



Study of the $^{49}\text{Ca}(d,p)$ reaction

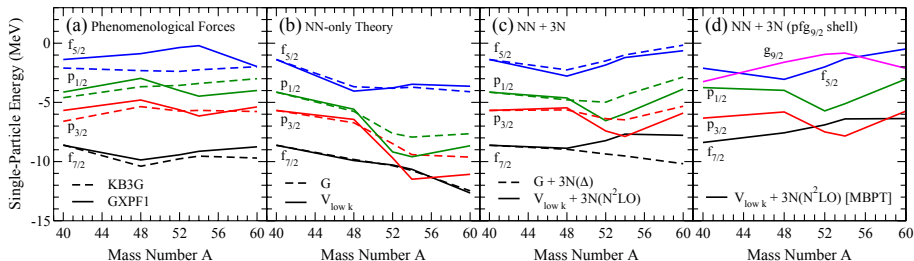
70th Meeting of the INTC 2022

Frank Browne

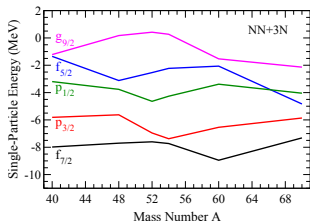
CERN, CH-1211 Geneva 23, Switzerland

Wednesday 22nd June, 2022

Shell evolution in N -rich Ca isotopes

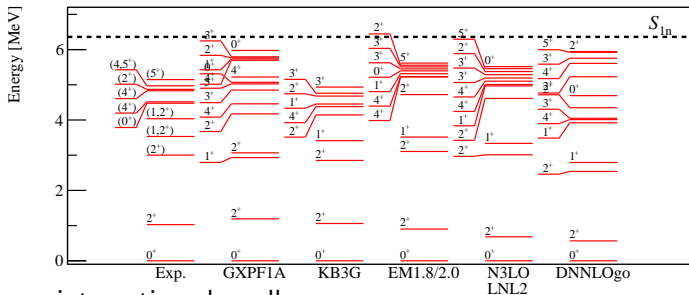


- ▶ Region of drastic shell evolution
 - New $N = 32, 34$ shell closures
- ▶ A frontline of *ab initio* capabilities
 - Recently: VS-IMSRG
- ▶ Conflicting theory
 - Some approaches \Rightarrow weak closures
- ▶ and experiment
 - For: $E(2^+)$, S_{2n} , K.O.; Against: R_{ch}

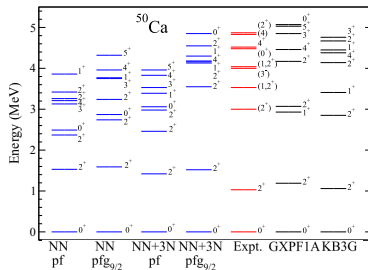


▶ $0g_{9/2}$ influence?

Recent predictions of ^{50}Ca levels



- ▶ Phen. interactions broadly agree
- ▶ Many-body perturbation theory (right):
 - dependent on $3N$ forces and $g_{9/2}$
 - **3.5 MeV state properties needed**
- ▶ VS-IMSRG (above) similar to phen. at low E
- ▶ All but 2_1^+ state tentative
 - $^{48}\text{Ca}(t,p)$, (p,p') , $^{50}\text{K}(\beta^-)$, $^{51}\text{K}(\beta^- n)$, $^{238}\text{U}/^{208}\text{Pb}(^{48}\text{Ca}, x\gamma)$

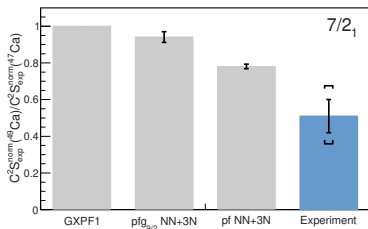


J. D. Holt *et al*, Phys. Rev. C **90** 024312 (2014).

J. D. Holt & B.-S. Hu, Private comm. (2022).

Neutron removal from ^{50}Ca

- ▶ ^{50}Ca neutron-stripping
 - Depleted $\nu f_{7/2}$ strength
 - Some evidence of enhanced $\ell = 1$
 - Similar to $\text{Sc}(-1n)$
- ▶ MBPT and phen. predictions agree
 - But not with experiment!



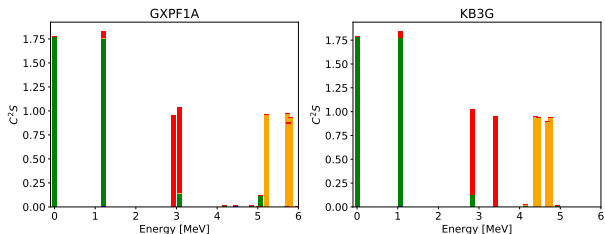
Level energy (keV)	J^π	σ_{-1n} (mb)	σ_{sp} (mb)	C^2S_{exp}	R_5	$C^2S_{\text{exp}}^{\text{norm}}$	Theoretical C^2S		
							GXPFI	pf NN+3N	$pf g_{9/2}$ NN+3N
0	$3/2^-$	$41.8^{+5.2}_{-5.9}$	18.63	2.1(3)	0.77	$2.7^{(+0.3)}_{(-0.4)}\text{stat}(\pm 0.5)_{\text{sys}}$	1.73	1.70–1.72	1.50–1.56
2023	$1/2^-$	$4.4^{+0.8}_{-0.5}$	15.04	$0.28^{+0.05}_{-0.03}$	0.74	$0.37^{(+0.07)}_{(-0.05)}\text{stat}(\pm 0.1)_{\text{sys}}$	0.17	0.12–0.14	0.12–0.14
3357	$7/2^-$	$38.9^{+5.1}_{-3.9}$	10.87	$3.4^{+0.4}_{-0.3}$	0.72	$4.7^{(+0.6)}_{(-0.5)}\text{stat}(\pm 0.9)_{\text{sys}}$	7.7	5.6–5.7	6.3–6.7
3750–3900 ^a	$7/2^-$							1.5–1.8	0.4–0.5
4017	$9/2^+$	0.8	11.39	0.07	0.71	0.09			0.15–0.20

Direct inclusive: 98(10) [Total inclusive: 116(10)]

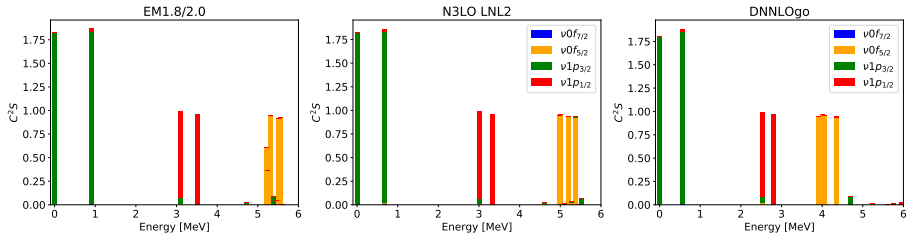
^aPrediction for $7/2_2^-$ state in NN+3N calculations; the range captures the prediction for calculations in the pf model space (400 keV above $7/2_1^-$) and $pf g_{9/2}$ model space (550 keV above $7/2_1^-$).

Spectroscopic factor predictions

Phenomenological



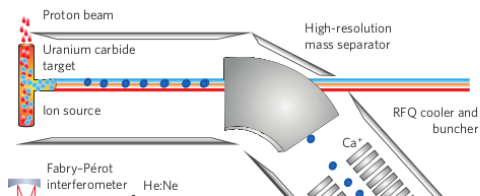
ab initio (VS-IMSRG)



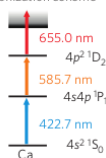
Measurement objectives

- ▶ Perform first nucleon-adding reaction to n-rich Ca
 - Populated states will likely be of single-particle nature
- ▶ Inform on the nature of observed states in ^{50}Ca
 - Almost all states are tentative
 - Necessary for testing of predictions
- ▶ Benefits of $^{49}\text{Ca}(d,p)$
 - S.p. orbits fragment into many states
 - Potential observation of new states
 - Location of s.p. energies
 - Mitigates possible sequential transfers of $^{48}\text{Ca}(t,p)$
- ▶ Search for inconsistencies in *ab initio* and phenomenological interactions
 - Enhancements of $\ell = 3$ and depletion of $\ell = 1$ in $^{50}\text{Ca}(-n)$
 - Not correctly predicted by either theory
- ▶ Any evidence of $\ell = 4$ transfer?

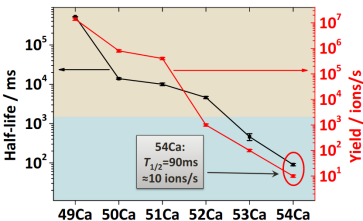
Beam production & yields



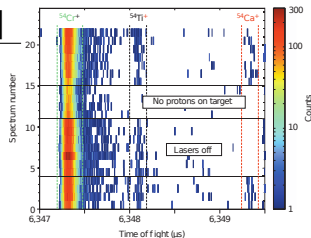
RILIS ionization scheme



- ▶ 1.4 GeV protons
- ▶ 3-step ionisation scheme
- ▶ 30 keV continuous beam
- ▶ HRS
- ▶ 60 ns bunches



A	Yield [ions/s]
49	1.37×10^7
50	8.05×10^5
51	3.97×10^5
52	1.00×10^3
53	9.81×10^1
54	1.00×10^1

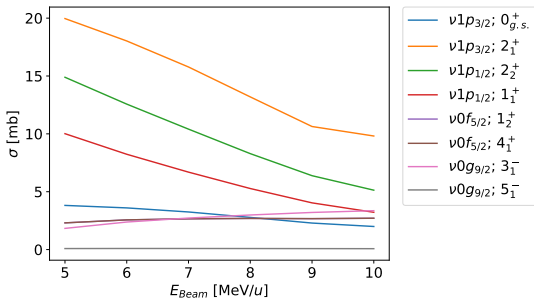


R. F. García Ruiz *et al*, Nat. Phys. **12** 594 (2016).

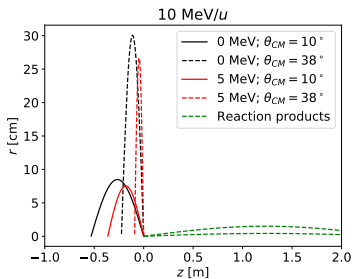
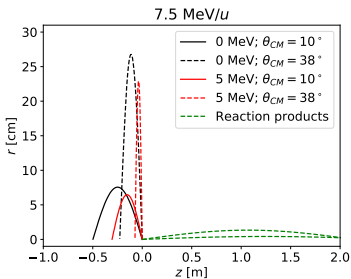
F. Wienholtz *et al*, Nature **498** 346 (2013).

F. Wienholtz, Presented at: Hirschegg 2015.

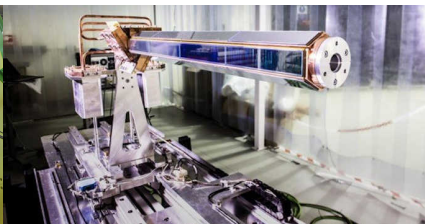
Experimental overview: reaction



- ▶ Lower E_{beam} beneficial
- ▶ 7.5 MeV/u:
possible $\ell = 4$ detection
 $E - \Delta E$ measurement
- ▶ Kinematics fine at lower E

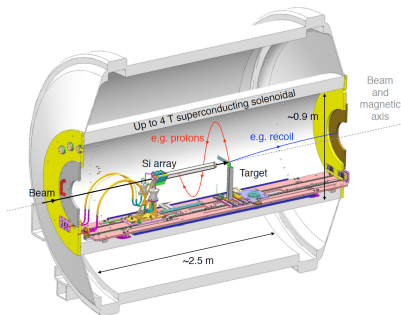


ISS setup & principle

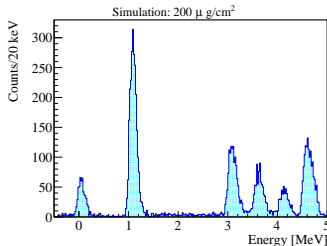
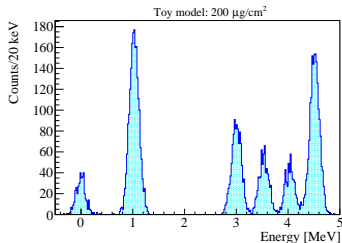
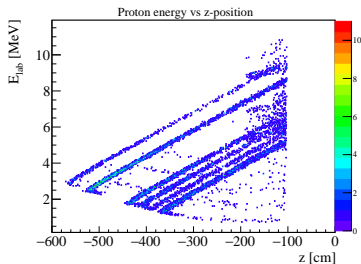
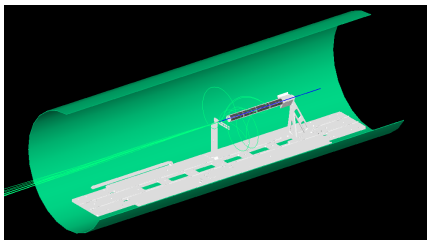


$$E_{CM} = E_{lab} + \frac{mV_{CM}^2}{2} - \frac{mzV_{CM}}{T_{cyc}}$$

- ▶ No kinematic compression
- ▶ Linear in z position
- ▶ High efficiency at high E



Experiment: ISS simulations



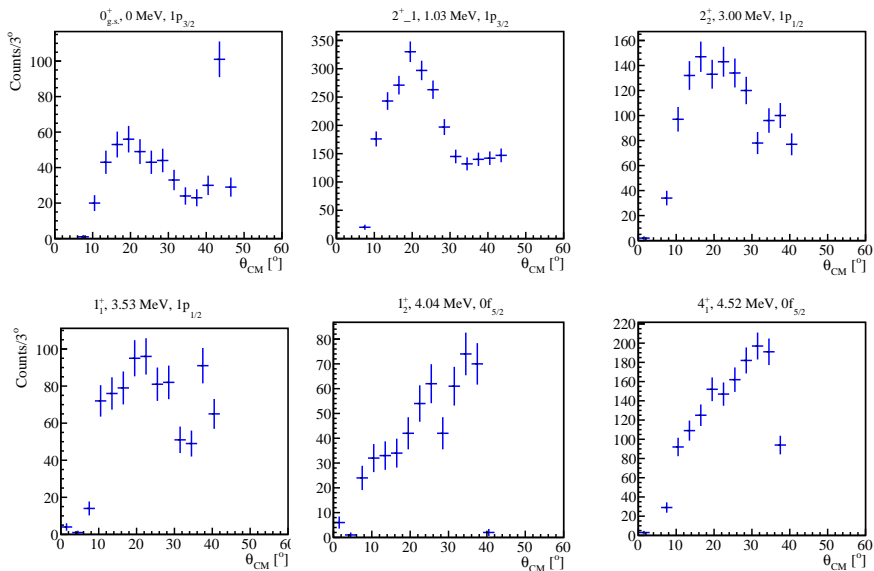
▶ FWHM = 210 keV $\forall E$

▶ Not a bad approximation

▶ 7.5 MeV/ u , same rates as proposal

▶ $150 \lesssim \text{FWHM} \lesssim 230$ keV

Angular cross section dependence



Summary

- ▶ Perform first nucleon-adding reaction to n-rich Ca
 - Characterise previously reported states
 - Cross sections & angular distributions
 - Search for new states
 - Any evidence of $\ell = 4$ ($0g_{9/2}$) transfer
 - Useful feedback for phen. and *ab initio* interactions
- ▶ Lower beam energy inquiry of TAC
 - No problem from physics perspectives
 - 7.5 MeV/*u* requested: $E-\Delta E$ measurement and some $\ell = 4$ cross section
- ▶ **Beam request:**
10 shifts data collection + 2 shifts set-up and tuning