS White Paper]




of interest for PDR studies

# Use one-neutron (d,p) transfer reaction for carefully chosen “target” nucleus




**Example of $^{61}$Ni(d,p)$^{62}$Ni measured at FSU SE-SPS**

- Spectroscopic strength is already significantly fragmented. For the strongest states, the SF does not exceed ~0.1.
- E1 strength is also strongly fragmented in $^{58,60}$Ni.

[MS *et al.*, submitted for publication (2023)]

→ So, why not choose an easier case than this first?

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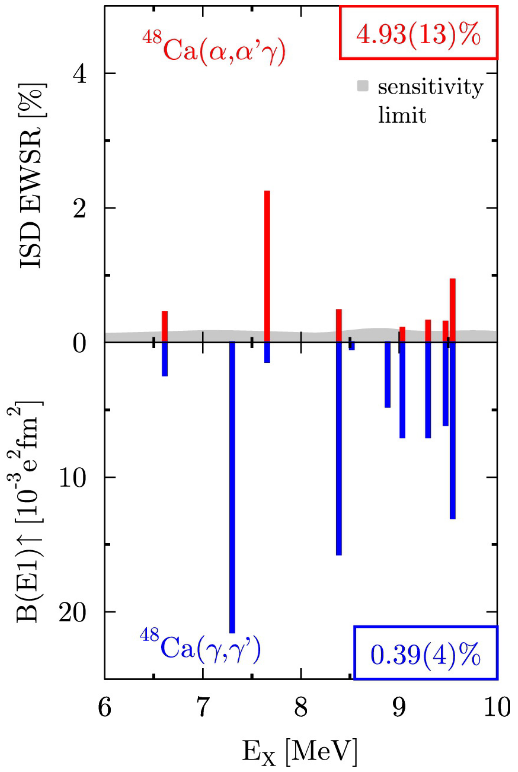


[V. Derya *et al.*, PLB **730**, 288 (2014)]

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## How about $^{50}$Ca populated through $^{49}$Ca(d,p)?

- $^{49}$Ca has known $J^\pi = 3/2^-$ ground state.

→ $J^\pi = 1^-$ states would be populated through $l = 0$ and $l = 2$ angular momentum transfers.

- $^{50}$Ca should be nearly spherical. Thus, the $3/2^-$ should correspond to a $2p_{3/2}$ configuration.
- E1 strength is not known but $^{48}$Ca is well studied. We will, thus, need theoretical calculations.

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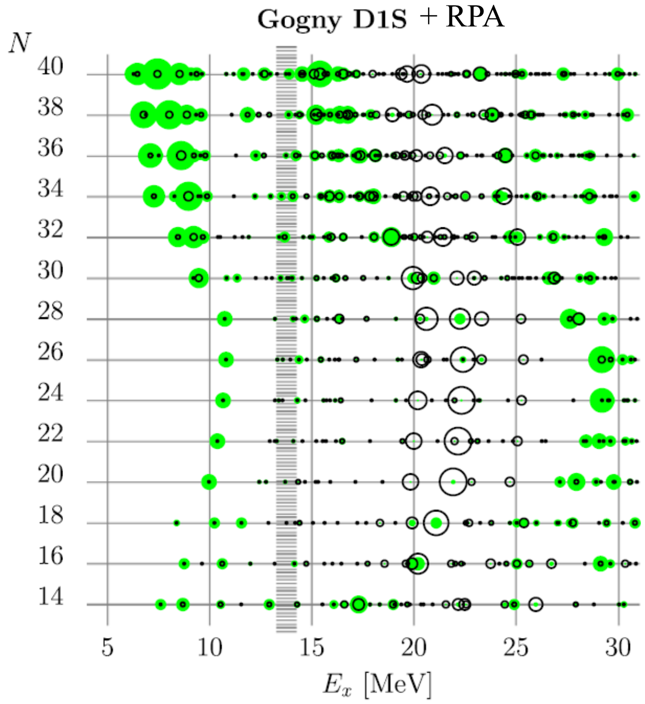
Ca isotopes




[P. Papakonstantinou *et al.*, PLB **709**, 270 (2012)]

Green: Isoscalar strength
Black: Isovector strength

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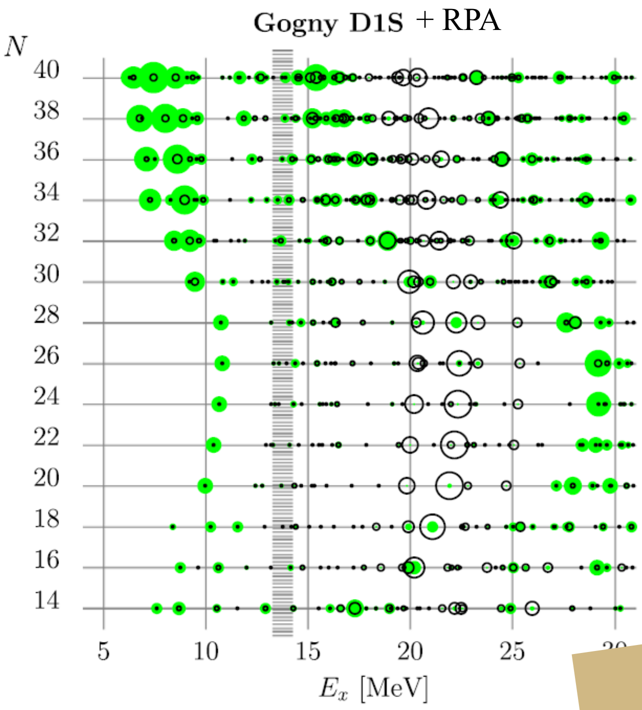


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and $l = 2$ an

Reaccelerated beam rate > $10^6$ pps for $^{49}$Ca!
(10-kW estimate)

$2p_{3/2}$ configuration.

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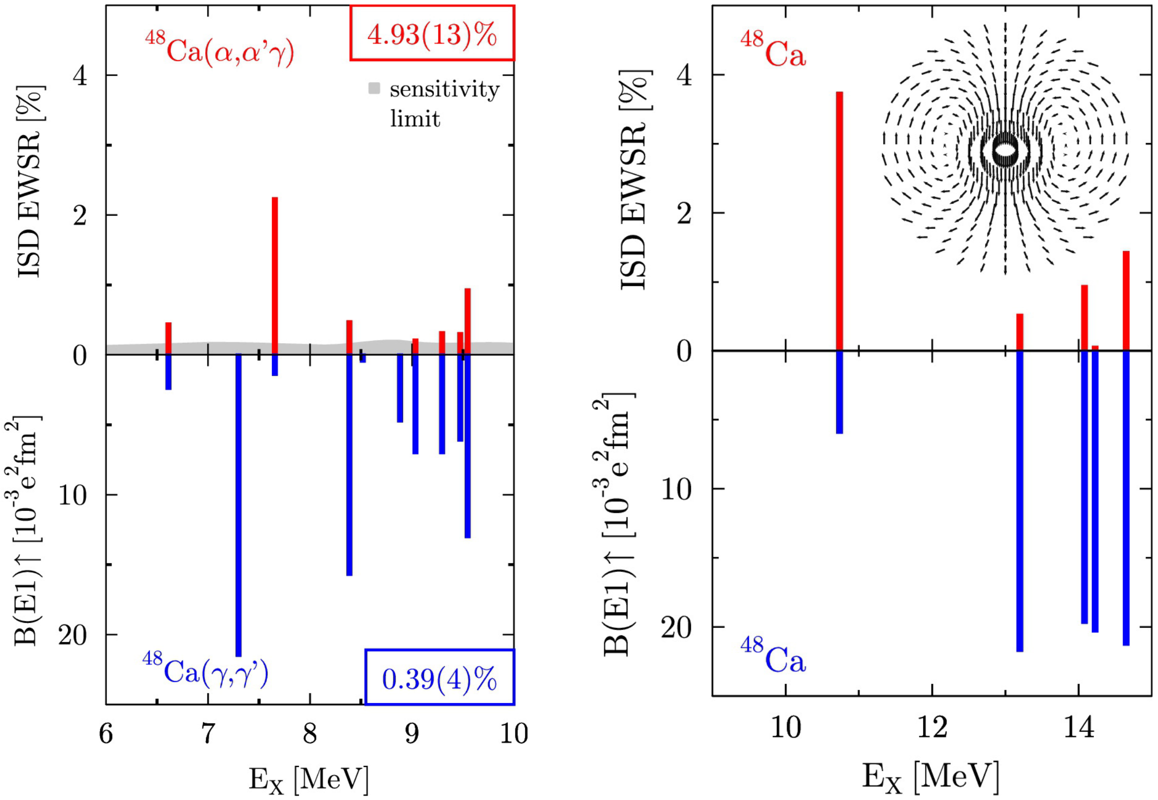
# Level of agreement between theory and experiment for $^{48}Ca$

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