TITAN

ISAC-TRIUMF

S1283

Precision Mass Measurements of the Halo Candidates ^{31}Ne and ^{22}C

stephan ettenauer
for the TITAN collaboration

UBC

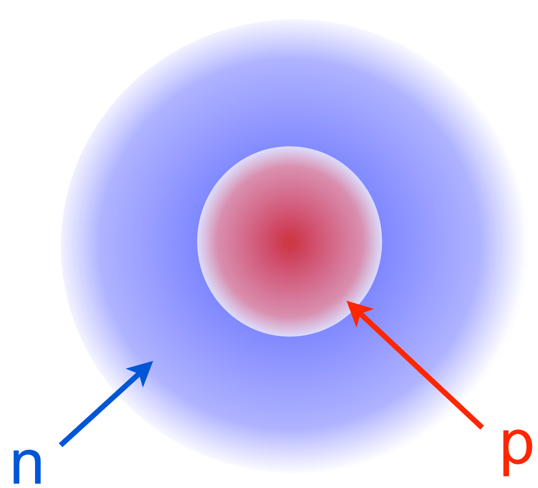
SAP-EEC, July 2010

Halo Nuclei

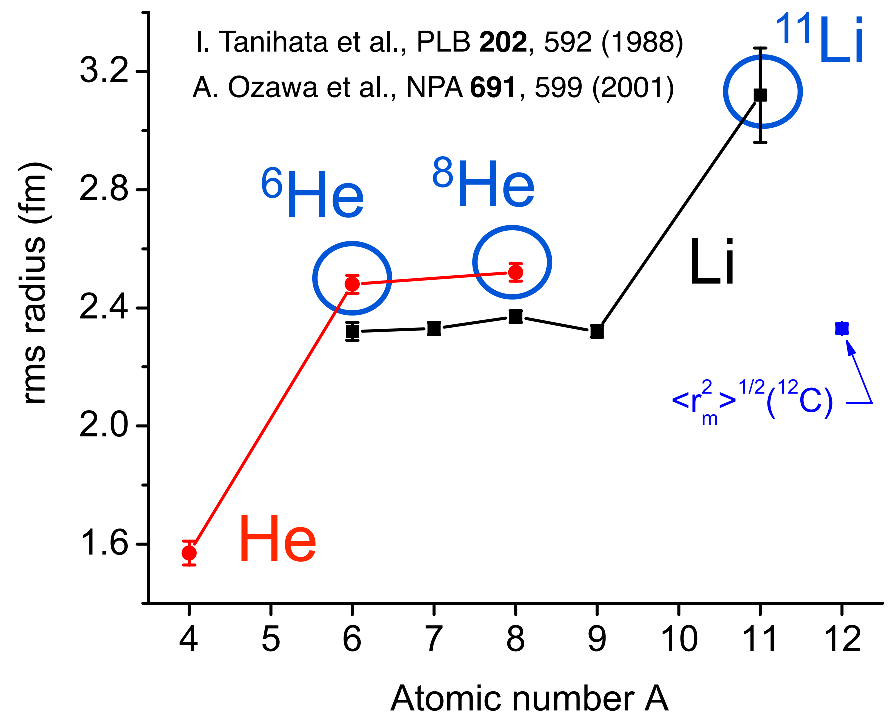
extreme n/p ratios

Halo	n/p
^{6}He	2
^{8}He	3
^{11}Li	2.66
^{14}Be	2.5
^{19}C	2.17
^{12}C	1

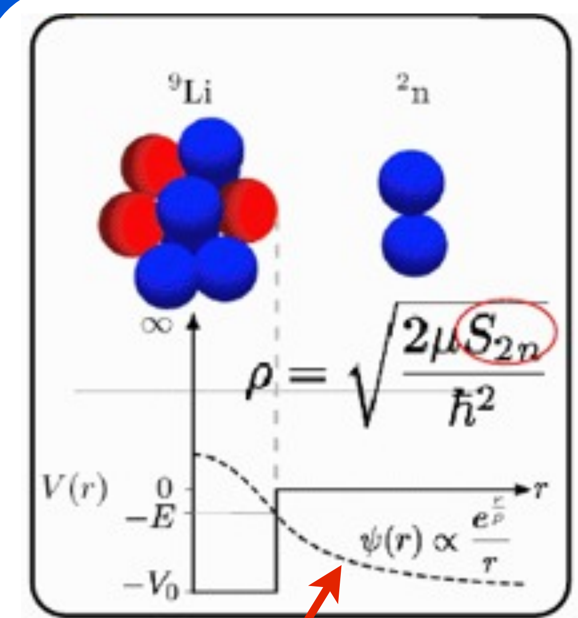
but $R_{matter} \neq R_{charge}$



large radii

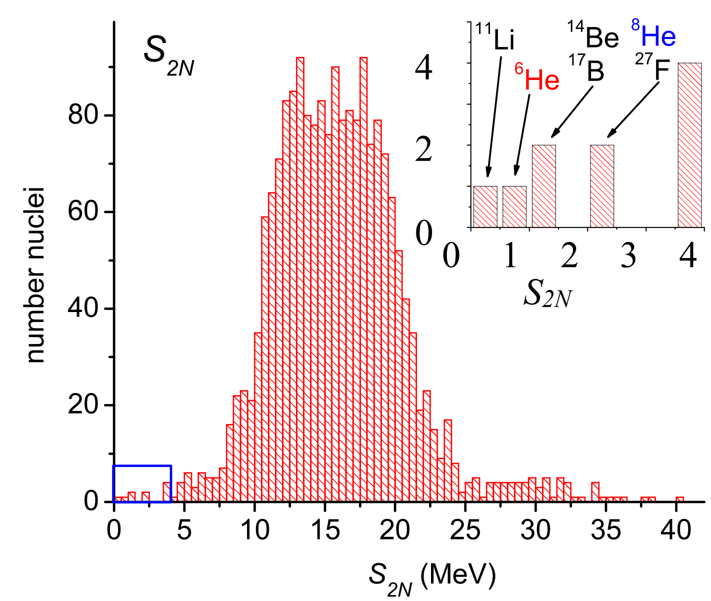


nucleons in classically forbidden region



exp. fall off

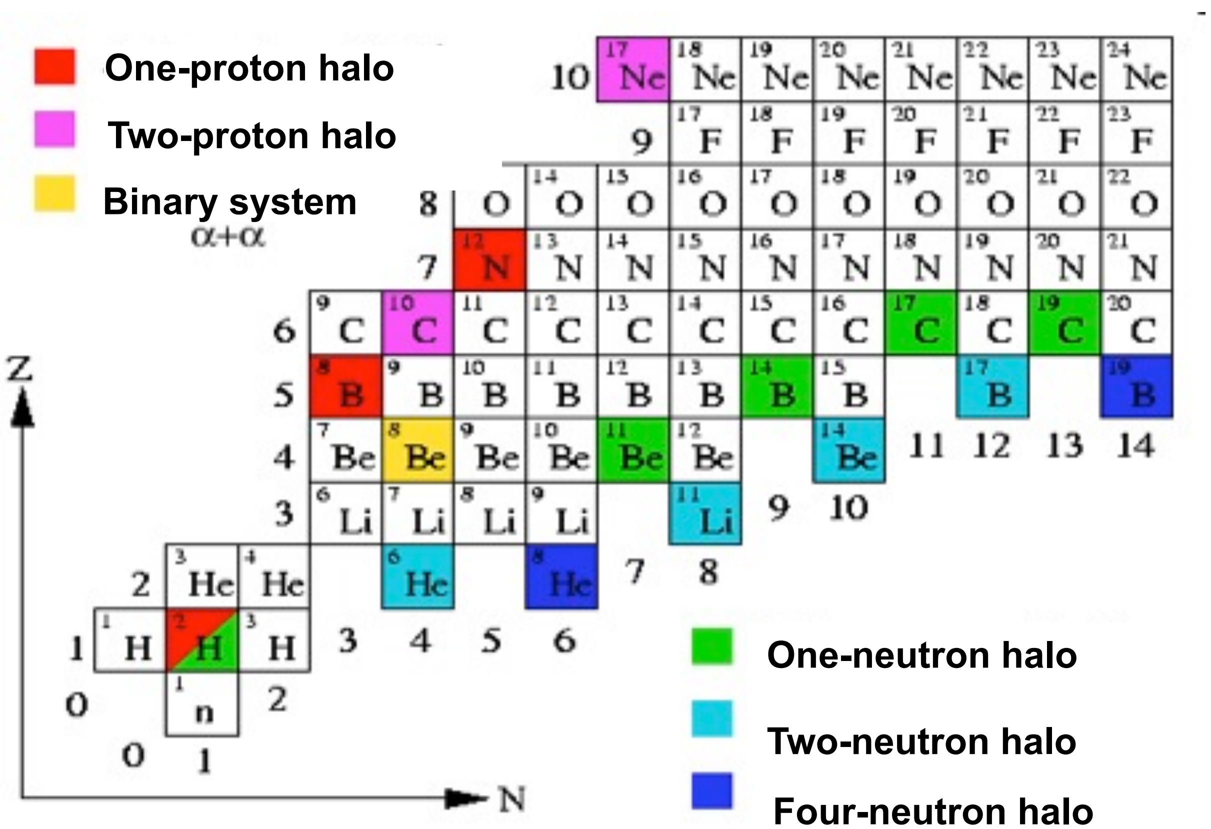
tiny separation energies

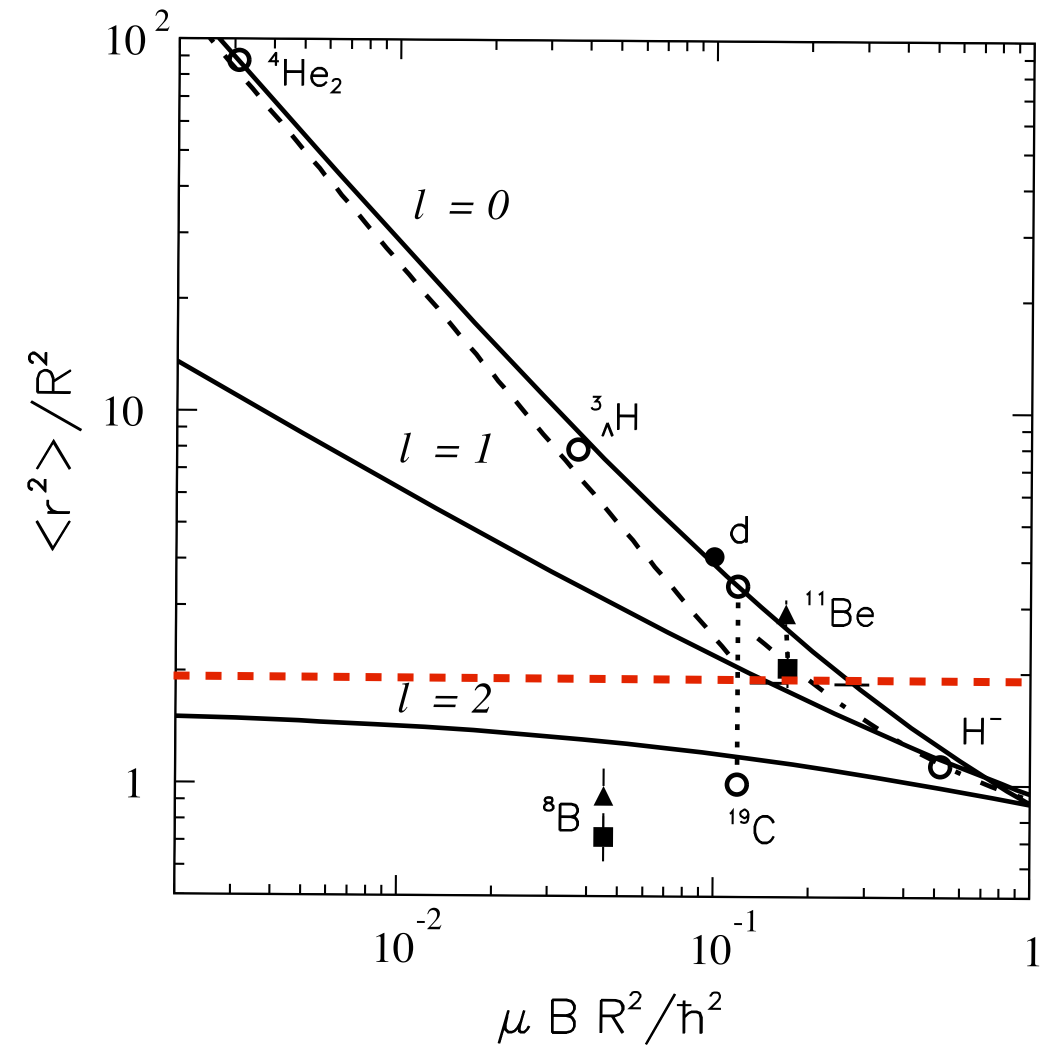


due to exotic features:

ideal test ground for nuclear structure theory

heavier halos?





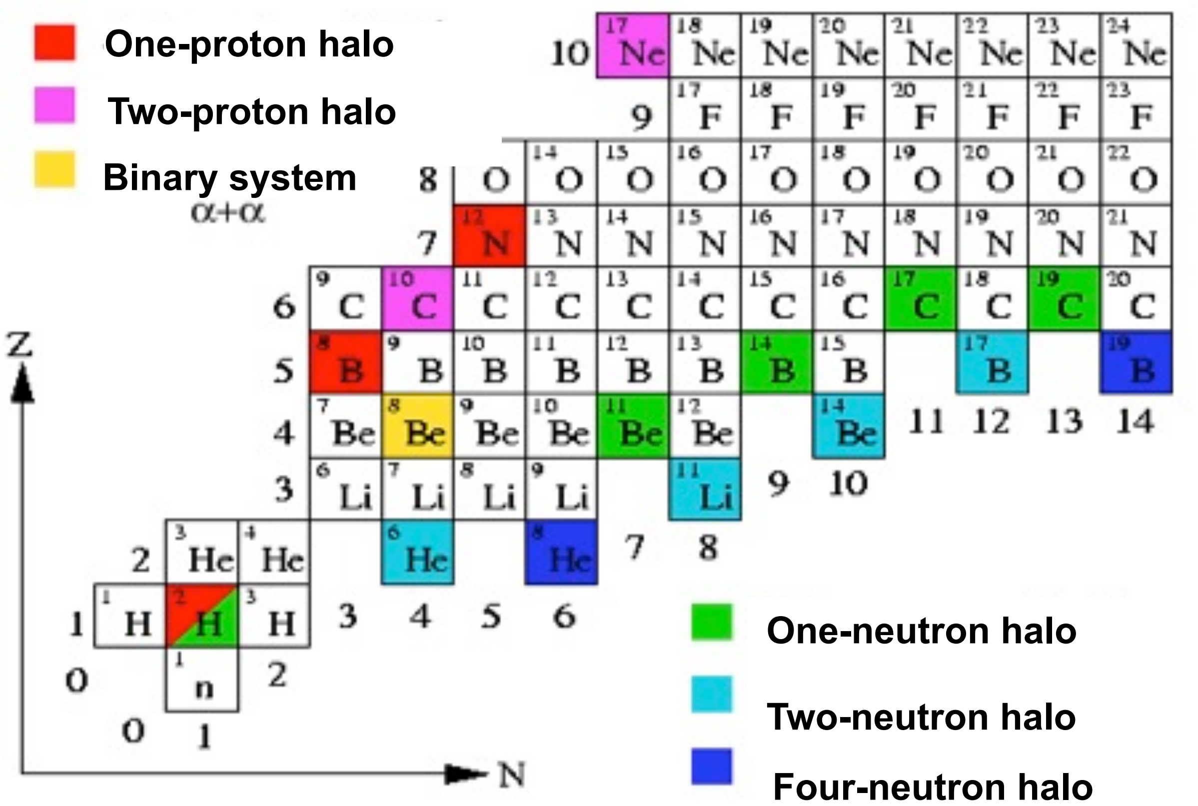
A. S. Jensen et al., Rev. Mod. Phys. 76, 215–261 (2004)

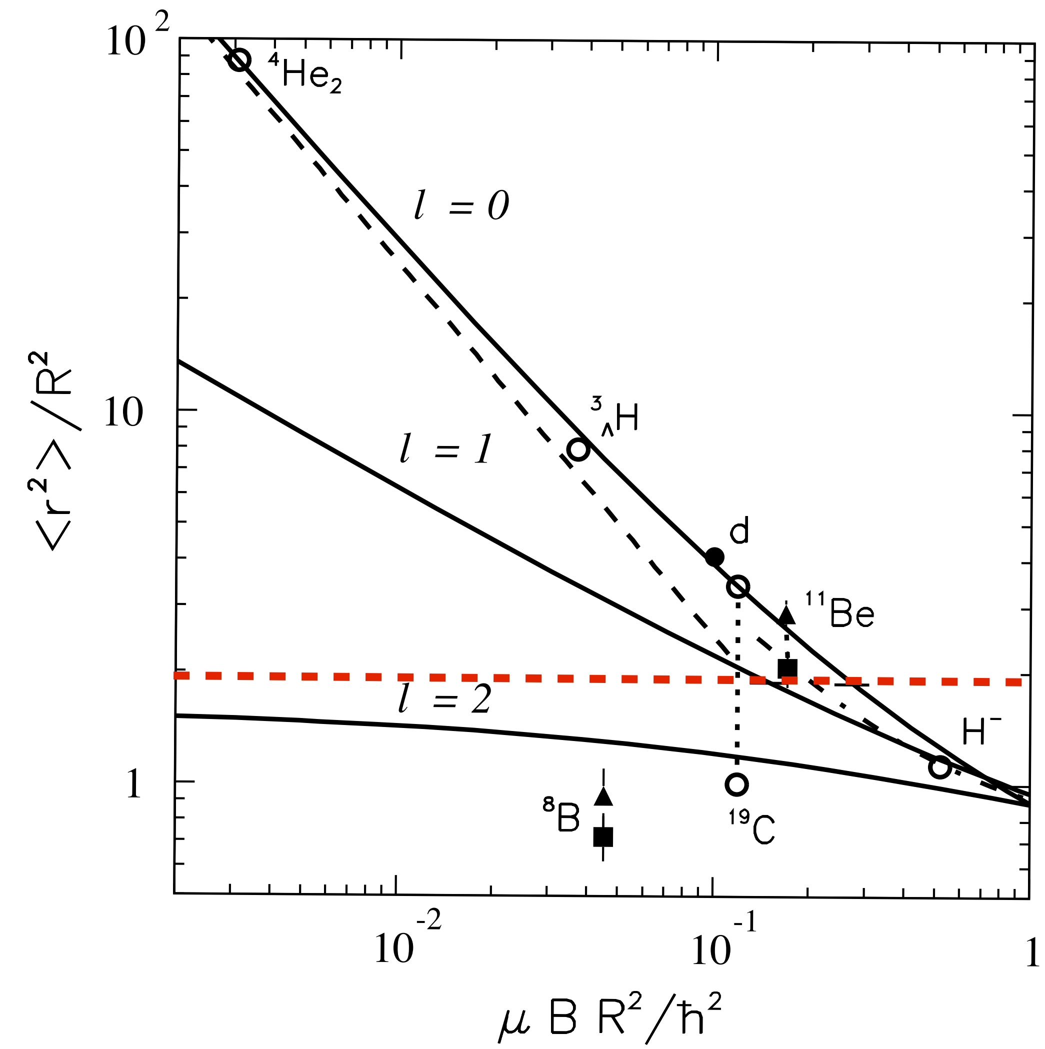
⇒ halos only for low orbital angular momentum (s and p)

⇒ generally not along the drip-line in heavier systems

⇒ halos limited to lighter masses ?

heavier halos?





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⇒ generally not along the drip-line in heavier systems

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potential mechanisms for low ℓ at heavier A:

- shell evolution
- deformation & halos
- halo formation adds extra stability ?

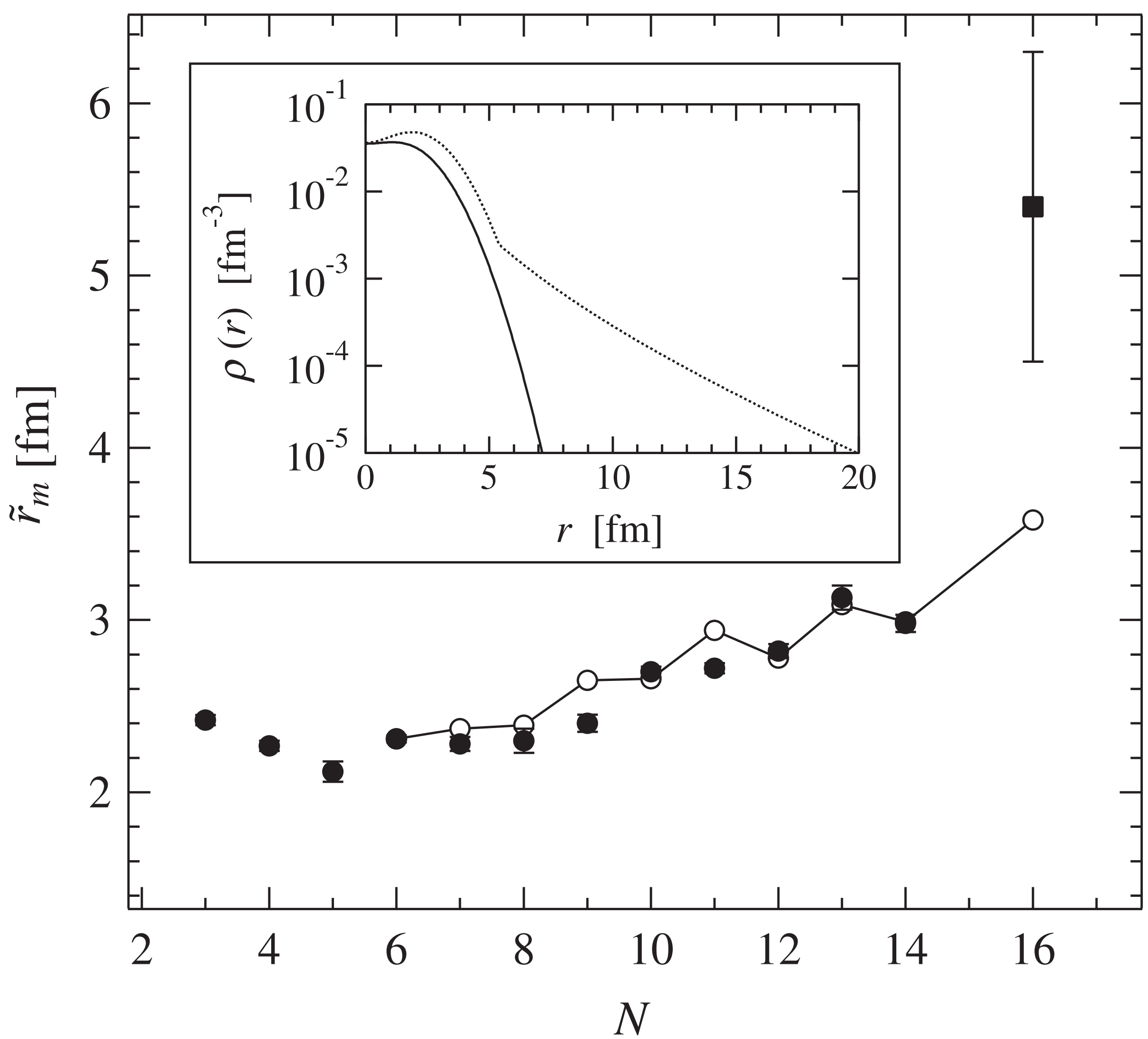
halos more common than expected?

reaction cross section of ^{22}C

- transmission experiment @ RIKEN
- $^{19,20,22}C$ on liquid H-target
- 40A MeV

TABLE I. Reaction cross sections (σ_R) in millibarns.

A	σ_R	$\sigma_R^{calc.}$ [22]
19	754(22)	758
20	791(34)	761
22	1338(274)	≥957



K. Tanaka et al., PRL 104, 062701 (2010)

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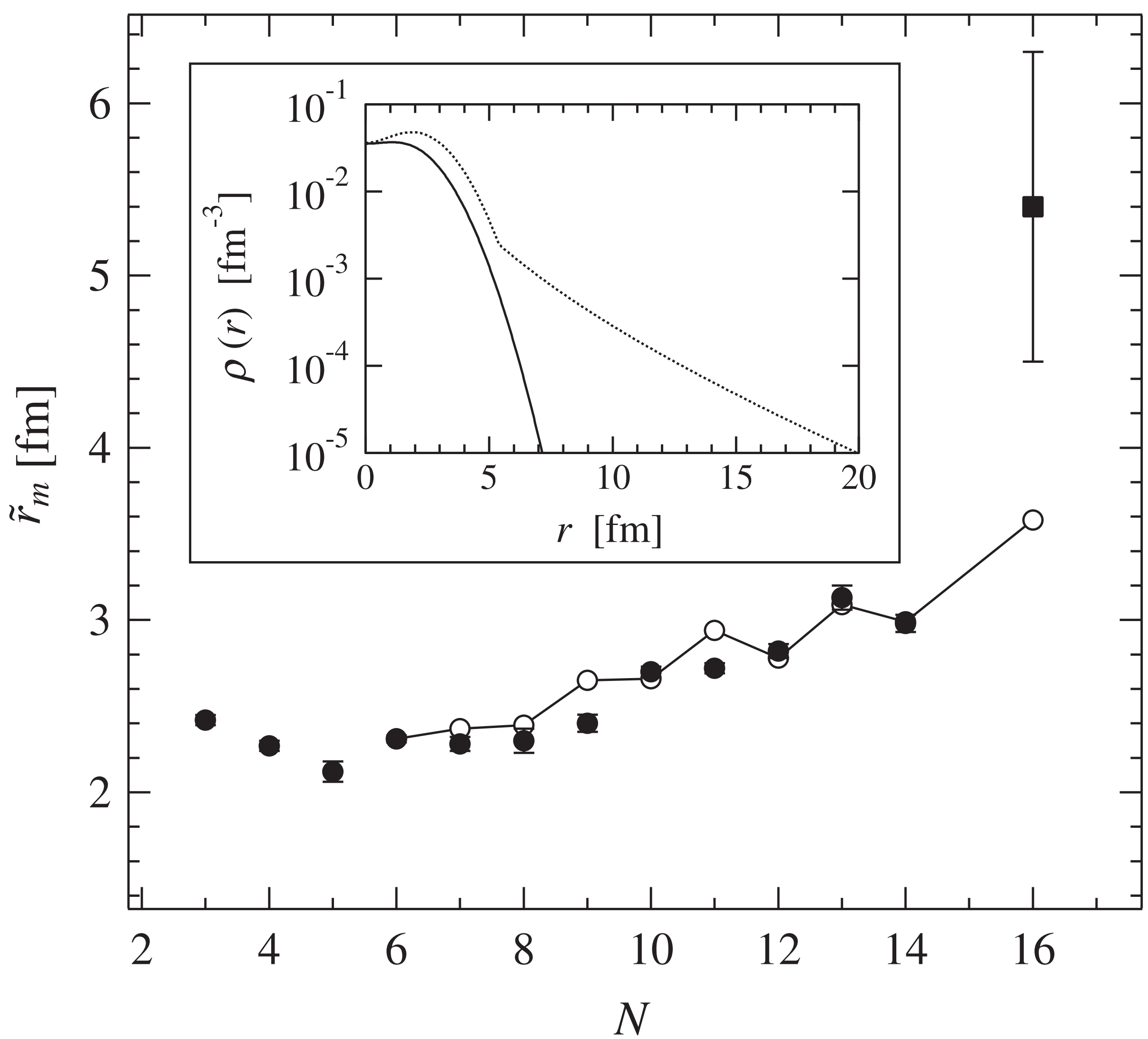

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Glauber type calculation:

- optical limit (^{20}C)
- FB approach
  - ^{18}C+n
  - ^{20}C+n+n (s-wave)

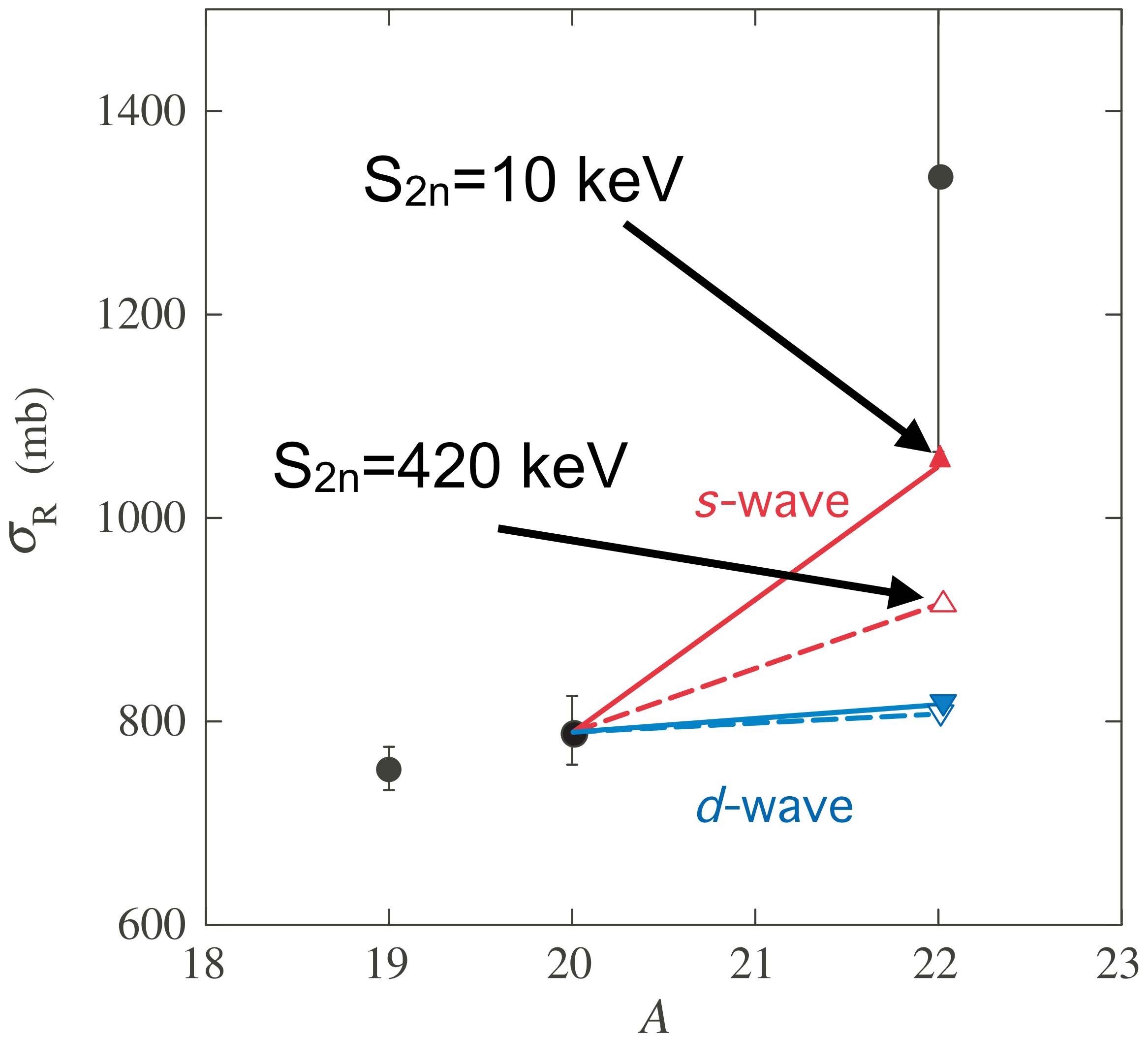
S_{2n} (MeV)	r_m (fm)	σ_R (mb)
0.489	3.6	957
0.361	3.7	969
0.232	3.8	985
0.122	4.1	1005

B. Abu-Ibrahim et al, PRC 77, 034607 (2008)

reaction cross section of ^{22}C

Glauber calculation for ^{22}C

- FB approach
- finite-range treatment
- vary S_{2n}
- spectroscopic factor $(0d5/2)^2_{J=0} \leftrightarrow (1s_{1/2})^2_{J=0}$

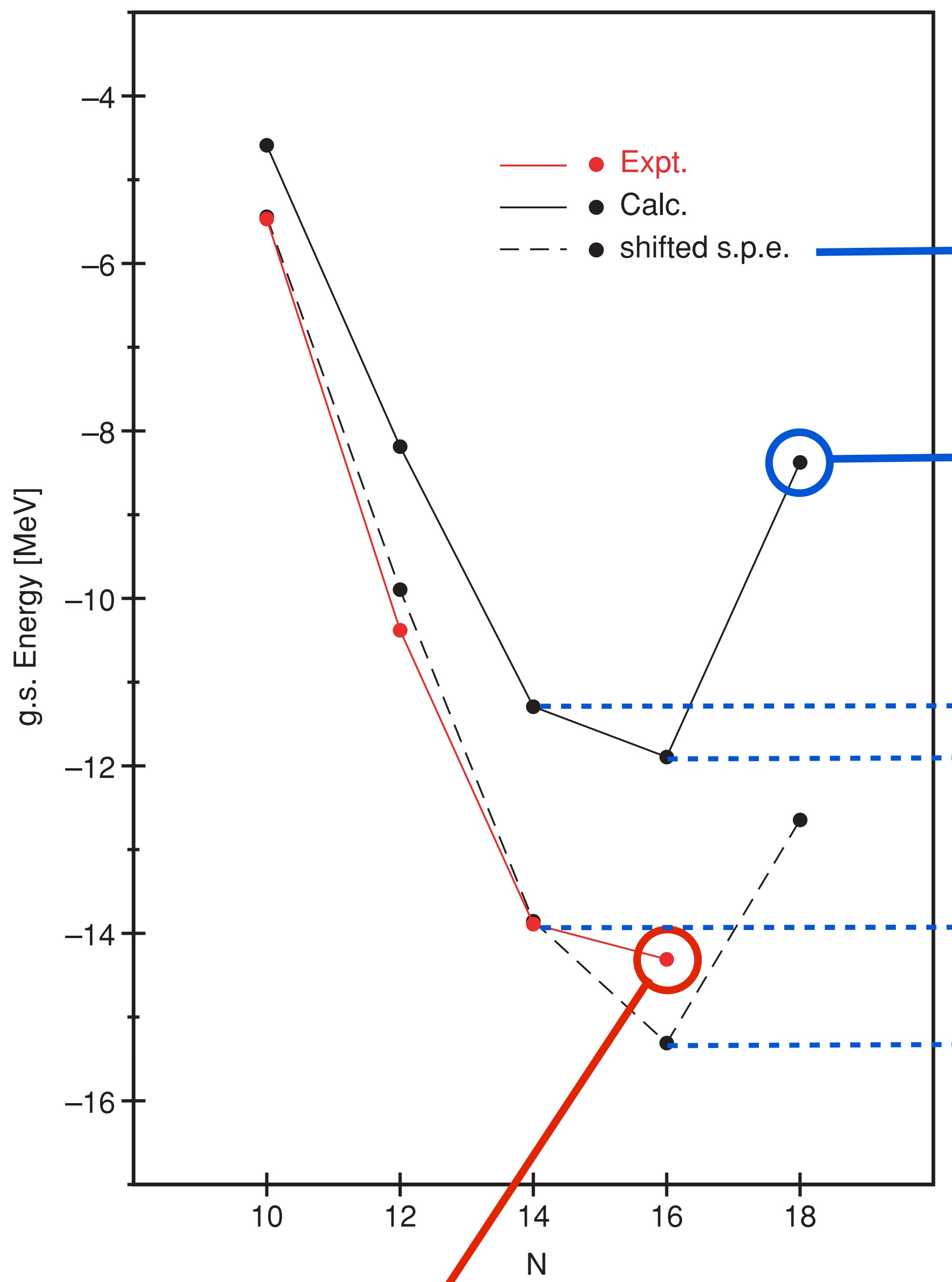


S_{2n}=420 ± 920 keV

- currently extrapolation in AME'03
- reaction data favours lower S_{2n}
- larger S_{2n}:
  validity of Glauber model at 40A MeV ?

K. Tanaka et al., PRL 104, 062701 (2010)

shell model calculation for ^{22}C



downshift of s.p.e. by 427 keV to reproduce $\Delta(^{15}C\text{-}^{14}C)$

^{24}C predicted to be unbound

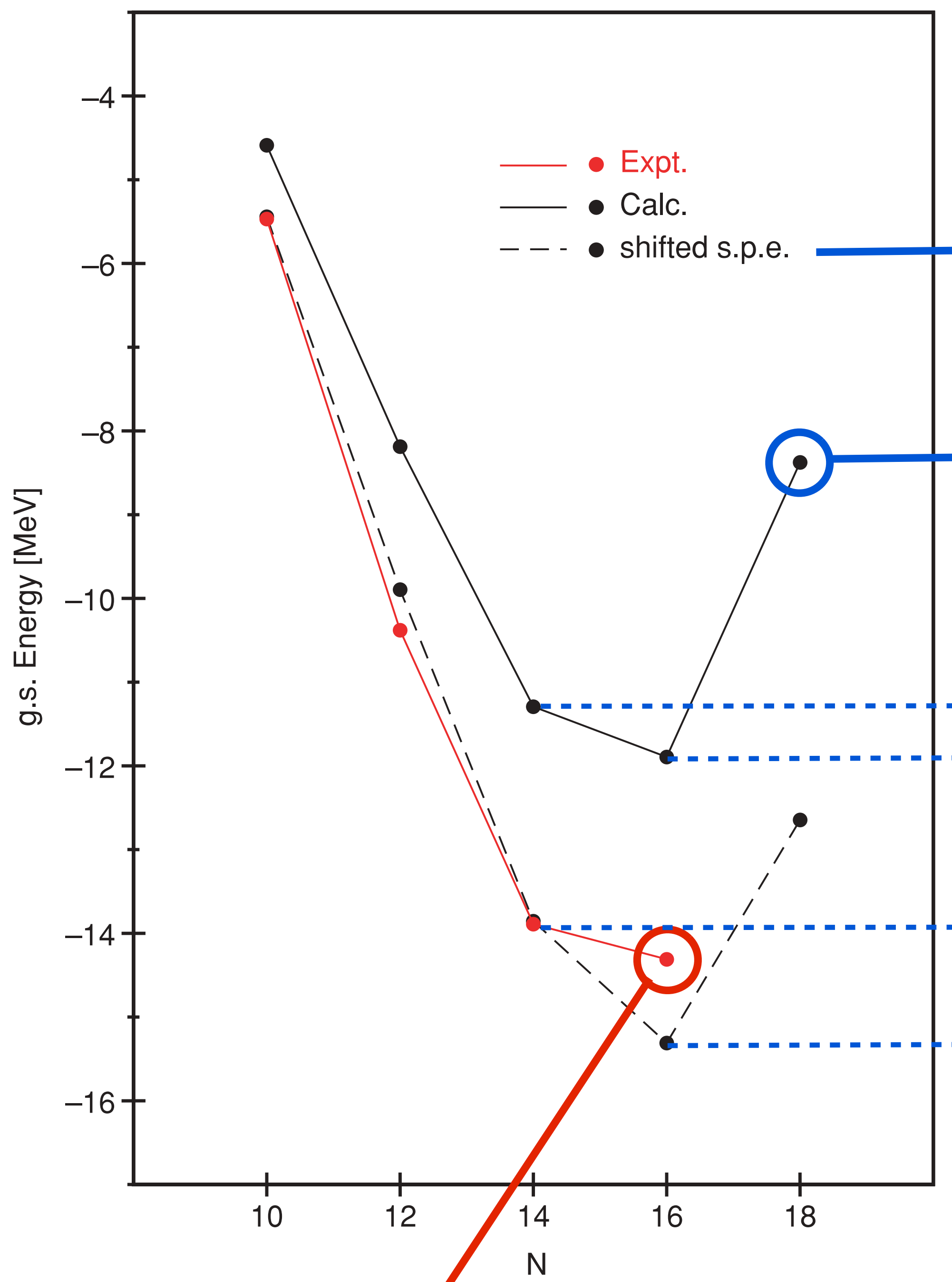
= S_{2n}= 601 keV

= S_{2n}

AME'03 prediction

L. Coraggio et al., PRC 81, 064303 (2010)

shell model calculation for ^{22}C



downshift of s.p.e. by 427 keV to reproduce $\Delta(^{15}C\text{-}^{14}C)$

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= S_{2n}= 601 keV

= S_{2n}

AME'03 prediction

⇒ shell model calculation favours larger S_{2n} (in contrast to reaction data)

L. Coraggio et al., PRC 81, 064303 (2010)

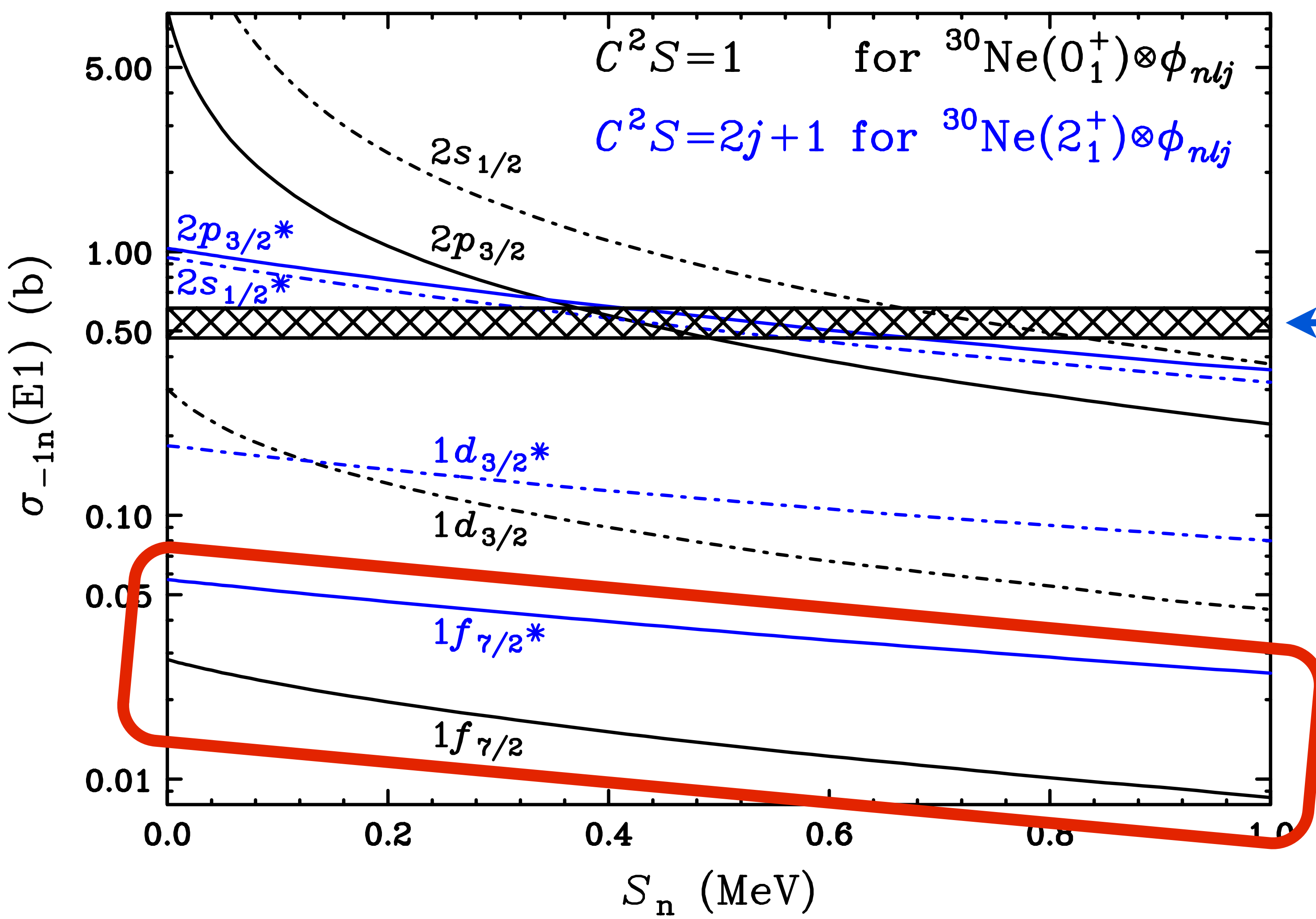
Coulomb breakup of ^{31}Ne (RIKEN)

TABLE I. Single-neutron removal cross sections (σ_{-1n}) for ^{31}Ne and ^{19}C on Pb and C targets at the incident energies shown. The ratio of the measured cross sections and the deduced Coulomb breakup cross sections are also listed.

Reaction	$\bar{E}/A$ (MeV)	σ_{-1n} (mb)	$\frac{\sigma_{-1n}(\mathrm{Pb})}{\sigma_{-1n}(\mathrm{C})}$	$\sigma_{-1n}(E1)$ (mb)
^{31}Ne + Pb	234	712(65)	9.0(1.1)	540(70)
^{31}Ne + C	230	79(7)		
^{19}C + Pb	243	969(34)	7.4(4)	690(70)
^{19}C + C	238	132(4)		

S_n=0.3 ± 1.6 MeV

B. Jurado et al., Phys. Lett. B 649, 43 (2007)



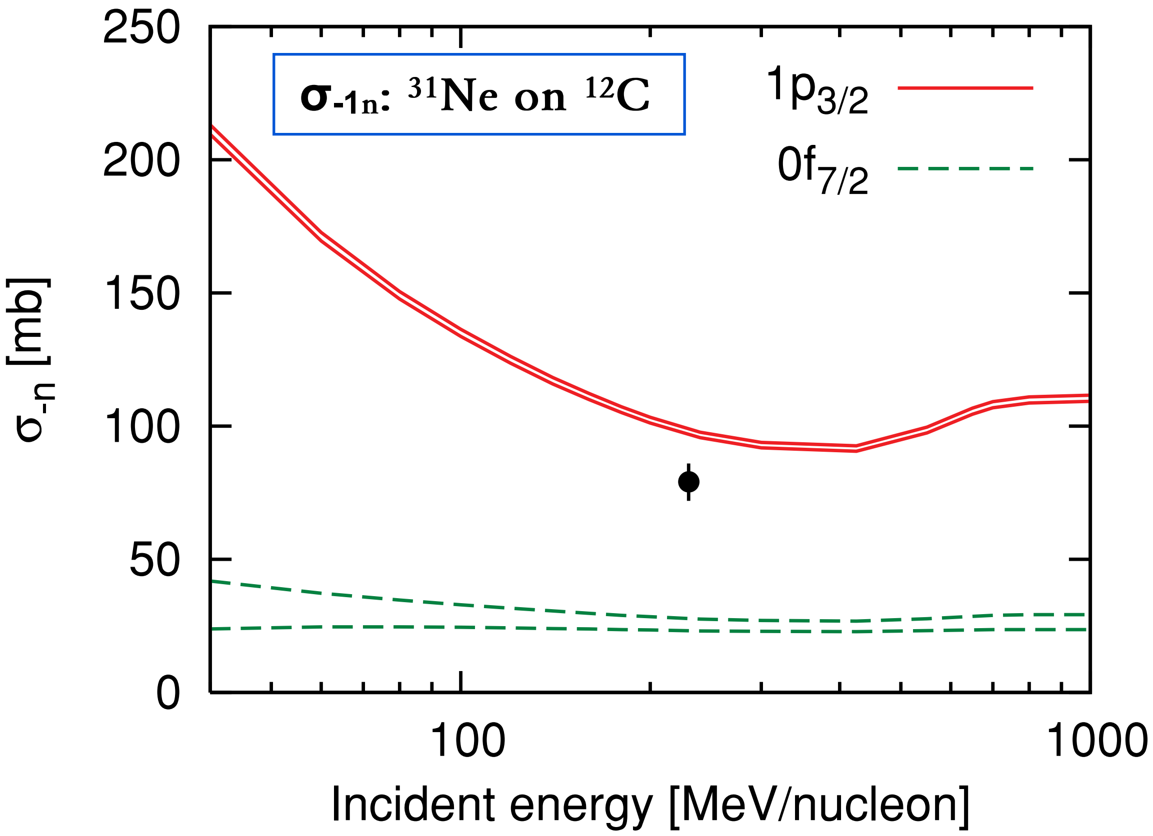
experiment:
consistent with formation of halo

expected from shell-model

T. Nakamura et al., PRL 103, 262501 (2009)

Glauber calculation σ_{-1n}

$$^{30}\mathrm{Ne}(0^+) \otimes 1p_{3/2} \leftrightarrow {}^{30}\mathrm{Ne}(0^+) \otimes 0f_{7/2}$$



[mb]	exp.	th.: $p_{3/2}$	th.: $f_{7/2}$
σ_{-1n} on ^{12}C	79(7)	96	26
σ_{-1n} on ^{208}Pb	712(65)	1140	91

W. Horiuchi et al., Phys. Rev. C 81, 024606 (2010)

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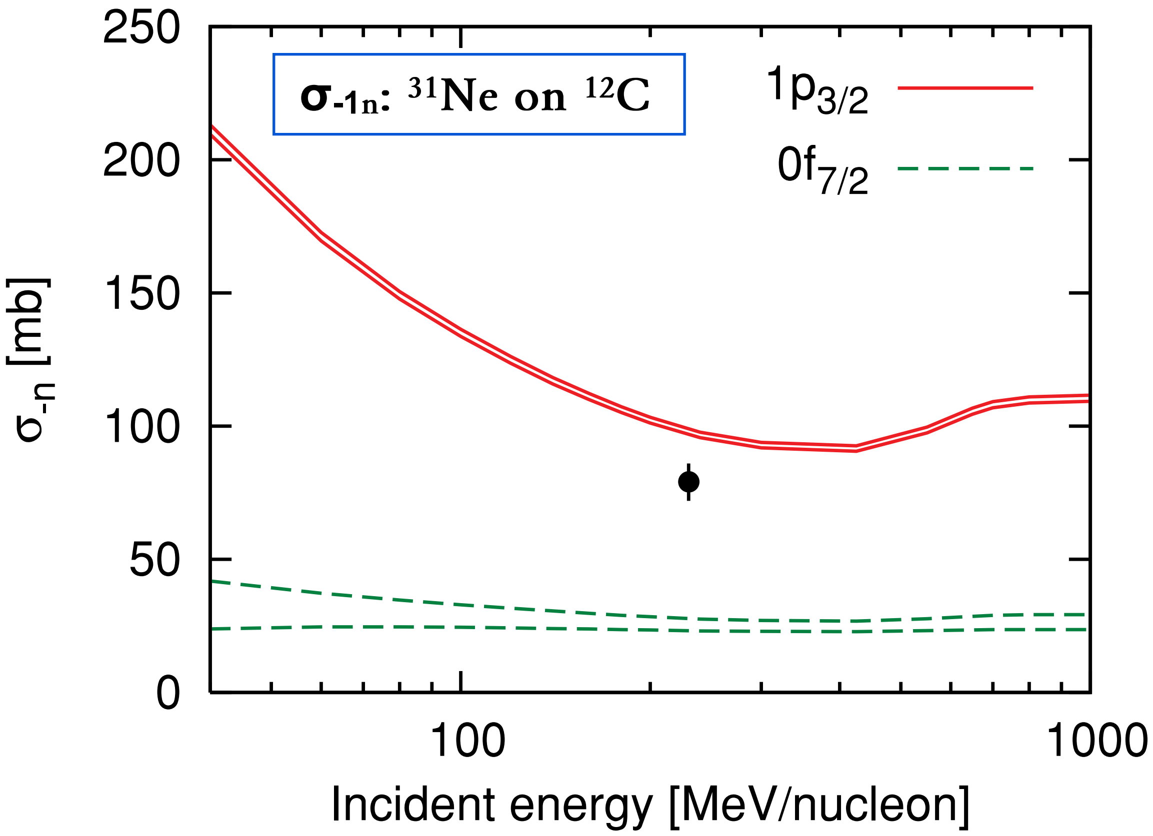


n removal cross section at ~240A MeV:

[mb]	exp.	th.: $p_{3/2}$	th.: $f_{7/2}$	S_n [keV]
σ_{-1n} on ^{12}C	79(7)	96	26	
σ_{-1n} on ^{208}Pb	712(65)	1140	91	0.33
		750		0.6

⇒ strong dependence on S_n

W. Horiuchi et al., Phys. Rev. C 81, 024606 (2010)

Island of Inversion

consistent with $I^{\pi}=3/2^{-}$

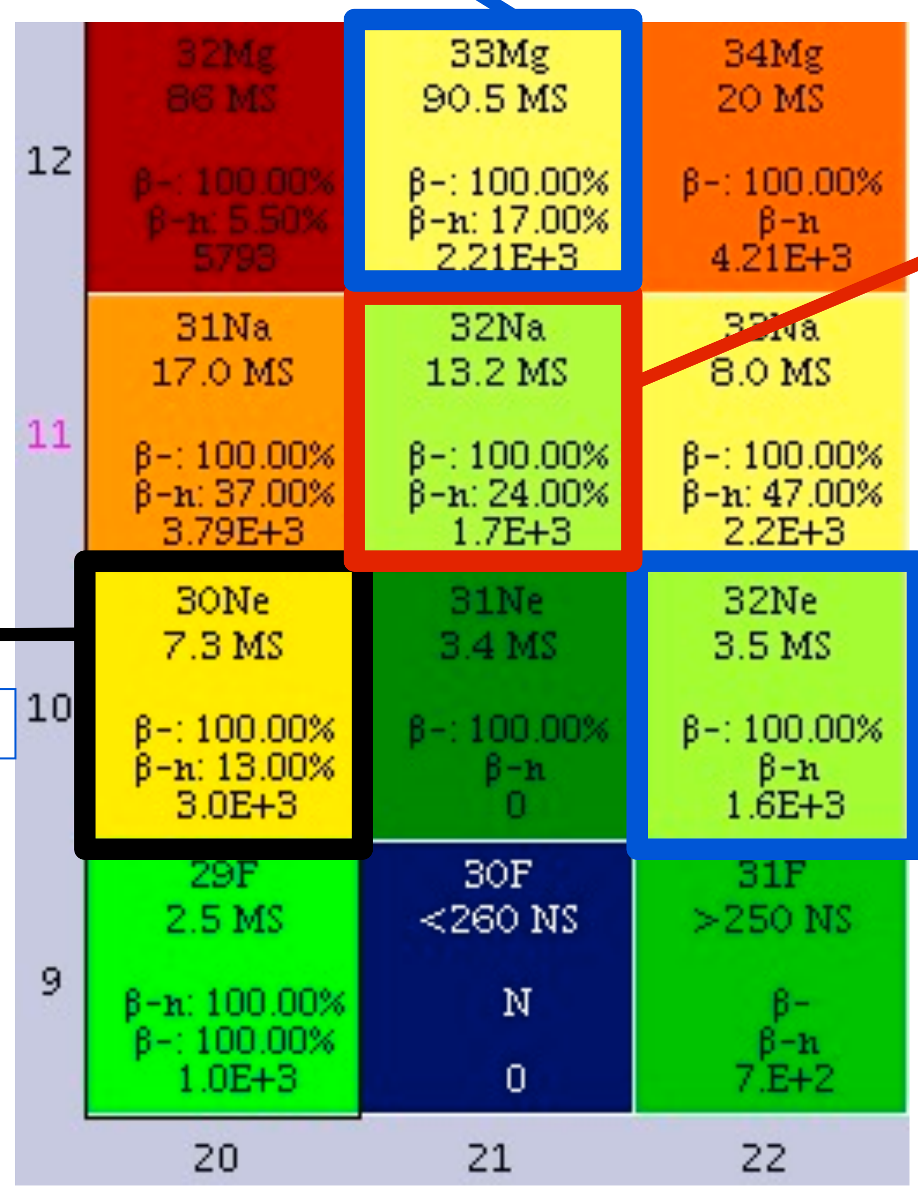
D. T. Yordanov et al., PRL 99,212501 (2007)

mass measurement

C. Thibault et al., Phys. Rev. C 12, 644 (1975)

low 2^{+} state

Y. Yanagisawa et al., PLB 566, 84 (2003)



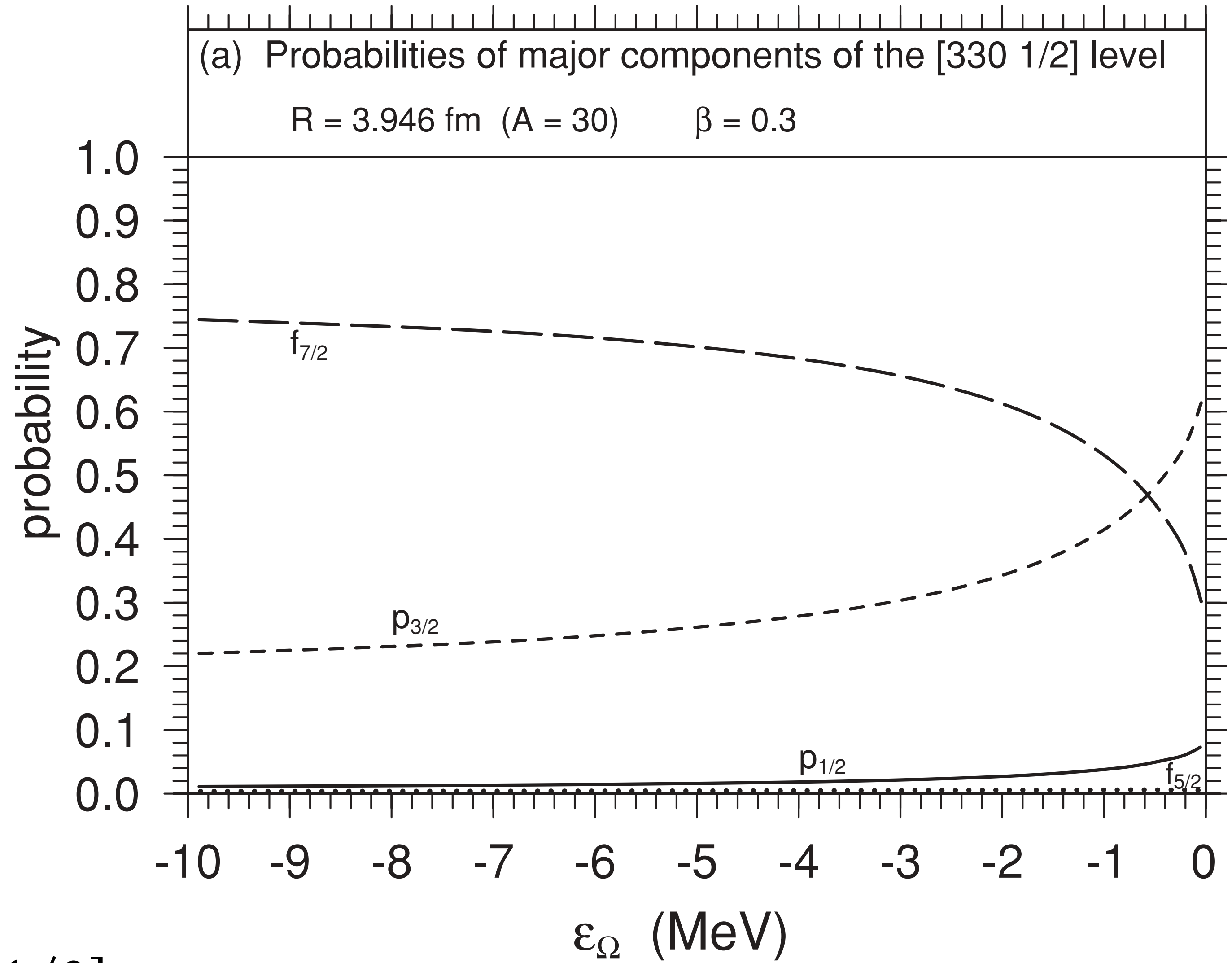
low 2^{+} state

P. Doornenbal et al., PRL 103, 032501 (2009)

⇒ ^{31}Ne likely to be deformed

Deformation in ^{31}Ne

- axially symmetric quad-deformed Wood-Saxon
- dominance of lowest ℓ-component for low binding energy
- irrespective of size of deformation or kind of orbit



<u>**Conclusions for ^{31}Ne:**</u>

- S_n>500 keV
  - the deformation large (β>0.6)
  - $I^{\pi}=1/2^{+}$ from the Nilson level [200 1/2].
- S_n<500 keV

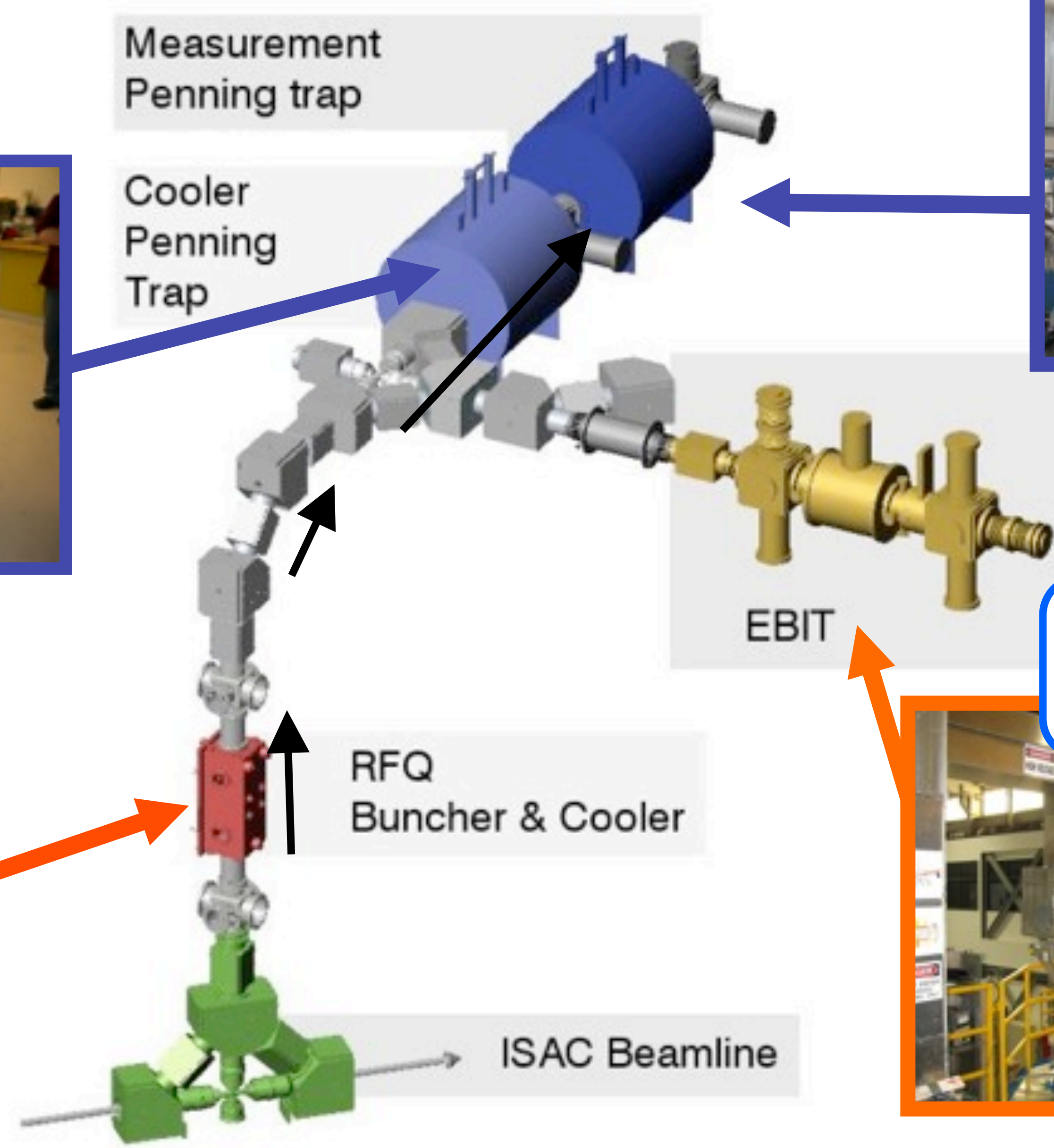
  I^{π}=3/2- and a p-wave neutron halo coming from either
  - [330 1/2] for 200 keV < S_n <500 keV or
  - [321 3/2] for 200 keV > S_n

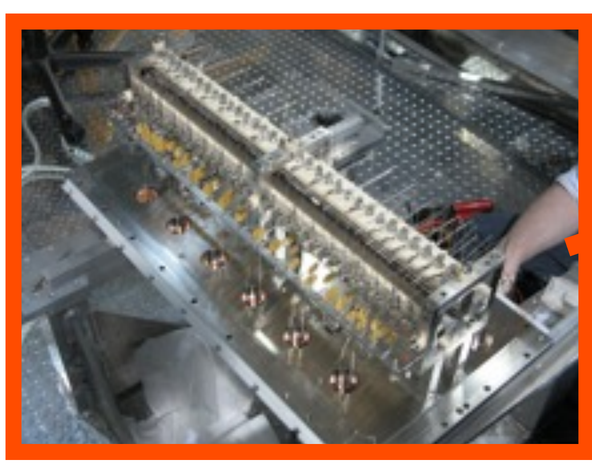
I. Hamamoto, Phys. Rev. C 81, 021304(R) (2010)
I. Hamamoto, Phys. Rev. C 76, 054319 (2007)
I. Hamamoto, Phys. Rev. C 69, 041306(R) (2004)

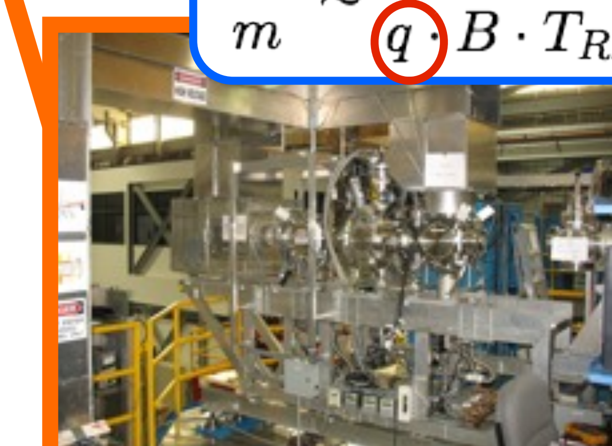
TITAN

determination of separation energies via direct mass measurement

$$S_n = m(Z, N-1) + m_n - m(Z, N)$$







$$\frac{\delta m}{m} \approx \frac{m}{q \cdot B \cdot T_{RF} \cdot \sqrt{N_{ion}}}$$

ISAC beam: A^+

Measurement @ TITAN

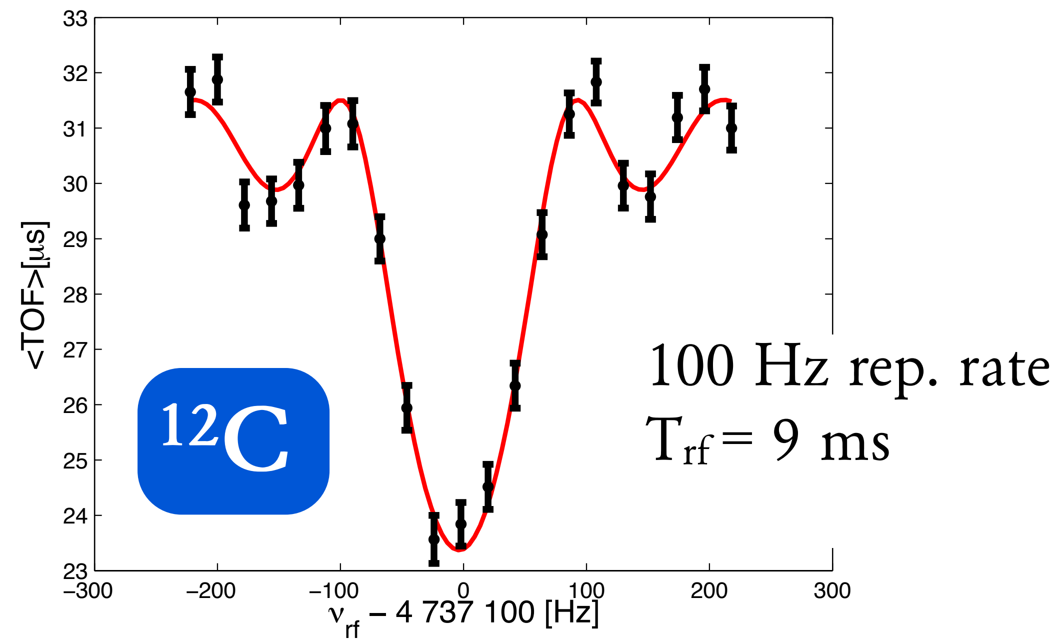
short half-lives:

3.4(8) ms for ^{31}Ne and 6.1(1.4) ms for ^{22}C

- ^{11}Li: 8.8 ms

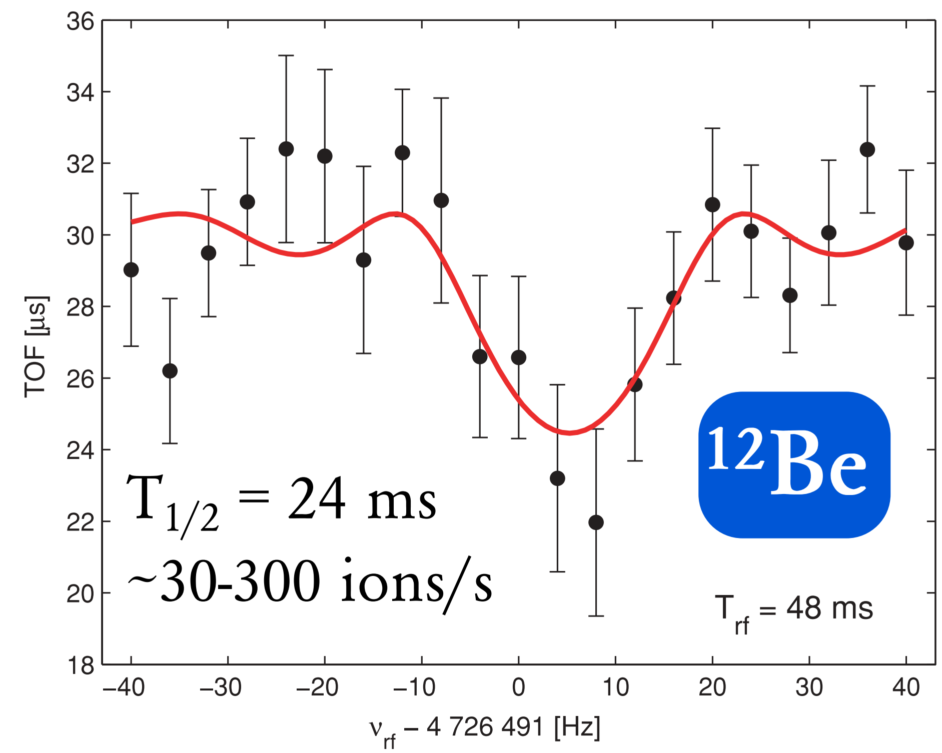
M. Smith et al., PRL 101, 202501 (2008)

- $T_{rf} \approx 2.9 \cdot T_{1/2} \Rightarrow$ **Trf = 10 ms**



low yields:

m.e.=25 078.0(2.1) keV



S. Ettenauer et al., PRC 81, 024314 (2010)

propose: mass measurement of ^{20,22}C and ^{31,30}Ne (^{30}Ne part of S1240) with $\delta m/m \approx 5 \cdot 10^{-7}$

request: 3 shifts + 1 shift setup for each case (12 shifts total)

requires beam development (UO or UC for Ne, UO for C) $\Rightarrow$ stage 1

Summary

- halo nuclei
  - ideal testing grounds for nuclear structure models
  - limited to lighter masses?
  - mechanism for halos in heavier systems?
- recent reaction measurements
  - ^{22}C in transmission experiment
  - ^{31}N in Coulomb breakup

  } evidence for halo structures in heavier systems
- in both cases: knowledge on S_{2n} limited

  ⇒ interpretation of data ambiguous

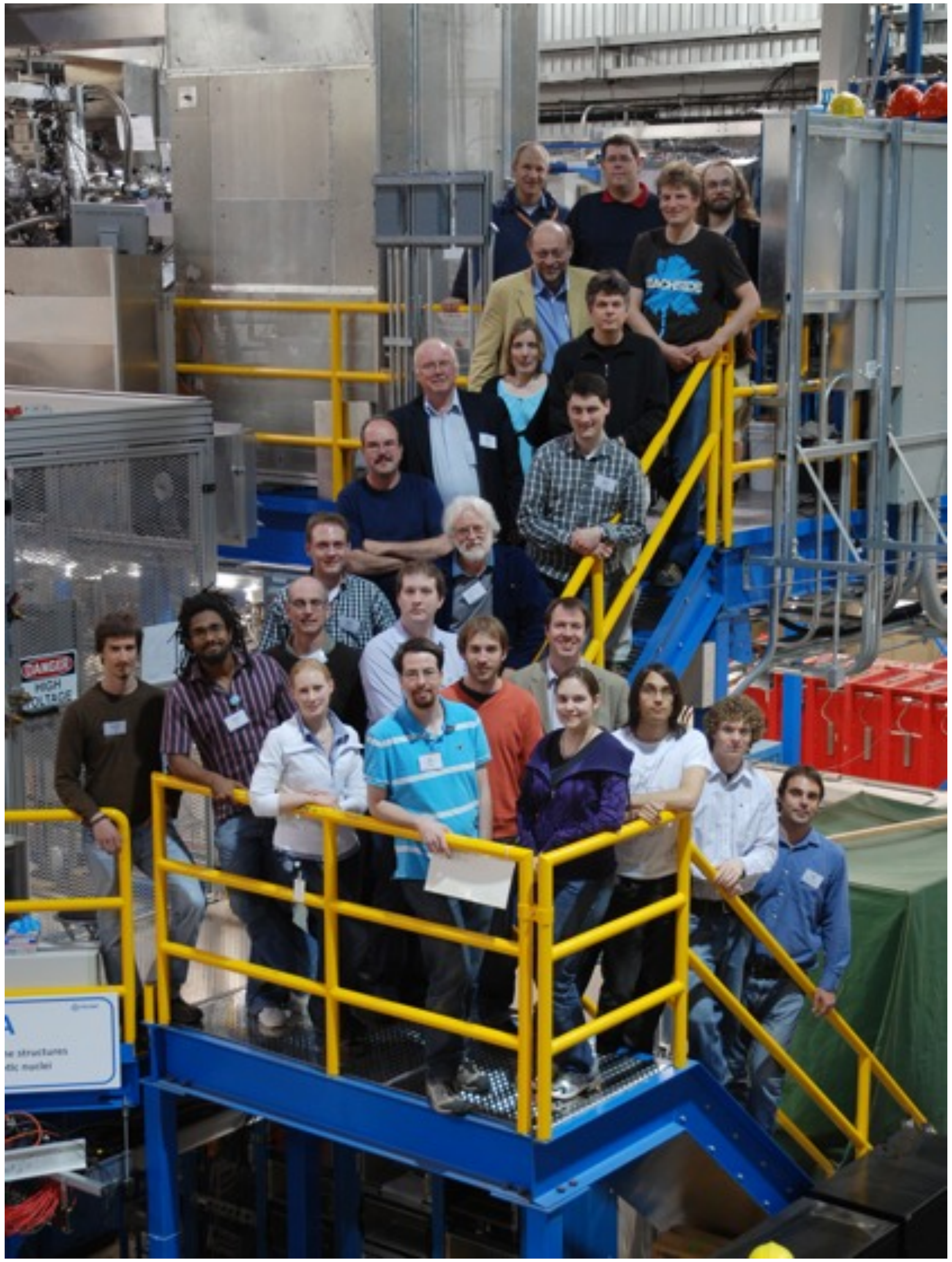
  ⇒ uncertainty in reaction models
- for ^{22}C: mass also benchmark for shell-model calculation
- **TITAN:**
  - fastest Penning trap spectrometer: $T_{1/2}$<10 ms possible
  - measurements with low yields feasible
  - propose mass measurement of $^{20,22}C$ and $^{31,30}Ne$ to extract S_{2n} and S_n
  - request 12 shifts / stage 1

TRIUMF ISAC

S1283 collaboration

- **TRIUMF:** J. Dilling, P. Delheij, M. Pearson, E. Mané, M. C. Simon, T. Brunner, U. Chowdhury, B. Eberhart, S. Ettenauer, A. Gallant, V. Simon
- **CSNSM-IN2P3-CNRS:** D. Lunney
- **University of Manitoba:** G. Gwinner
- **NSCL:** M. Brodeur, R. Ringle

U. of Manitoba	CNRS- CSNSM
McGill U.	U. of Windsor
Muenster U.,	Colorado School of Mines
Max Plank Inst. of Heidelberg	TRIUMF
GANIL	UBC



Backup Slides

Precise & Accurate

line width (FWHM):

$$\Delta\nu \approx 1/T_{rf}$$

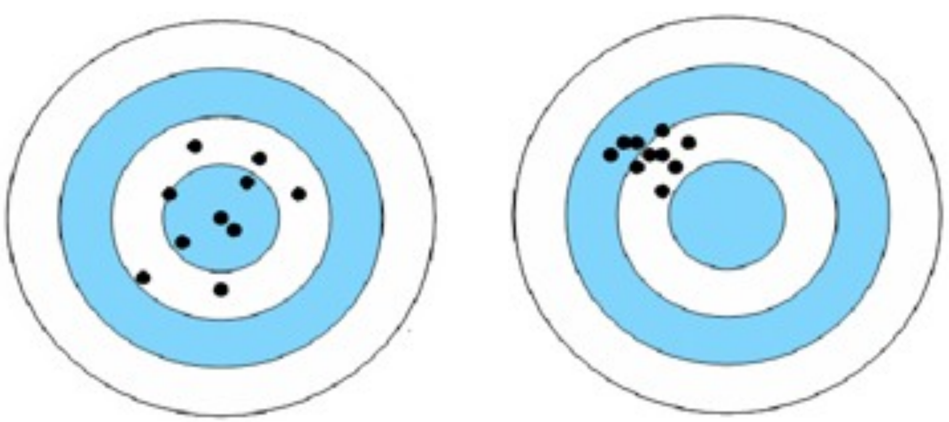
⇒ resolution:

$$R = \frac{m}{\Delta m} = \frac{\nu_c}{\Delta \nu_c} \approx \nu_c T_{rf}$$

$$\approx \frac{qBT_{rf}}{2\pi m}$$

⇒ even for $T_{rf} \sim 10\text{ms}$

$$(\delta m/m)_{\texttt{stat}} < 10^{-7}$$



accurate,
but not precise

precise,
but not accurate

- exact theoretical description

L.S. Brown and G. Gabrielse, Rev. Mod. Phys. 58, 233 (1986)
G. Bollen et al., J. Appl. Phys. 88, 4355 (1990)
M. König et al., Int. J. Mass Spect. 142, 95 (1995)
M. Kretzschmarr, Int. J. Mass Spect. 246, 122 (2007)

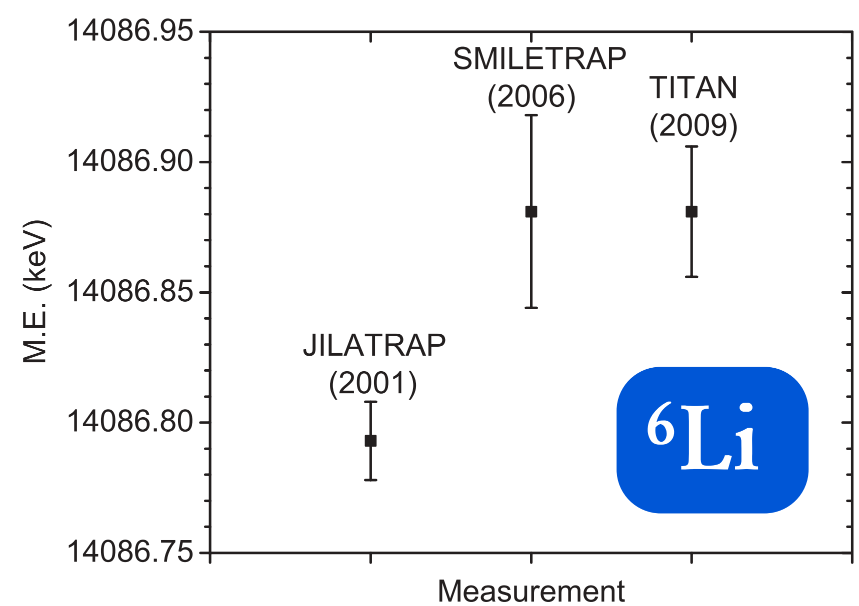
- even for non-ideal traps

G. Bollen et al., J. Appl. Phys. 88, 4355 (1990)
G. Gabrielse, PRL 102, 172501 (2009)

- off-line tests with stables

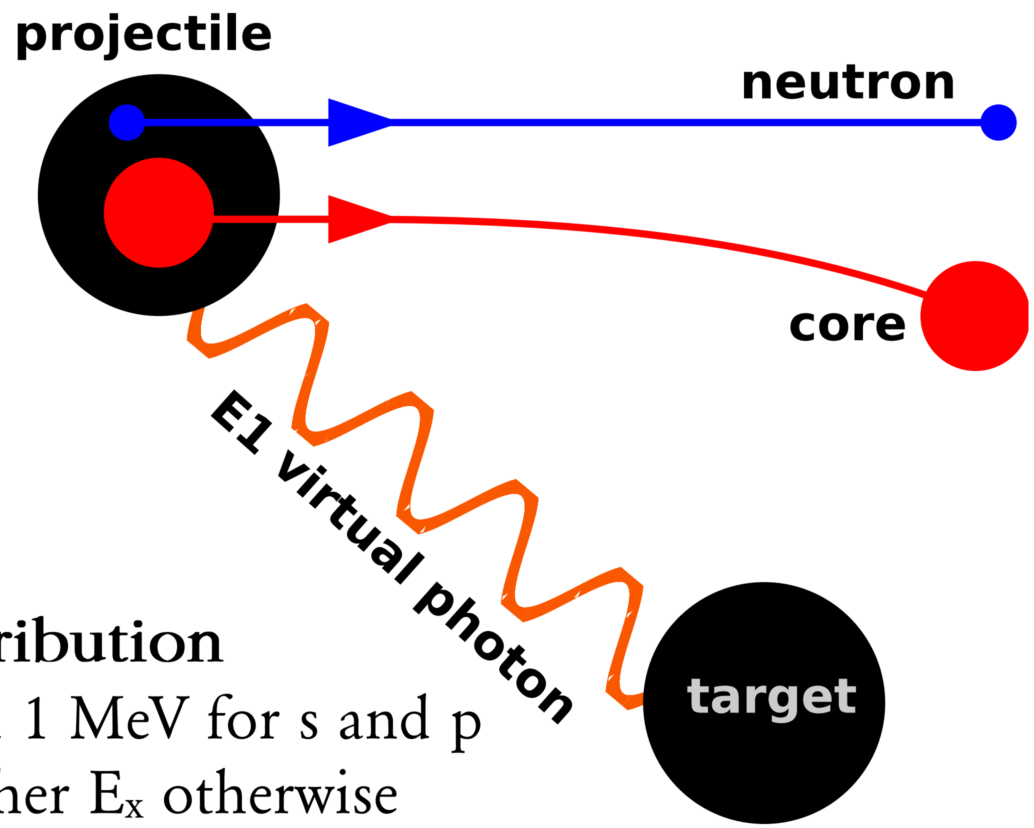
⇒ control over systematics

<u>for TITAN:</u> < 5 ppb possible



M. Brodeur et al, PRC 80, 044318 (2009)

Coulomb Breakup



- low-lying electric dipole strength E1 is enhanced for halos, because:
- one neutron-removal cross section $\sigma_{-1n}(E1)$ due to dipole strength E1 follows

$$\sigma_{-1n}(E1) = \int_{Sn}^{\infty} \frac{16\pi^3}{9\hbar c} N_{E1}(E_x) \frac{dB(E1)}{dE_x} dEx$$

E1 virtual photon number
- exponentially decreasing

E1 strength distribution
- peaked at around 1 MeV for s and p
- maximum at higher E_x otherwise

  - enhanced for s and p orbitals
  - estimating $\sigma_{-1n}(E1)$ is thus a signature for a halo

- measured σ_{-1n} has contributions from Coulomb and from nuclear interaction
- 2 targets:
  - Pb (Z=82): Coulomb dominated
  - C: pure nuclear contribution
  - Γ scales nuclear part from C to Pb

$$\sigma_{-1n}(E1) = \sigma_{-1n}(Pb) - \Gamma\sigma_{-1n}(C)$$