

## **New Results from the S-DALINAC\***

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- S-DALINAC and its research program
- Electro-induced deuteron breakup at the threshold
- Charge radius of the proton
- Mixed-symmetry states as building blocks of low-energy structure – <sup>94</sup>Mo
- New insight into the electric Pygmy Dipole Resonance

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## **Experiments at the S-DALINAC**

3-130 MeV c.w.





## **Primordial Nucleosynthesis**



• D, <sup>3</sup>He, <sup>4</sup>He, <sup>7</sup>Li are synthesized

## **Test of Cosmological Standard Model**



 Abundances depend on baryon/photon ratio (baryon density)

Observational constraints

S. Burles et al., Phys. Rev. Lett. 82, 4176 (1999)

## Uncertainty of <sup>7</sup>Li Abundance



S. Burles et al., Phys. Rev. Lett. 82, 4176 (1999)

## $p(n,\gamma)d$ : Data and Predictions



- No data close to threshold
- M1 dominates
- M1/E1 ratio  $\rightarrow$  talk of H. Weller

EFT calculations: S. Ando et al., Phys. Rev. C, in press

#### Electron Scattering at 180°



• At 180° selective excitation of transverse cross section  $\rightarrow$  M1 enhanced

# D(e,e') at 180°



• Good energy resolution:  $\Delta E = 45 \text{ keV}$  (FWHM)

## **Comparison to Potential Model Calculation**



- Absolute and relative normalization agree within 6%
- Excellent agreement with potential model (H. Arenhövel)

#### $p(n,\gamma)d$ : Data and Model Predictions



## **Deuteron GDH Sum Rule**



• Impulse approximation  $\rightarrow D \approx p + n$ 

$$\rightarrow \int_{\mathsf{E}_{\pi}}^{\infty} \mathsf{GDH}_{\mathsf{D}} = 204 \ \mu \mathsf{b} + 232 \ \mu \mathsf{b} = 436 \ \mu \mathsf{b}$$

Low-energy part dominated by resonance at threshold

• With reasonable assumptions  $\sigma_P(E) - \sigma_A(E) = -3\sigma_{M1}$ 

#### **Deuteron GDH Structure**



R. Weller and W. Ahmed, Mod. Phys. Lett. A 18, 1569 (2003)

present (e,e') data will provide a sensitive test in the threshold region

## **Charge Radius of the Proton**



• New high-precision measurement needed

## **New Experiment**



## Setup



472 mm

#### **Online Results**



## Mixed-symmetry states in <sup>94</sup>Mo

• IBM  $\rightarrow$  pairing of nucleons to s- / d-bosons • IBM-2  $\rightarrow$  F-spin:  $\pi$  boson:  $F_0 = 1/2$   $\nu$  boson:  $F_0 = -1/2$   $\stackrel{|N_{\pi} - N_{\nu}|}{2} \leq F \leq F_{max} = \frac{N_{\pi} + N_{\nu}}{2}$   $\rightarrow F = F_{max}$ : symmetric states  $\rightarrow F < F_{max}$ : mixed-symmetry states (ms) • Q-phonon scheme:  $Q_s \propto Q_{\pi} + Q_{\nu}$   $|2_1^+ \rangle \propto Q_s |0_1^+\rangle$ 

$$\mathbf{Q}_{\mathrm{ms}} \propto \frac{\mathbf{N}}{2} \left( \frac{\mathbf{Q}_{\pi}}{\mathbf{N}_{\pi}} - \frac{\mathbf{Q}_{\nu}}{\mathbf{N}_{\nu}} \right) \qquad |\mathbf{2}_{\mathrm{ms}}^{\dagger}\rangle \propto \mathbf{Q}_{\mathrm{ms}} |\mathbf{0}_{1}^{\dagger}\rangle$$

- Are ms states elementary excitations like low-energy surface vibrations (phonons)?
- Coupling to multiphonon states
  - → harmonic?
  - → pure?

## **Signatures of MS States**



Strong E2 transitions for decay of symmetric Q-phonon

- Weak E2 transitions for decay of ms Q-phonon
- Strong M1 transitions for decay of ms states to symmetric states



N. Pietralla et al., Phys. Rev. Lett. 83, 1303 (1999); Phys. Rev. Lett. 84, 3775 (2000) C. Fransen et al., Phys. Lett. B 508, 219 (2001); Phys. Rev. C 67, 024307 (2003)

## Combined Study of <sup>94</sup>Mo(e,e') and <sup>94</sup>Mo(p,p')

- Complete observation of all 2<sup>+</sup> states up to 4 MeV required
  → high resolution
- Sensitive to one-phonon components of the wave functions
- Mixed-symmetry ↔ isovector excitation in the valence shell
  - $\rightarrow$  isoscalar / isovector decomposition
- UCT / U Cologne / TU Darmstadt / iThemba LABS / Wits collaboration

## Data



#### **One-Phonon MS State**



Phonon character confirmed

O. Burda et al., Phys. Rev. Lett. (to be published)

## **Electric Dipole Response in Nuclei**



- Two-phonon state  $(2^+ \otimes 3^-)$
- Pygmy dipole resonance (PDR)
- Giant dipole resonance (GDR)

## PDR in <sup>208</sup>Pb



## **Theoretical Interpretation of the PDR in <sup>208</sup>Pb**



Very good description by Quasiparticle Phonon Model including complex configurations

#### Nature of the Mode



PDR charge transition density largely isoscalar

But surface neutron density oscillations

## PDR from Coulomb Breakup in Exotic Nuclei



Relation to E1 strength at threshold in stable nuclei?
 P. Adrich et al., Phys. Rev. Lett. 95, 132501 (2005)

### **PDR** in the Sn Isotope Chain



• Recent study of  $^{112,120}$ Sn( $\gamma,\gamma'$ )

Connection to E1 Strength above the Threshold in Stable Nuclei

Low Energy Photon Tagger @ S-DALINAC NiederEnergiePhotonenTagger



• High-resolution measurement (< 0.25%) of photon induced reaction rates in the energy range 8 MeV <  $E_{\gamma}$  < 20 MeV

## Systematics of the PDR at N = 82



Trend confirmed by <sup>136</sup>Xe?

0

# Gas Target for <sup>136</sup>Xe( $\gamma$ , $\gamma'$ )



- Titan walls
- High pressure
  50 bar <sup>2</sup>/<sub>2</sub> 700 mg <sup>136</sup>Xe
- $S_n = 8.06 \text{ MeV}$  $\rightarrow E_0 = 8.2 \text{ MeV}$

#### **Preliminary Result for <sup>136</sup>Xe**



- Similar fragmentation
- **Φ** ΣB(E1) smaller than <sup>138</sup>Ba
- $\rightarrow$  no simple relation to N/Z ratio

## **Experimental Test of the Isospin Character of the PDR**

Isospin character of PDR

- → use  $(\alpha, \alpha')$ : pure isoscalar response but resolution insufficient in heavy nuclei
- $\rightarrow$  ( $\alpha$ , $\alpha'\gamma$ ) with Ge detectors challenging because of background
- → feasibility study at KVI TU Darmstadt / KVI collaboration

## Setup at KVI



Total photopeak efficiency: 0.5% at 1.33 MeV
 D. Savran et al., Nucl. Inst. Meth. 561, 267 (2006)

# <sup>140</sup>Ce(α,α΄γ)



Selectivity by gating on g.s. and 2<sup>+</sup> decay

## <sup>140</sup>Ce( $\alpha, \alpha' \gamma$ ) vs. <sup>140</sup>Ce( $\gamma, \gamma'$ )





Is the PDR a superposition of two modes?

0

## Summary

- Broad research program in few-body physics, structure and astrophysics
- Some highlights:
  - $\rightarrow$  D(e,e') at 180° close to threshold
  - $\rightarrow$  charge radius of the proton
  - $\rightarrow$  mixed-symmetry states in <sup>94</sup>Mo
  - $\rightarrow$  new aspects of the E1 pygmy resonance



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#### **One-Phonon MS State**



Phonon character confirmed

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#### Symmetric Two-Phonon State



very pure

two-step contributions

 $\rightarrow$  coupled-channel analysis