Neutron removal reactions of Ne, Mg, and Si isotopes near/inside the island of inversion

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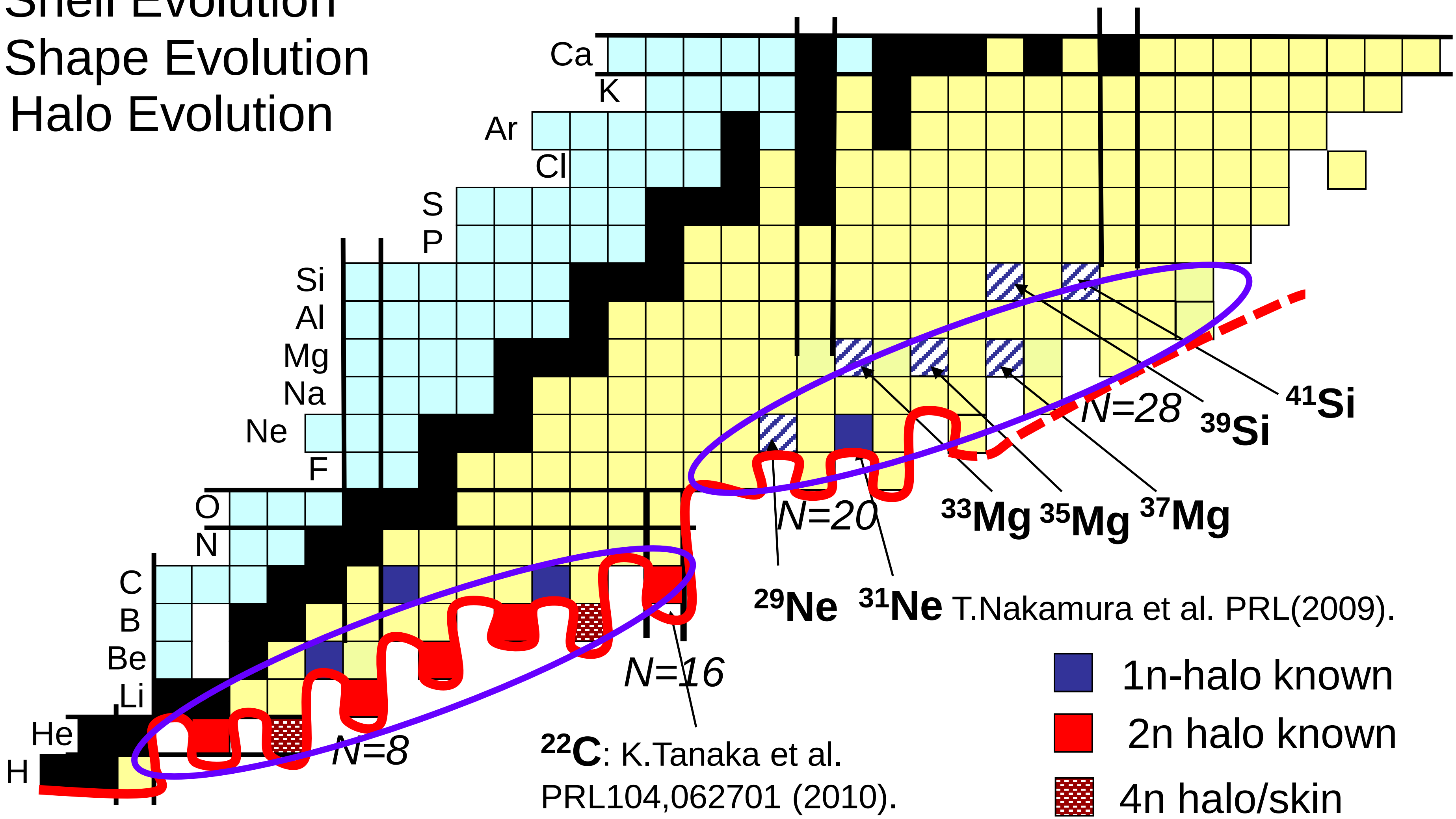
RIBF Discussion Meeting on Deformed Halo

Evolution Towards the Stability Limit

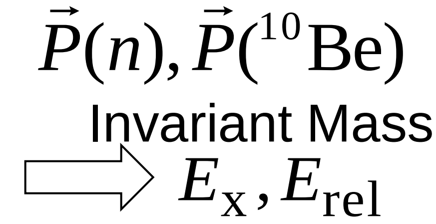
A 30~40 (20<N<28)

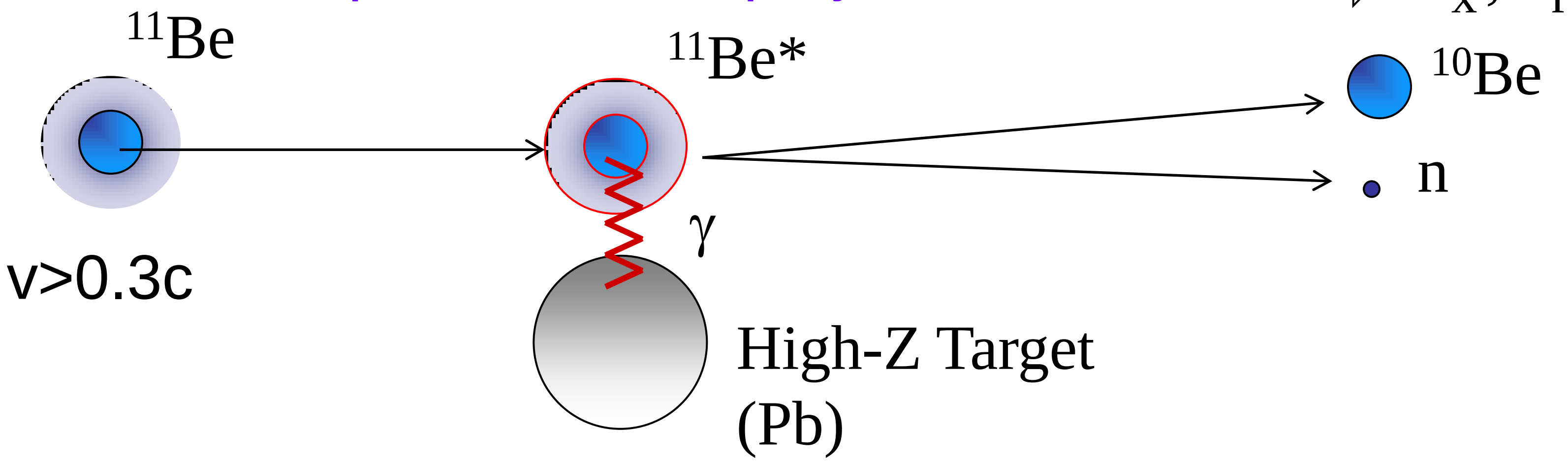
Shell Evolution
Shape Evolution
Halo Evolution



Probe-1: Coulomb Breakup

→Photon absorption of a fast projectile



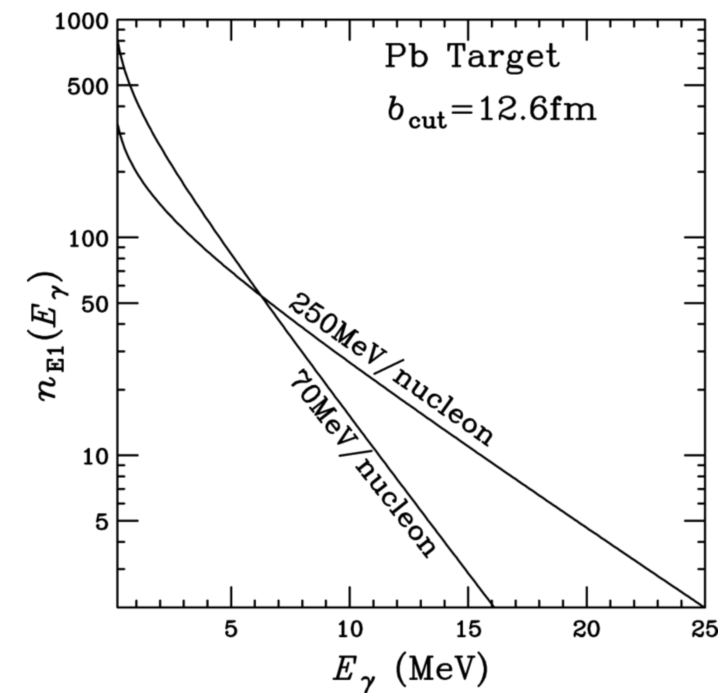


Equivalent Photon Method

$$\frac{d\sigma_{CB}}{dE_x} = \frac{16\pi^3}{9\hbar c} N_{E1}(E_x) \frac{dB(E1)}{dE_x}$$

Cross section = (Photon Number)x(Transition Probability)

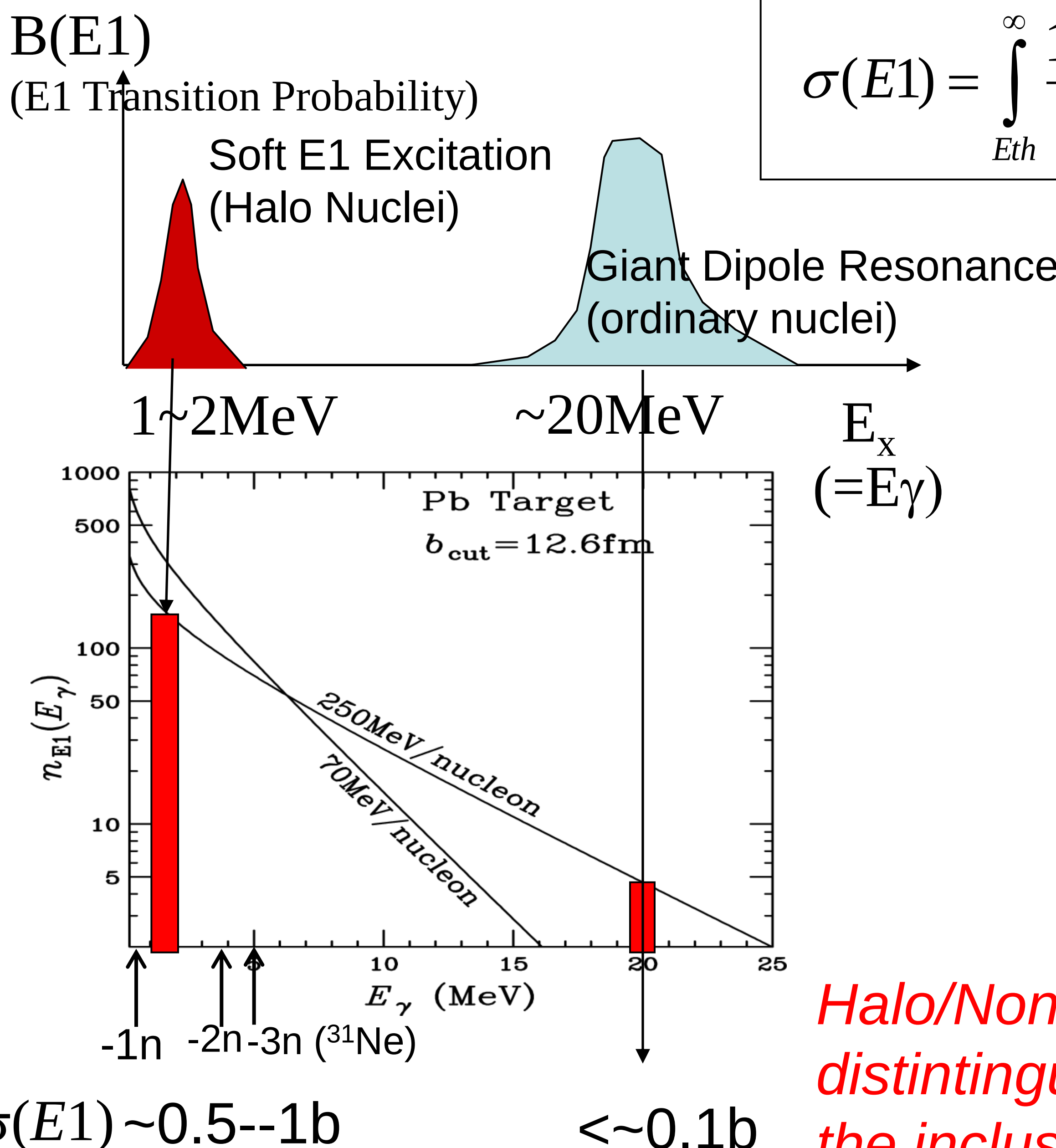
C.A. Bertulani, G. Baur, Phys. Rep. 163,299(1988).



Inclusive Coulomb Breakup

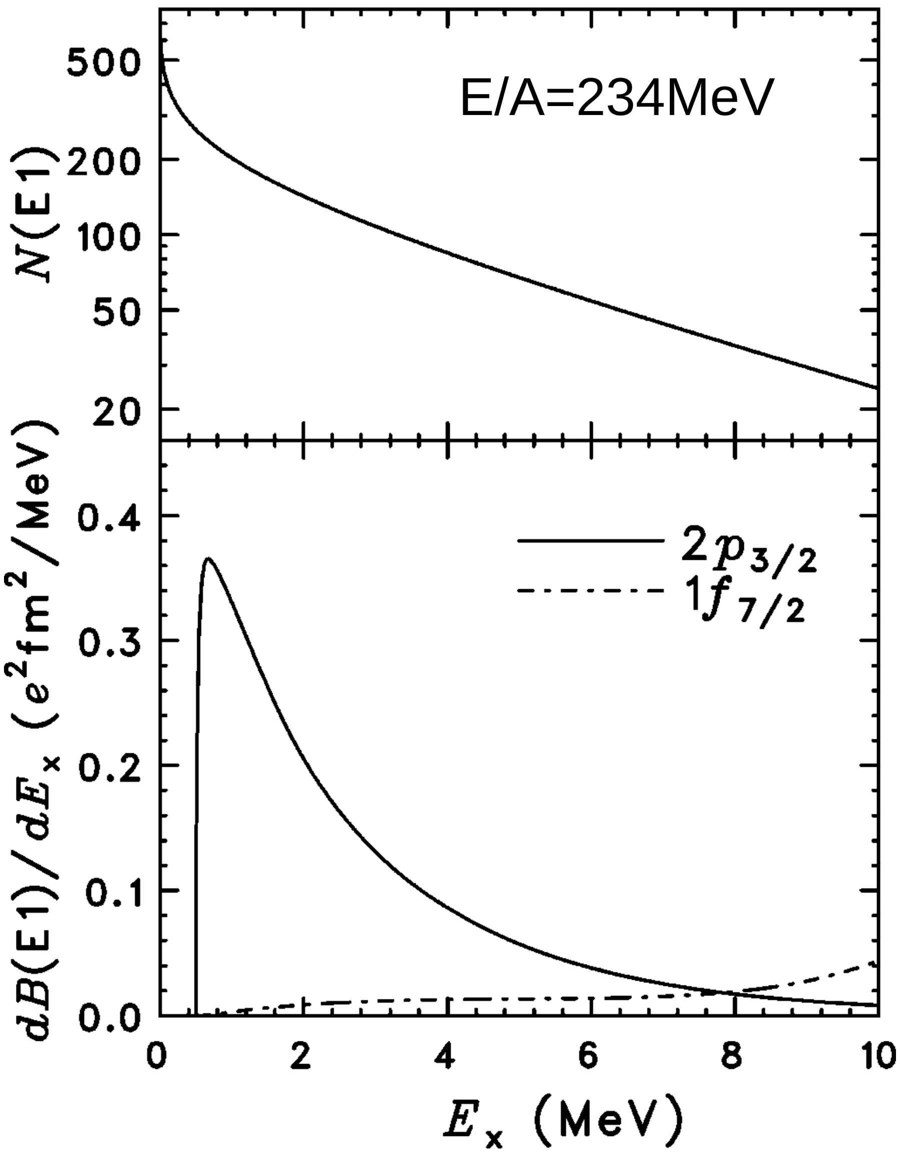
$$\sigma(E1) = \int_{Eth}^{\infty} \frac{16\pi^3}{9\hbar c} N_{E1}(E_x) \frac{dB(E1)}{dE_x} dE_x$$

$^{31}Ne + Pb \rightarrow {}^{30}Ne + X$



Halo/Non Halo can be distintinguished only from the inclusive cross section !

^{31}Ne (N=21) S_n=0.29(1.64)MeV

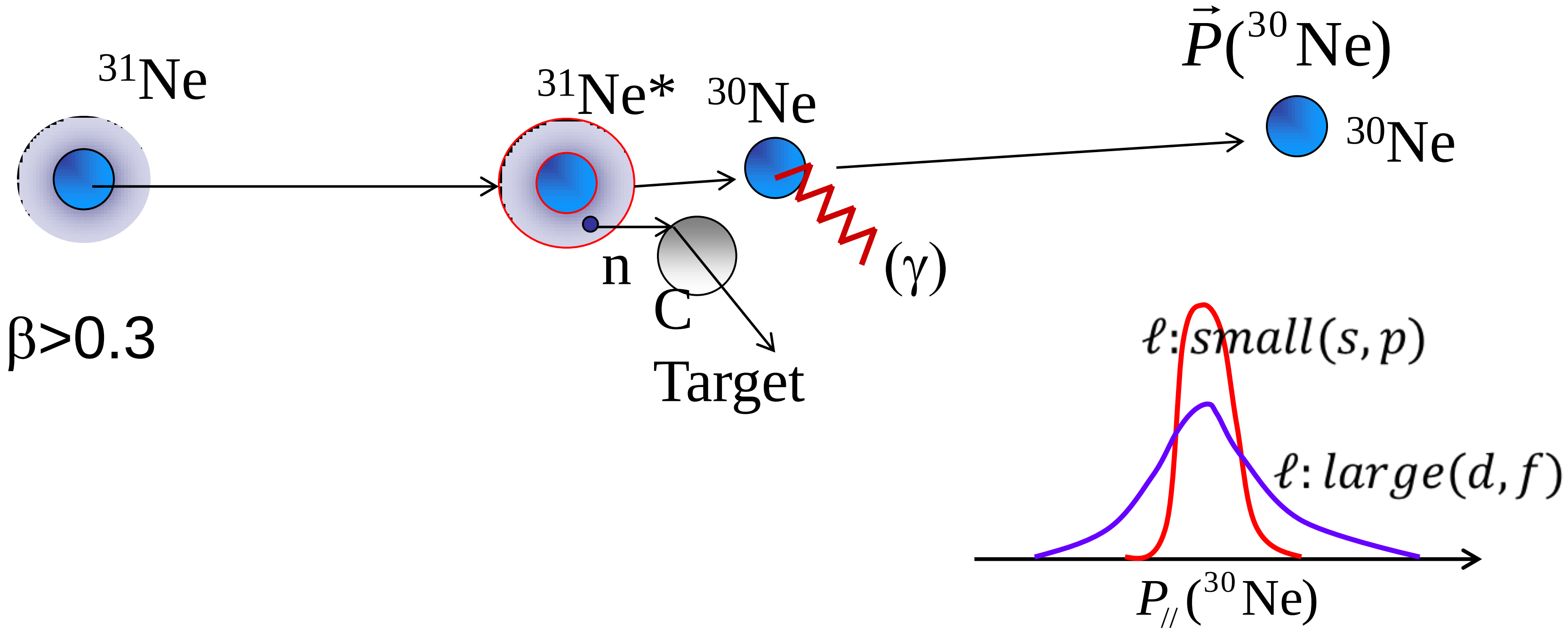


$$\sigma(E1) = \int_{Eth}^{\infty} \frac{16\pi^3}{9\hbar c} N_{E1}(E_x) \frac{dB(E1)}{dE_x} dE_x$$

$$\frac{dB(\mathrm{E1})}{dE_\mathrm{x}} \propto \left| \langle \boldsymbol{q} | \frac{Z}{A} \mathrm{r} \mathrm{Y}^1{}_\mathrm{m} | \Phi_\mathrm{gs} \rangle \right|^2 = \Sigma C^2 S \left| \langle \Phi_\mathrm{f} | \frac{Z}{A} \mathrm{r} \mathrm{Y}^1{}_\mathrm{m} | \phi_{nlj} \rangle \right|^2$$

Probe-2: **Nuclear Breakup**

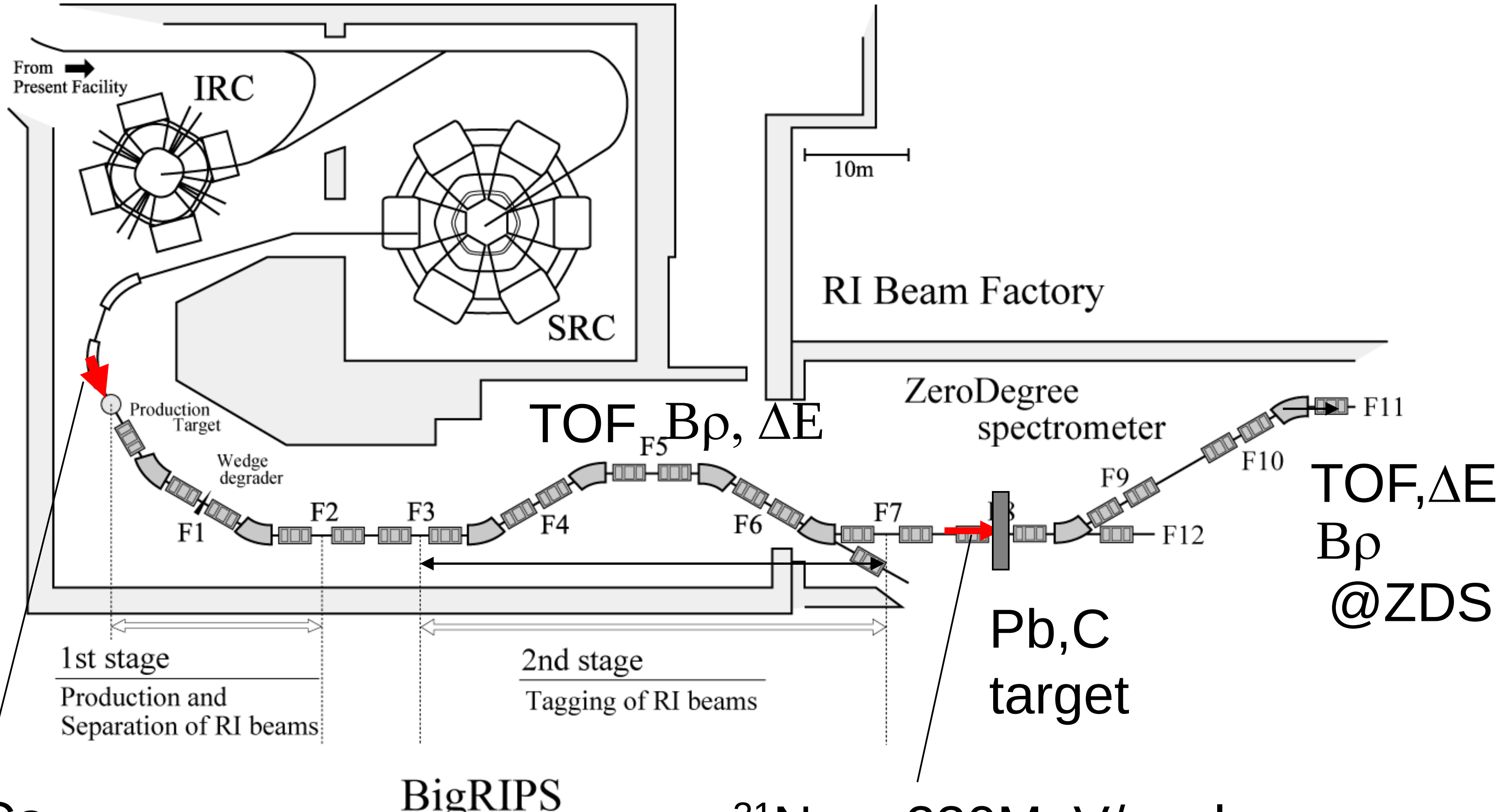
→e.g. 1n knockout reaction of ^{31}Ne



- γ ray in coincidence → ^{30}Ne(2^{+}) / ^{30}Ne(0^{+}) Contribution
- σ_{-1n} and $P_{//}$ distribution → ℓ of valence n, configuration

Theory: Eikonal Approximation

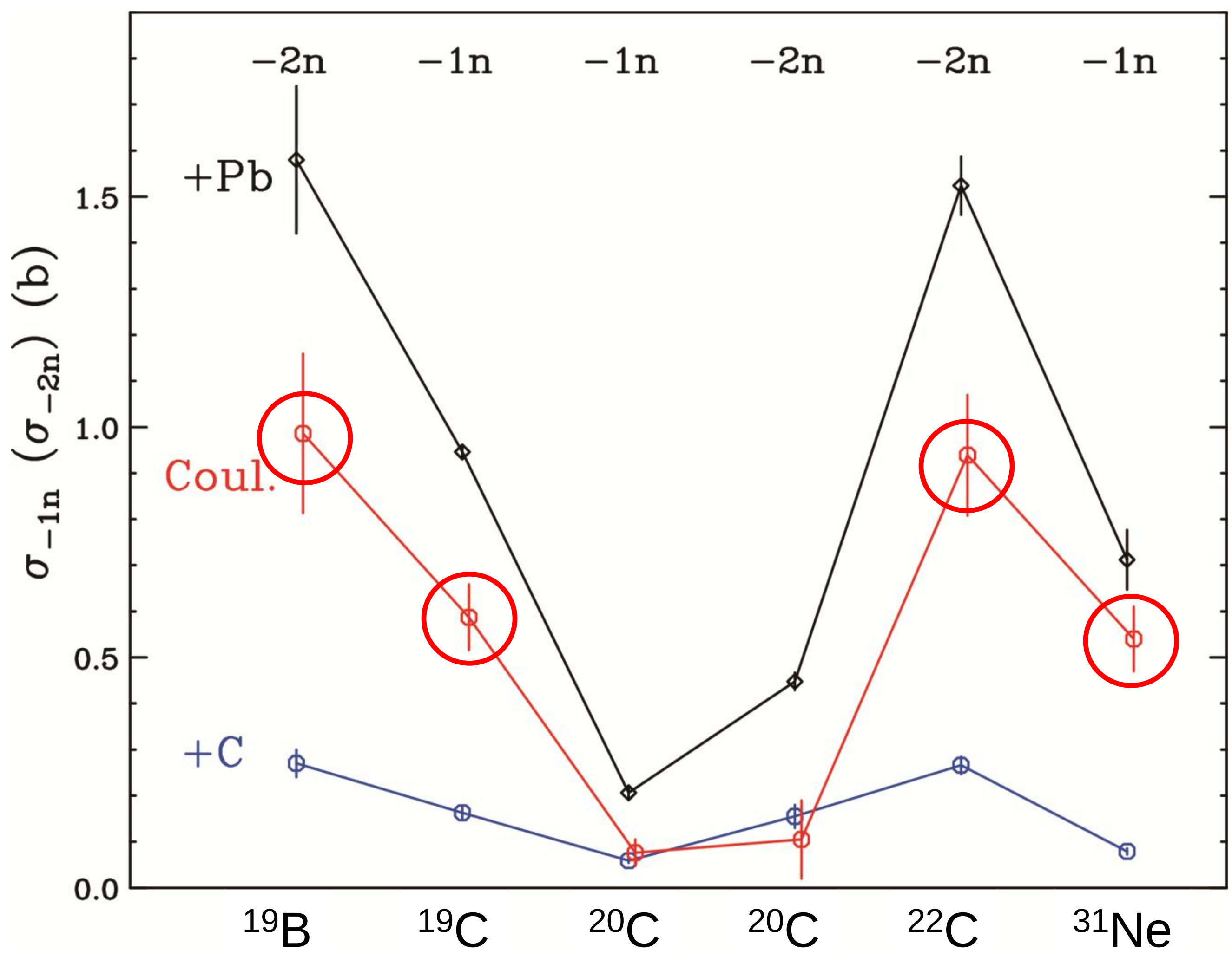
Experiment at BigRIPS & ZDS at RIBF



^{48}Ca
345MeV/nucleon
60-150pnA

^{31}Ne ~230MeV/nucleon
^{19}C,^{20}C,^{22}C ~240MeV/nucleon
^{19}B ~ 226MeV/nucleon

RESULTS: 1n (or 2n) removal cross section →Coulomb breakup cross section



Evidence for

2n Halo in ^{22}C

1n Halo in ^{31}Ne

c.f. ^{19}C (known halo)

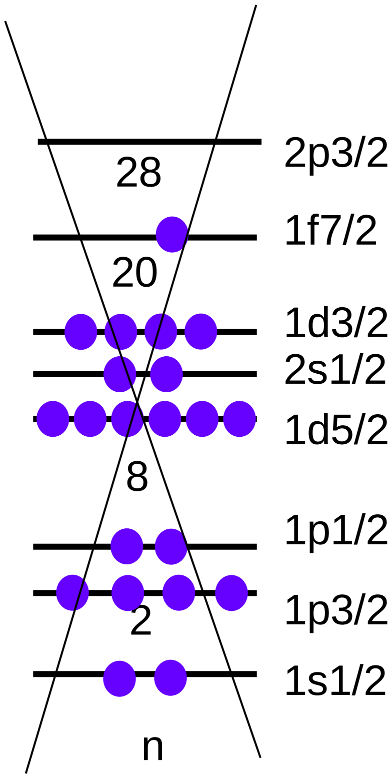
2n Halo in ^{19}B :
First Measurement

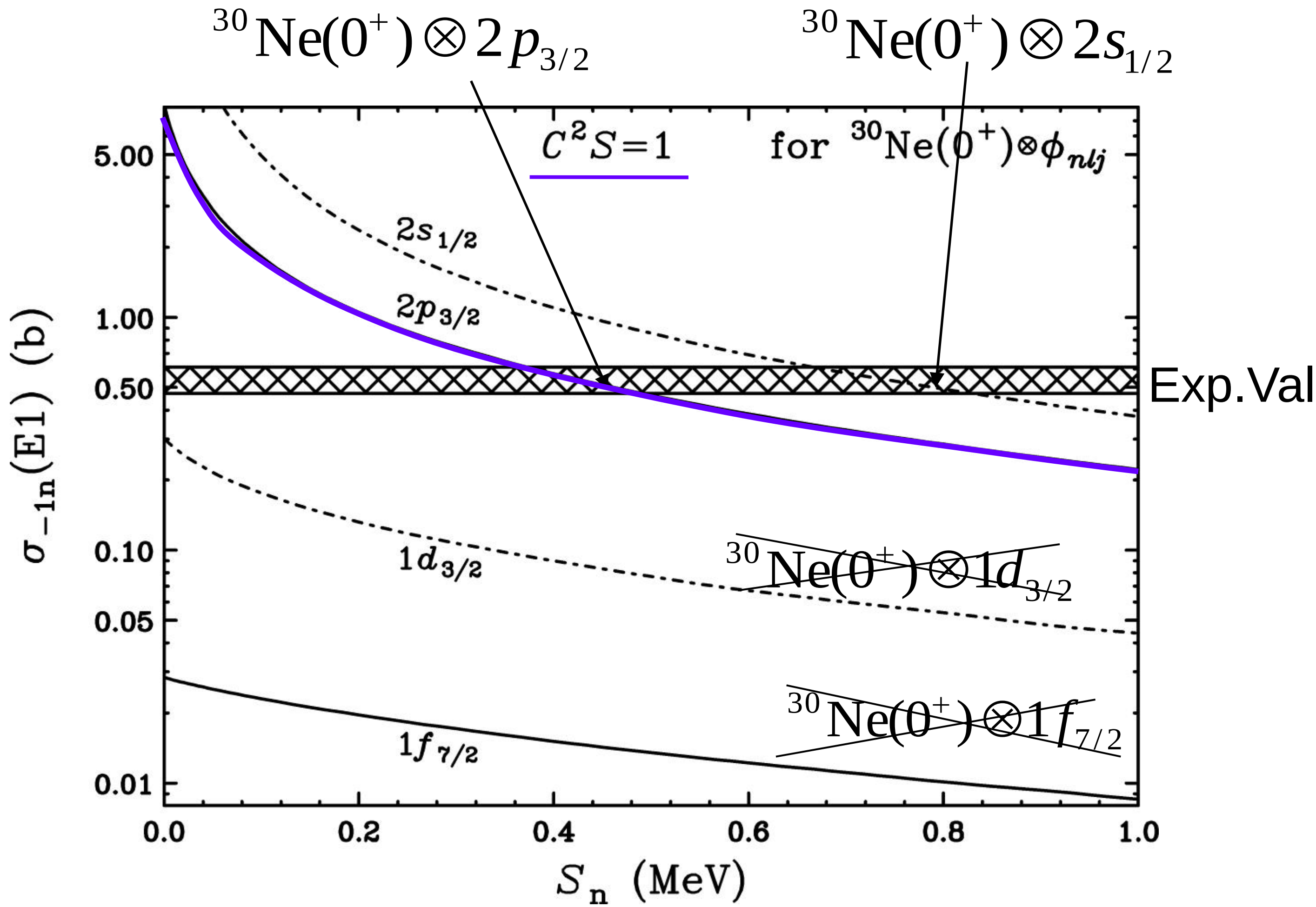
$$\sigma(E1) = \sigma(Pb) - \Gamma\sigma(C)$$

$$\Gamma = \sim 1.7 - 2.6$$

c.f. ^{22}C: Reaction cross section, K.Tanaka et al.PRL104,062701 (2010).
^{31}Ne: Reaction cross section, M. Takechi et al.PLB707, 357 (2012).

^{31}Ne (N=21) Shell Configuration





$2p_{3/2}$ or $2s_{1/2}$ Low-L orbits → Large E1→1n-halo structure of ^{31}Ne

^{30}Ne(0$^+$)X1$f_{7/2}$ Excluded →Shell gaps(20,28) vanish at ^{31}Ne

→Island of inversion

Still Unknown: Sn/Configuration Mixing $C^2S<1$

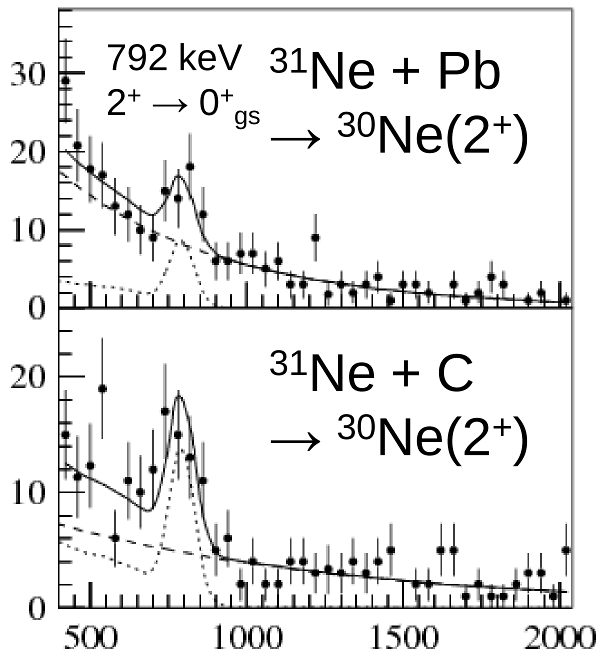
How the ^{31}Ne g.s. is made of ?

⇨ γ and Nuclear Breakup data

Monte Carlo Shell Model
by Utsuno ,Otsuka
→ $3/2^-$ g.s.

$$^{30}\mathrm{Ne}(0^+)\otimes 2p_{3/2} \quad C^2S = 0.12$$
$$^{30}\mathrm{Ne}(2^+)\otimes 2p_{3/2} \quad C^2S = 0.27$$
$$^{30}\mathrm{Ne}(2^+)\otimes 1f_{7/2} \quad C^2S = 0.25$$

Possible Large Proportion for the ^{30}Ne(2$^+$)x(nlj) Configuration



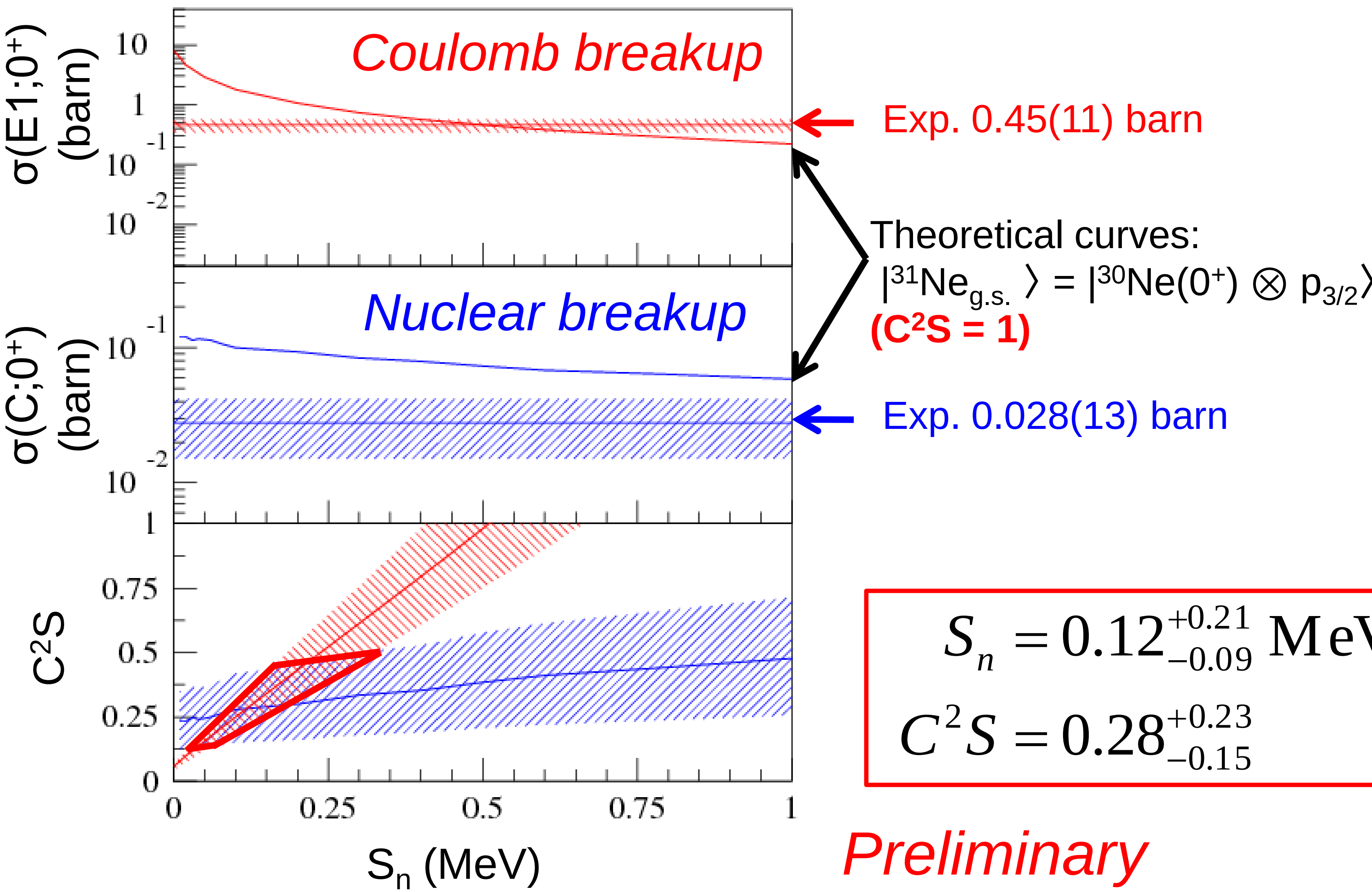
^{31}Ne+Pb→^{30}Ne(0$^+$) : 0.515(103) barn
^{31}Ne+Pb→^{30}Ne(2$^+$) : 0.197(79) barn

→σ(E1;0$^+$) = 0.45(11) barn
(~90% of Total σ(E1)=0.54(7)barn)

^{31}Ne+C→^{30}Ne(0$^+$) : 0.028(13) barn ~35%
^{31}Ne+C→^{30}Ne(2$^+$) : 0.051(12) barn ~65%

Estimation of C^2S & S_n

Channel: $^{31}Ne \rightarrow {}^{30}Ne(0^+)$



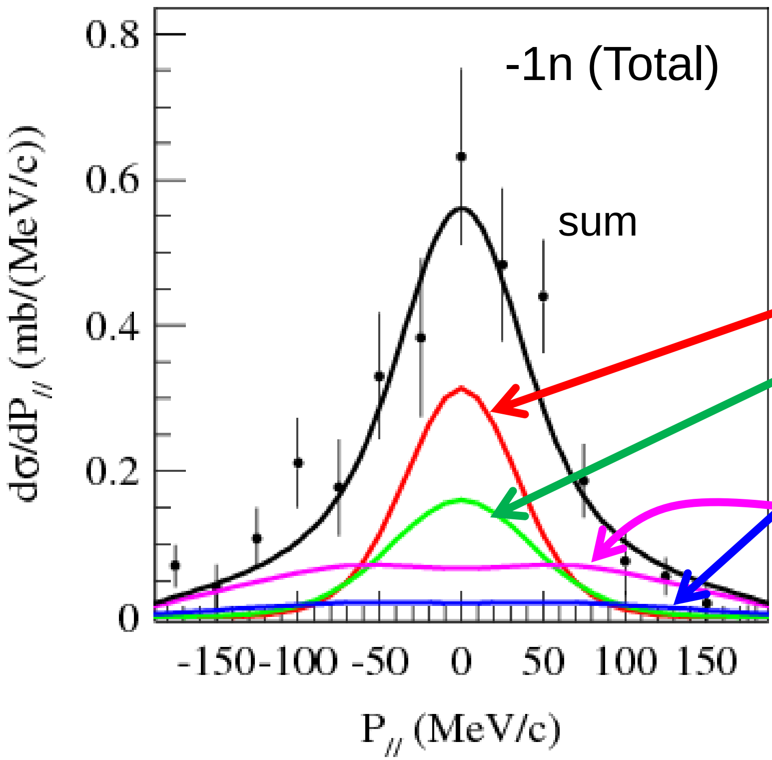
$$S_n = 0.12^{+0.21}_{-0.09}\ \mathrm{MeV}$$

$$C^2S = 0.28^{+0.23}_{-0.15}$$

Preliminary

Momentum distribution of ^{30}Ne fragment

^{31}Ne+C→^{30}Ne+X



Resolution(σ)= 24 MeV/c
Γ (FWHM) =73(11) MeV/c

S_n =0.12 MeV

state	C^2S	σ(barn)
$\|^{30}Ne(0^+)\otimes 2p_{3/2}\rangle$	0.28	0.028
$\|^{30}Ne(2^+)\otimes 2p_{3/2}\rangle$	0.27	0.018
$\|^{30}Ne(2^+)\otimes 1f_{7/2}\rangle$	0.25	0.0058
$\|^{30}Ne(4^+)\otimes 1f_{7/2}\rangle$	1.06	0.021
	total	0.073 b (0.079(7)b)

Exp.

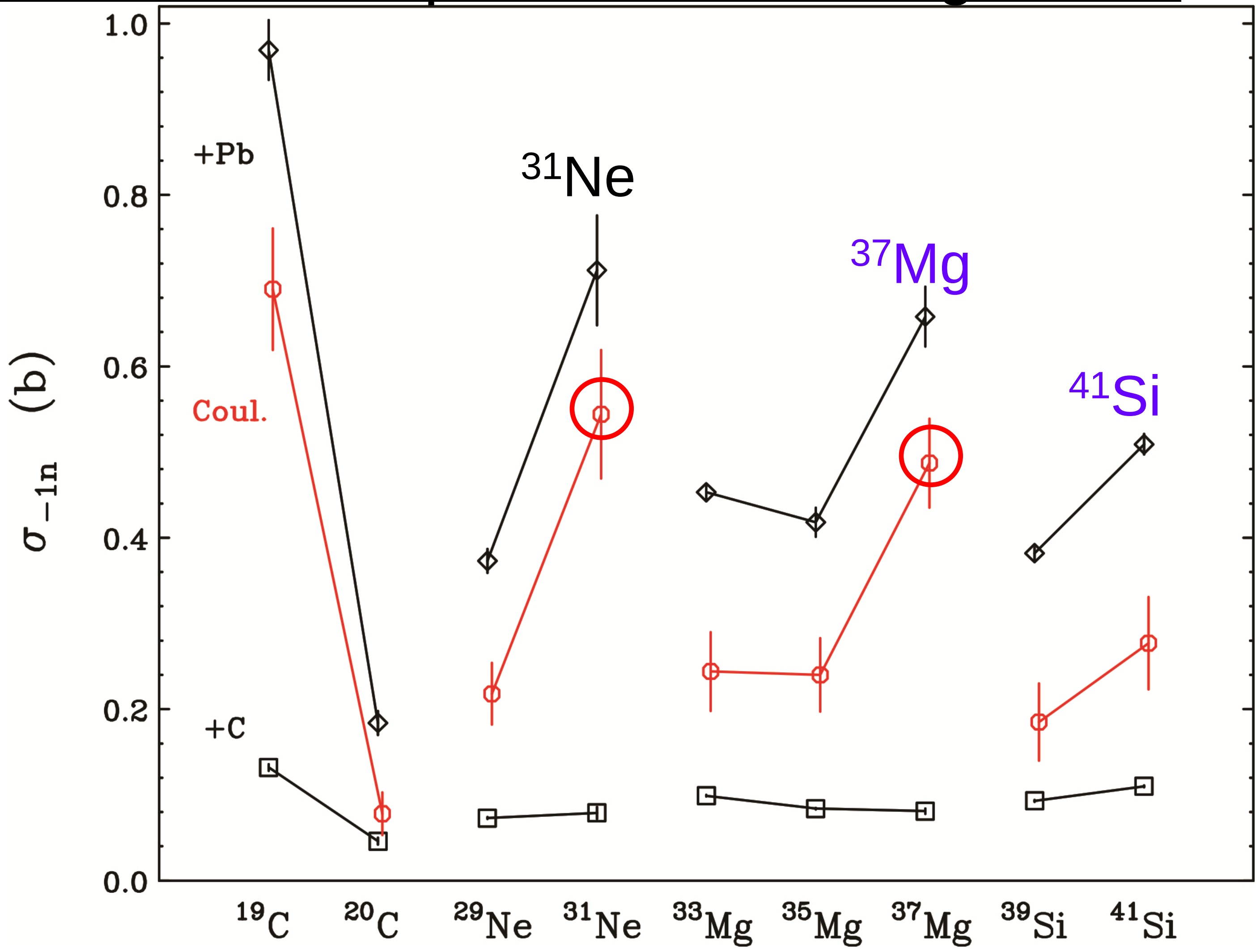
Shell model calculation
by using SDPF-M interaction

Preliminary

"p-wave neutron halo composed of two components"

Results of ^{29}Ne,^{33,35,37}Mg,^{39,41}Si

Coulomb Breakup of ^{29}Ne, ^{33,35,37}Mg, ^{39,41}Si



^{37}Mg: σ(E1)=490(50) mb *(preliminary)*

→ ***^{37}Mg: Possible 1n-Halo State***

c.f. ^{31}Ne σ(E1)=540(70) mb

preliminary

Momentum Distribution

$^{37,35,33}Mg + C \rightarrow ^{36,34,32}Mg$

Curves: Fitted with Eikonal Calculation assuming
gs(Odd Mg 7/2- or 3/2-) to gs (Even Mg 0+) transition

N.B. In reality these two components should not be directly added, but the p and f ratio could be estimated.

Mixture of $p_{3/2}$ and $f_{7/2}$

$\sigma_{-1n}(f_{7/2}) \sim \sigma_{-1n}(p_{3/2})$

preliminary

Momentum Distribution

$^{29}Ne+C \rightarrow ^{28}Ne$

$^{39,41}Si+C \rightarrow ^{38,40}Si$

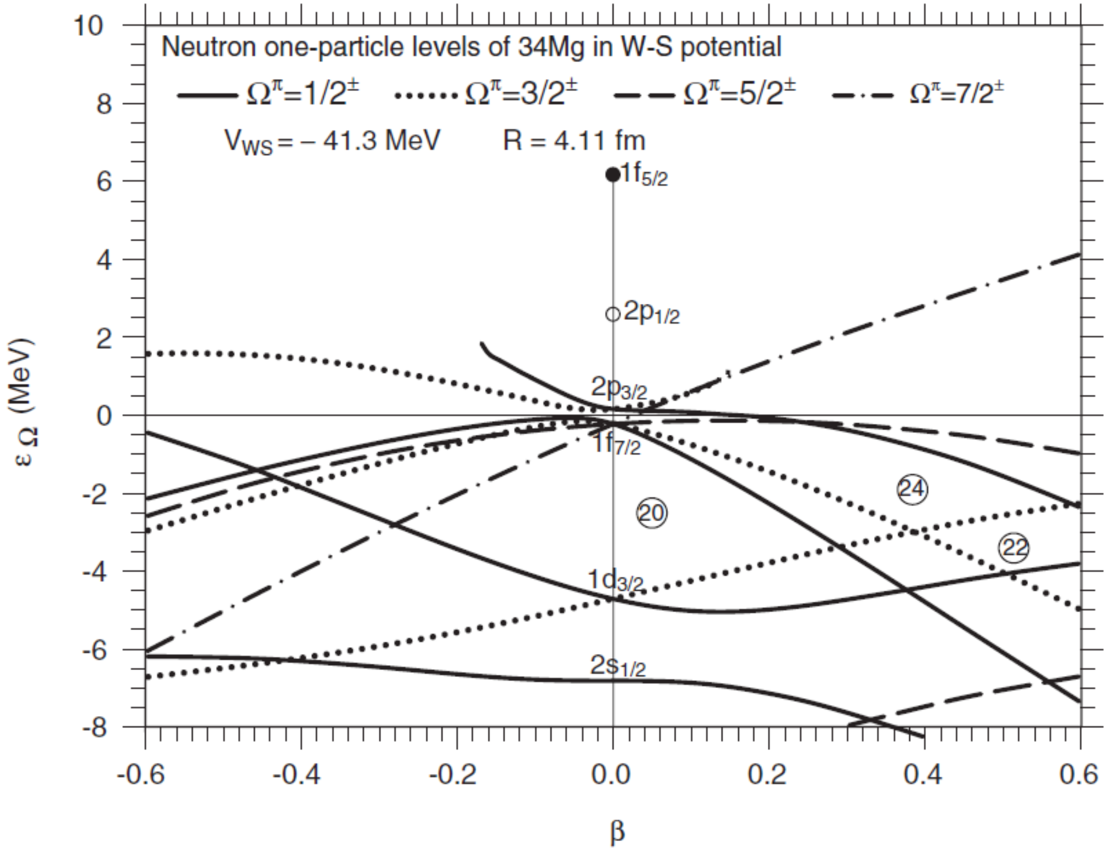
Mixture of $s_{1/2}$ and $d_{3/2}$

σ_{-1n} ($d_{3/2}$) > σ_{-1n} ($s_{1/2}$)

Mixture of $p_{3/2}$ and $f_{7/2}$

σ_{-1n} ($f_{7/2}$) > σ_{-1n} ($p_{3/2}$)

Preliminary Interpretation by Nilsson Model



I.Hamamoto PRC85, 064329 (2012).

^{29}Ne,^{33}Mg,^{35}Mg,^{37}Mg,^{39}Si,^{41}Si
(N=19, 21, 23, 25, 25, 27)

eg. β=0.2

^{29}Ne(N=19) $3/2^+$ (Ω=3/2+)
^{31}Ne(N=21) $3/2^-$ (Ω=1/2-)
^{33}Mg(N=21) $3/2^-$ (Ω=1/2-)
^{35}Mg(N=23) $3/2^-$ (Ω=3/2-)
^{37}Mg(N=25) $5/2^-$ (Ω=5/2-)
^{39}Si (N=25) $5/2^-$ (Ω=5/2-)
^{41}Si (N=27) $3/2^-$ (Ω=1/2-)

^{37}Mg(N=25)
most probably 3/2- → β>0.25

^{33,35,37}Mg seems to have similar behavior except that ^{37}Mg is like halo. 2+ energy of the core is similar, too.

Summary

- **Coulomb/Nuclear Breakup of ^{31}Ne (inclusive)**

  Combinatorial Analysis → S_n~0.12MeV, $C^2S(p_{3/2} \times {}^{30}Ne(0^+))$~0.27

  Mixed with $p_{3/2} \times {}^{30}Ne(2^+)$

  $f_{7/2} \times {}^{30}Ne(2^+)$

- **Coulomb/Nuclear Breakup of ^{29}Ne, ^{33,35,37}Mg, ^{39,41}Si (inclusive)**

  ^{37}Mg ---- Large E1 Cross Section 0.49(5) barn → Halo Like Structure

  Momentum Distribution of fragment with C target →

  ^{33,35,37}Mg Mixture of $p_{3/2}$ and $f_{7/2}$ configuration $\sigma(f_{7/2}) \sim \sigma(p_{3/2})$

  ^{39,41}Si $\sigma(f_{7/2}) > \sigma(p_{3/2})$

  ^{29}Ne $\sigma(d_{3/2}) > \sigma(s_{1/2})$

---"Island of inversion"→Halo with Deformed Core

(How do we call this?

Deformed Halo ?

Deformed-core coupled halo?)

Collaborators

Inclusive Coulomb Breakup of ^{31}Ne and ^{22}C (^{31}Ne Coulomb BU: PRL103,262501(2009))

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Inclusive Coulomb/Nuclear Breakup of ^{29}Ne, ^{33,35,37}Mg, ^{39,41}Si

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