Lawrence Livermore National Laboratory

Physical Sciences

Narrowing of the neutron *sd-pf* shell gap in ^{29}Na

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Kernz 08: Interfacing Structure and Reactions at the Centre of the Atom

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Overview

Motivation:

- Why measure ^{29}Na [$T_{1/2}$ = 44.9 ms]?

Experimental highlights:

- TRIUMF/ISAC-II + TIGRESS/BAMBINO
- Coulomb excitation of ^{29}Na @ 70 MeV on ^{110}Pd

Results and interpretation:

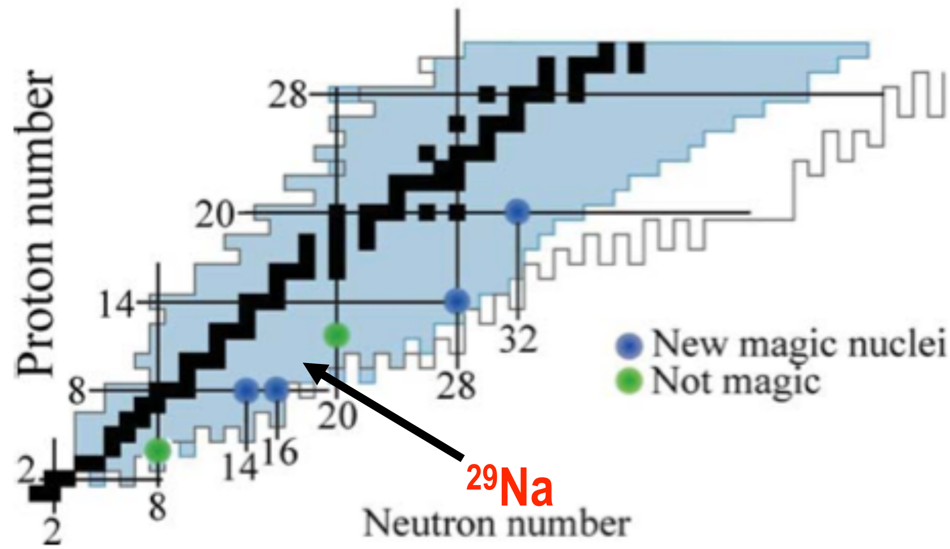
- coincident γ-ray spectroscopy of ^{29}Na
- $\mathcal{M}(E2; 3/2^+ \rightarrow 5/2^+)$ value for ^{29}Na
- structural implications for ^{29}Na

Summary and outlook

Physical problem: ^{29}Na

Motivation:

- Test predictive capability of *modern* nuclear theory
- ^{29}Na is at the transitional region for breakdown of *traditional* shell model
- Magic number *N* = *20* vanishes for exotic nuclei (extreme *N/Z* ratio)



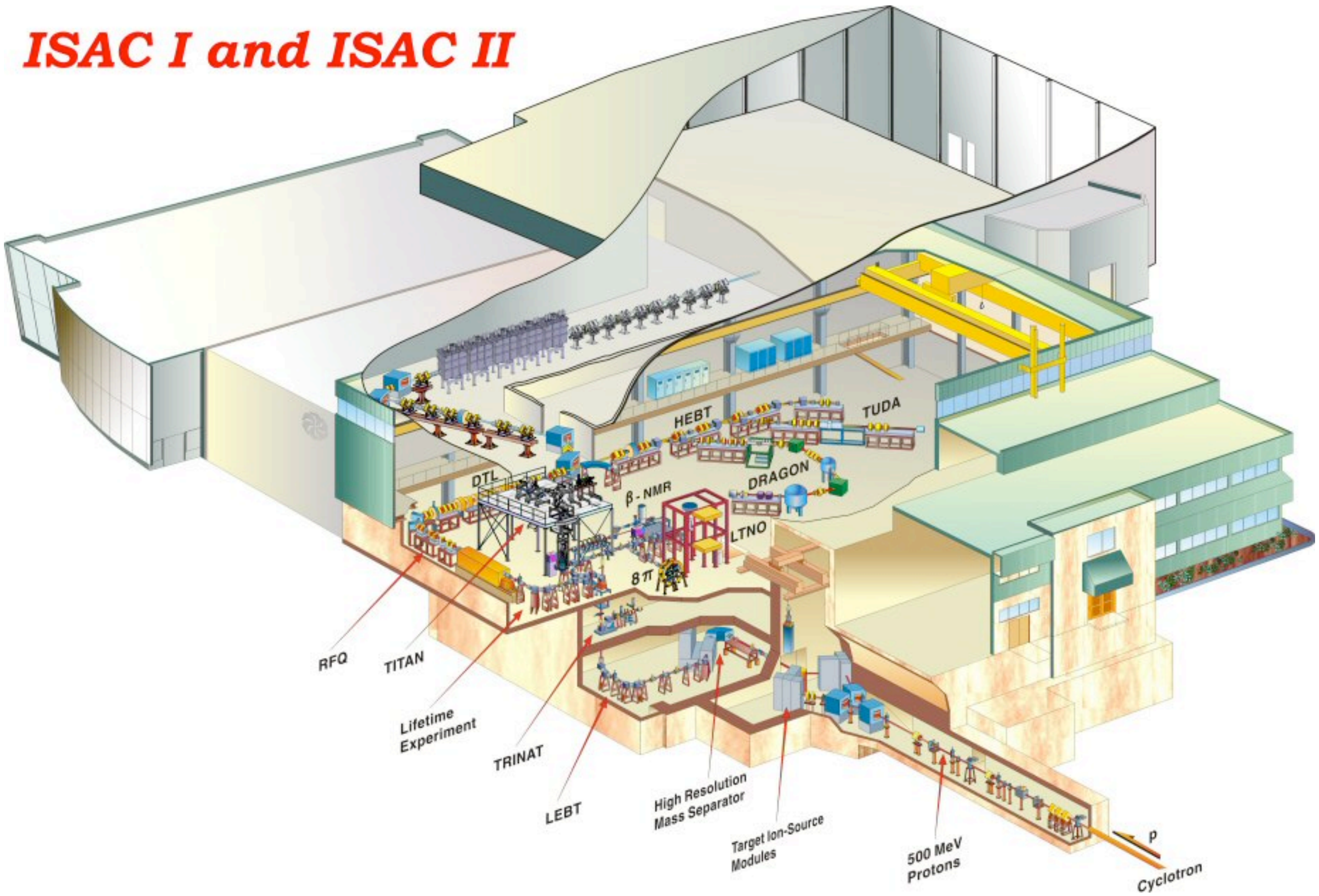
Goal:

- Quantify the configuration mixing between the *sd* and *pf* major shells in ^{29}Na
- Measure transition *M(E2)* to first excited state in ^{29}Na; sensitive to strength of shell gap

Methodology:

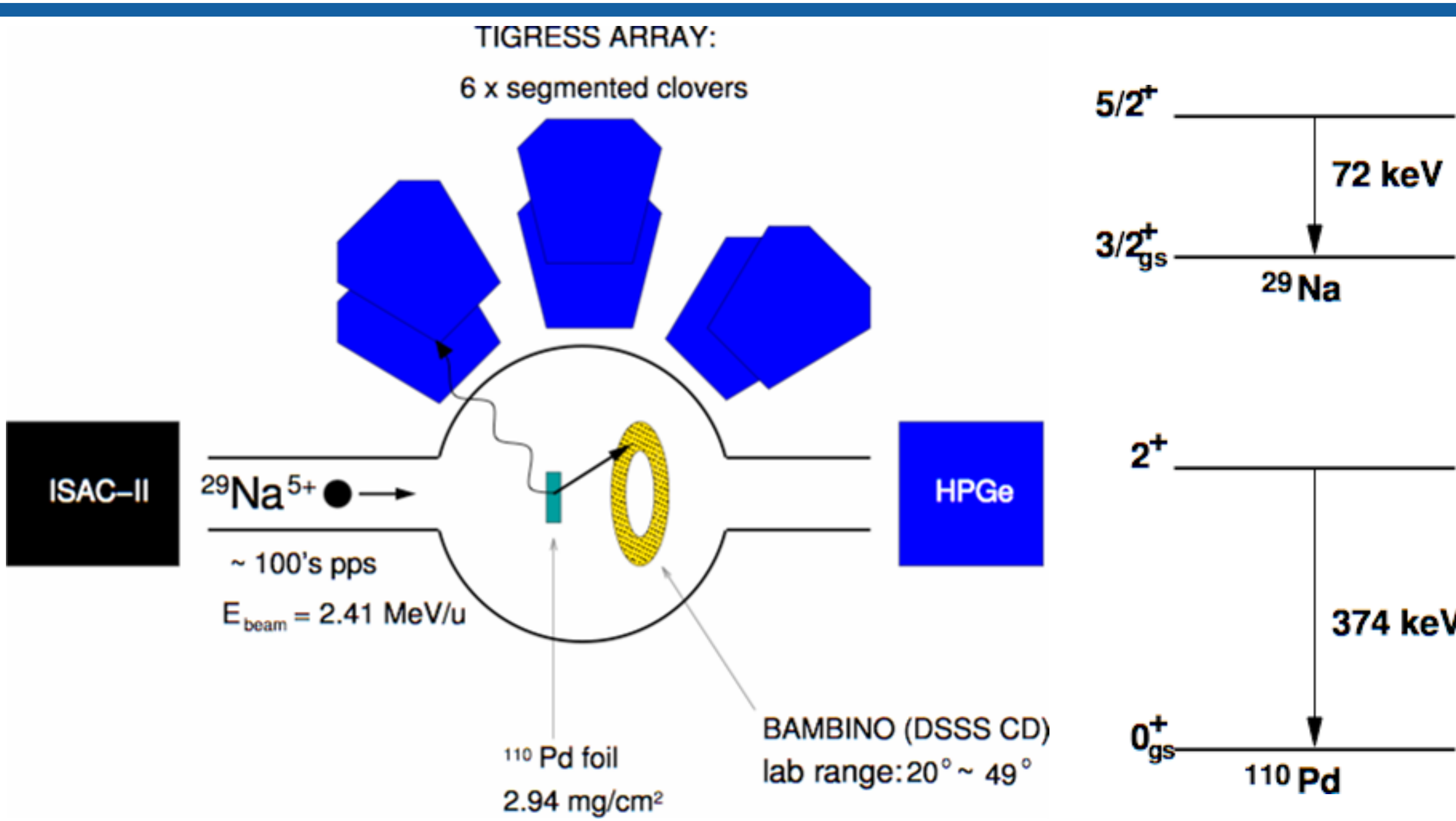
- Sub-barrier Coulomb excitation (Coulex)
- Post accelerated radioactive beam of neutron-rich ^{29}Na @ TRIUMF/ISAC-II

ISOL @ TRIUMF



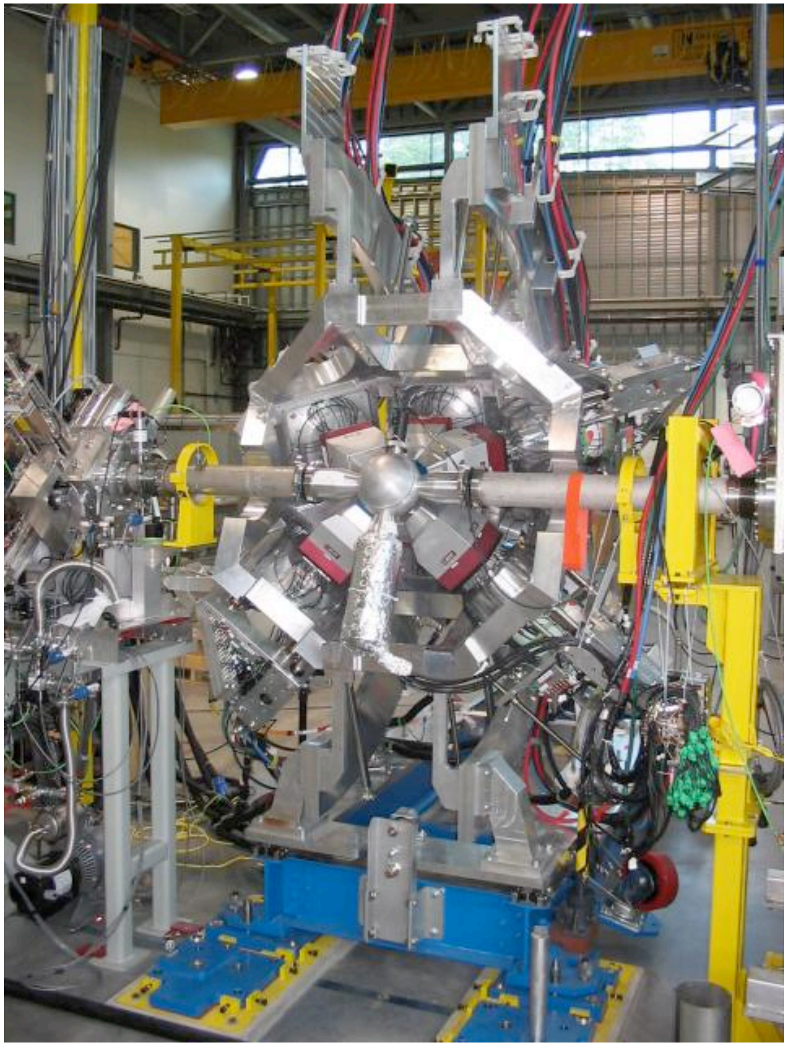
- 500 MeV, 70 μA proton beam + ^{nat}Ta production target
- Produce ^{29}Na atoms
- ^{nat}Re surface-ion source
- Produce $^{29}Na^{+}$ ions
- Stripper foil
- Produce $^{29}Na^{5+}$ ions
- ISAC-II: A/q = 5.8

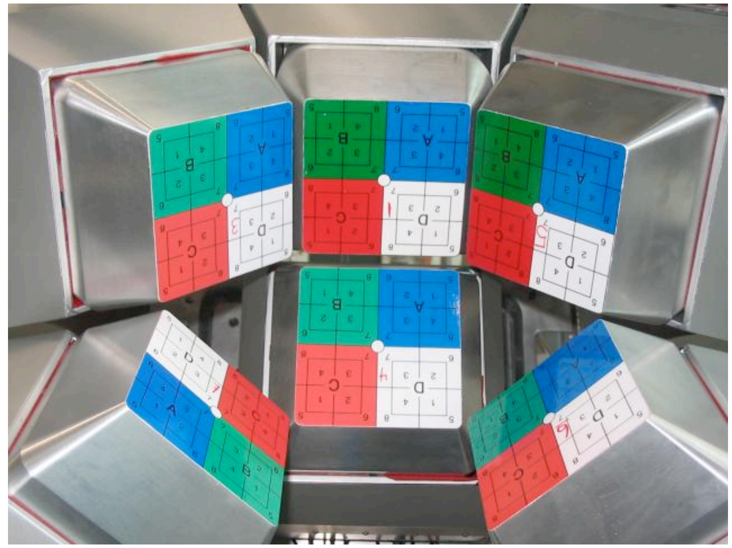
Experimental setup: ^{110}Pd(^{29}Na,^{29}Na*) @ 70 MeV



Measure particle-γ coincidences

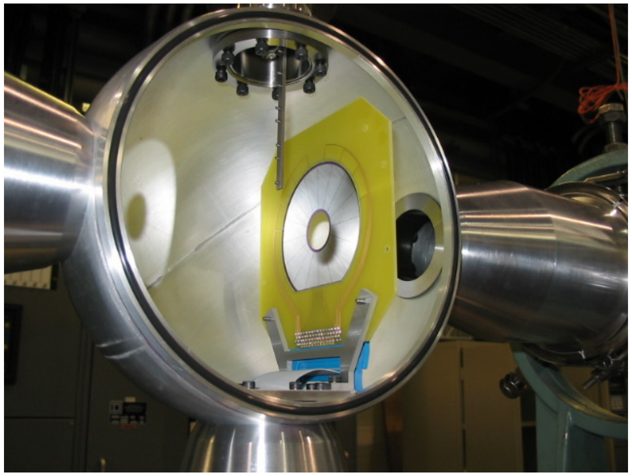
TIGRESS γ-ray spectrometer

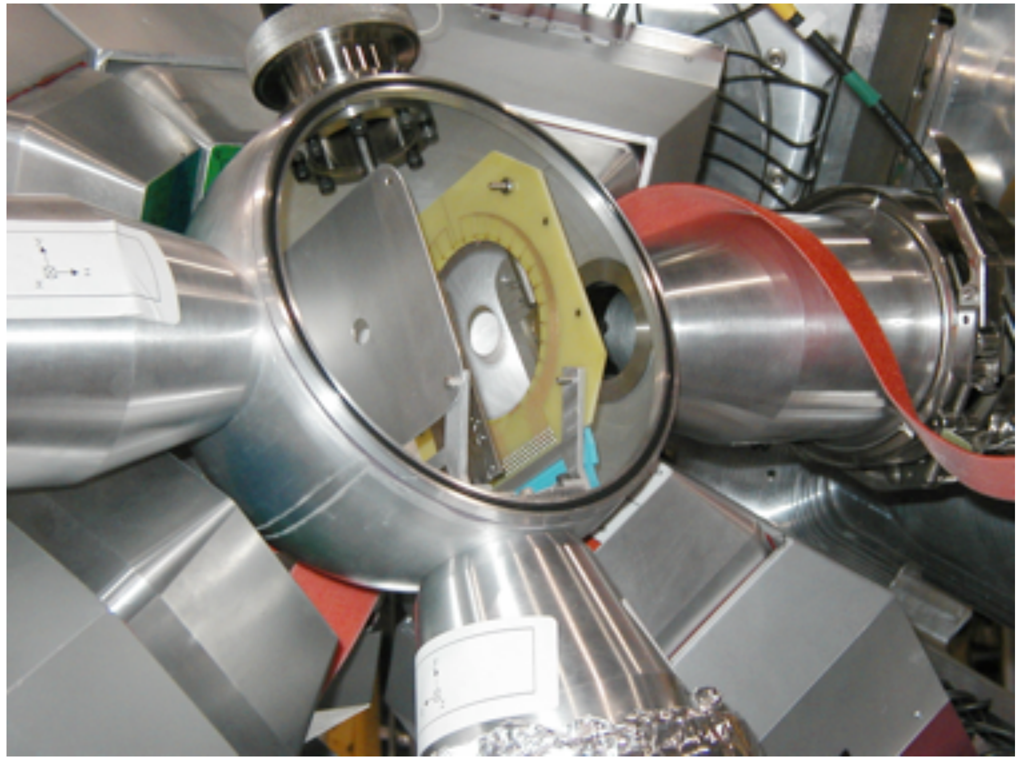




- 6 x 32-fold clover detectors
- Each clover mounted with segmented suppression scintillators (BGO and CsI)
- Close geometry around target chamber
- ~36 % of 4π

BAMBINO auxiliary particle detector

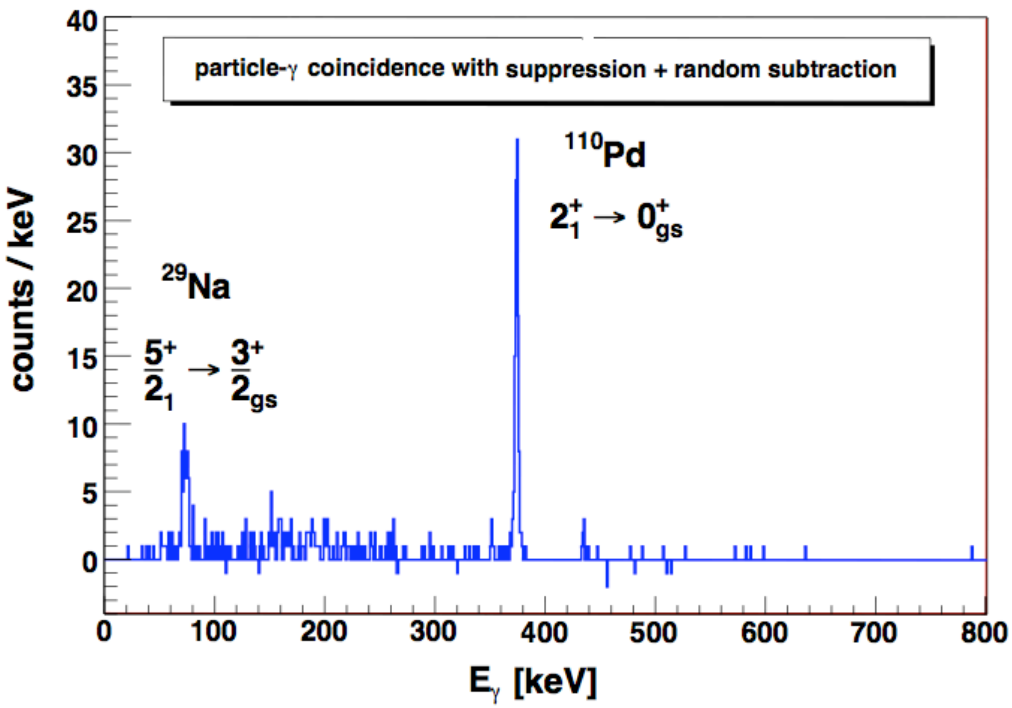


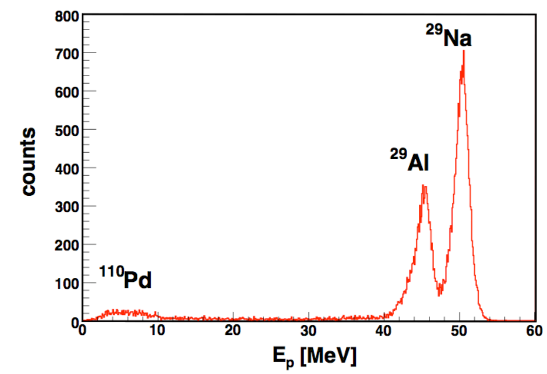


- Provided by LLNL
- Segmented DSSSD for heavy-ion detection: scattered beam and recoiling target particles
- Front face: 32 x sector strips
- Back face: 24 x annular rings

Coulomb excitation of ^{29}Na + ^{110}Pd @ 70 MeV

Any particle-γ coincidence: projectile + recoil





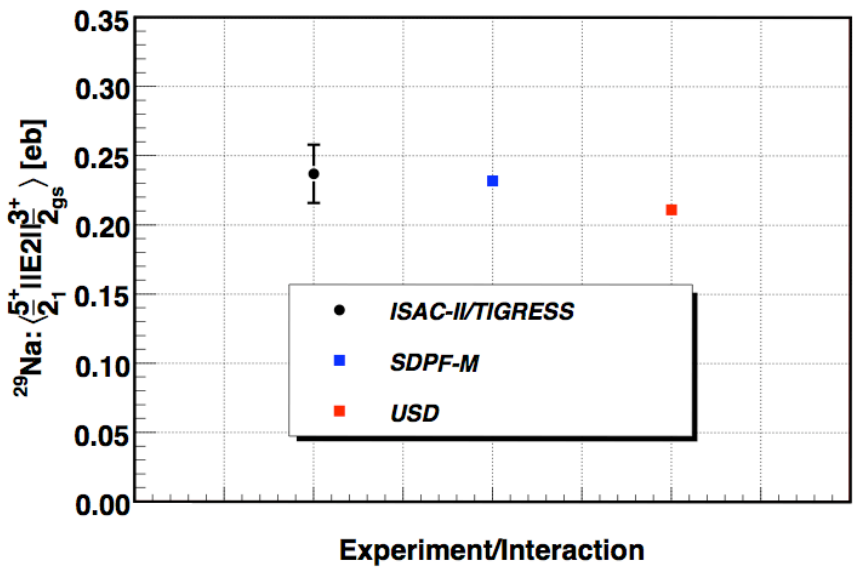
BAMBINO: enables ^{29}Na/^{29}Al isobar separation

Beam on target ~ 70 h

Intensity ~ 600 pps

$$\sigma_{CE}(^{29}\mathrm{Na}) = \frac{N_\gamma(^{29}\mathrm{Na})}{N_\gamma(^{110}\mathrm{Pd})} \cdot \frac{\varepsilon_\gamma(^{110}\mathrm{Pd})}{\varepsilon_\gamma(^{29}\mathrm{Na})} \cdot \frac{W_\gamma(^{110}\mathrm{Pd})}{W_\gamma(^{29}\mathrm{Na})} \cdot \sigma_{CE}(^{110}\mathrm{Pd})$$

Results: extracted $\langle 5/2^+_1||E2||3/2^+_{gs}\rangle$ for ^{29}Na

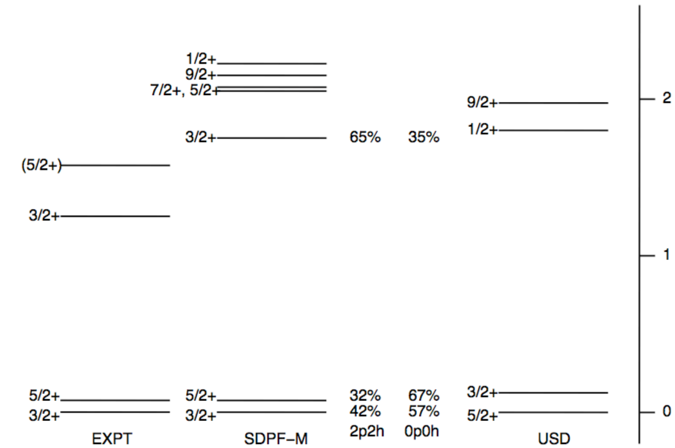


EXPT [eb]	SDPF-M [eb]	USD [eb]
0.237(21)	0.232	0.211

SDPF-M: *sd*, $p_{3/2}f_{7/2}$ shell-model spaces + cross-shell mixing

USD: constrained *sd* shell-model space (universal *sd*)

Calculations: Y. Utsuno *et al*., PRC **70**, 044307 (2004)



Coulomb-excitation measurement:

- **Consistent with SDPF-M calculation**
- **Aligned with previous work, e.g. $I_{gs} = 3/2^+_{gs}$, spectroscopic *Q*, consistent with SDPF-M prediction**
- **Neutron excitations across *sd-pf* shell gap: 30 ~ 40% 2p-2h admixture in $\psi(5/2^+_1)$**
- **Consistent with narrow *sd-pf* neutron shell gap of ~ 3 MeV (c.f. ~ 6 MeV along line of β-stability)**

Strong evidence for *sd-pf* shell mixing in $3/2^+_{gs}$ and $5/2^+_1$ in ^{29}Na

Phenomenological Interpretation

Rotational model analysis:

- Reduced matrix elements
- Intrinsic quadrupole moment
- Spectroscopic quadrupole moment

$$\langle I_f \| E2 \| I_i \rangle = \sqrt{\frac{5}{16\pi}} \cdot \sqrt{2I_i + 1} \cdot \langle I_i K 2 0 | I_f K \rangle \cdot Q_t$$

$$Q = \frac{3K^2 - I(I+1)}{(I+1)(2I+3)} \cdot Q_0$$

Experimental measurements:

- *B(E2)* ≈ 18 W.u., large overlap of ground and first excited states: enhanced transition probability
- Similar underlying single-particle configurations for $3/2_{gs}^{+}$ and $5/2_{1}^{+}$ states
- Rotational model: intrinsic quadrupole moment derived according to measurements of:
  - (1) transition matrix element: Q_t = 0.524(46) eb [this work!]
    c.f. SDPF-M calculation: Q_t = 0.513 eb
  - (2) static quadrupole moment: Q_0 = 0.430(15) eb
    c.f. SDPF-M calculation: Q_0 = 0.455 eb

Summary and outlook

• We have performed a succes sful Coulomb excitation measurement with a very low-flux radioactive-ion beam with only a few hundred pps - beyond the expectations of the community.

• First-ever measurement of transition probability between ground and first-excited state in ^{29}Na.

• Most neutron-rich Na isotope where this measurement has been made using the ISOL technique.

• ^{29}Na is the most striking example where such large degrees of mixing between normal (*sd*) and intruder (*pf*) configurations have been observed at the boundary to the island of inversion.

• TRIUMF/ISAC-II experiments are in the production phase providing new and exciting data that challenge current shell-model theories.

• ^{29}Na results have been submitted for publication.

Meaningful test of theoretical predications requires measurements in a region, not just a solitary nucleus

• Extend our measurements to ^{30}Na and ^{31}Mg after 2010 - working with TIGRESS collaboration at TRIUMF with accompanying theoretical support from LLNL.

• Opens the door to the ever-more exotic nuclei with a few tens of pps when the next generation of γ-ray detector arrays (AGATA and GRETA) come online

TIGRESS Collaboration

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