Efimov Effect in 2-Neutron Halo Nuclei

Indranil Mazumdar
Dept. of Nuclear & Atomic Physics,
Tata Institute of Fundamental Research,
Mumbai 400 005

Critical Stability
Erice, 0ct.08

Halo World:

The story according to Faddeev, Efimov and Fano

Plan of the talk

- *Introduction to Nuclear Halos*
- *Three-body model of 2-n Halo nucleus*

  probing the structural properties of ^{11}Li
- *Efimov effect in 2-n halo nuclei*
- *Fano resonances of Efimov states*
- *Summary and future scope*

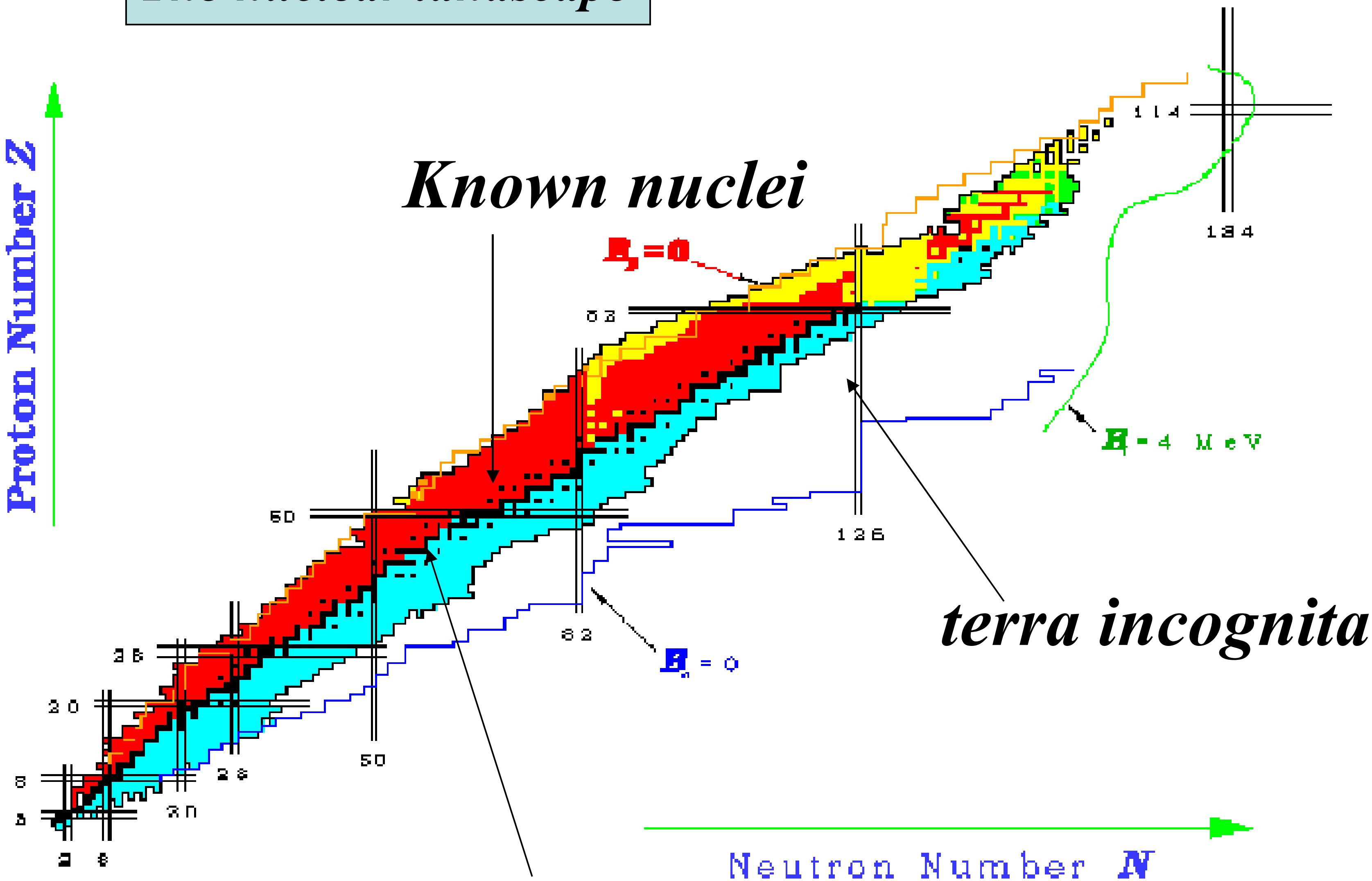
Collaborators

- V.S. Bhasin *Delhi Univ.*
- V. Arora *Delhi Univ.*
- A.R.P. Rau *Louisiana State Univ.*

- *Mazumdar & Bhasin (Under review)*
- *Phys. Rev. Lett. 99, 269202*
- *Nucl. Phys. A790, 257*
- *Phys. Rev. Lett. 97, 062503*
- *Phys. Rev. C69, 061301(R)*
- *Phys. Rev. C61, 051303(R)*
- *Phys. Rev. C56, R5*
- *Phys. Rev. C50 , 550*
- *Phys. Rev. C65,034007*

Phys. Rep 212 (1992) J.M. Richard
Phys. Rep. 231 (1993) (Zhukov et al.)
Phys. Rep. 347 (2001) (Nielsen,Fedorov,Jensen, Garrido)
Rev. Mod. Phys. 76,(2004)(Jensen, Riisager, Fedorov, Garrido
Phys. Rep. 428, (2006) 259(Braaten & Hammer)
Ann Rev. Nucl. Part. Sci. 45, 591 (Hansen, Jensen, Jonson)
Rev. Mod. Phys. 66 (1105)(K. Riisager)

The nuclear landscape



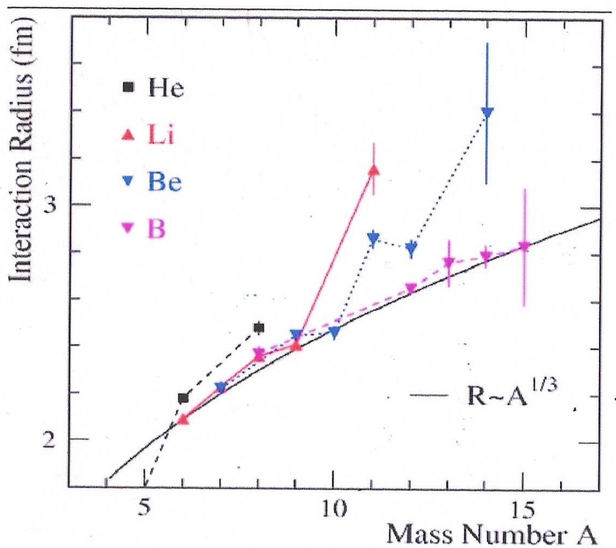
$$R = R_O A^{1/3}$$

Advent of Radioactive Ion Beams

Interaction cross section measurements

Discovery of the Neutron Halo in Light Dripline Nuclei

Interaction Radii extracted from Interaction cross section measurements

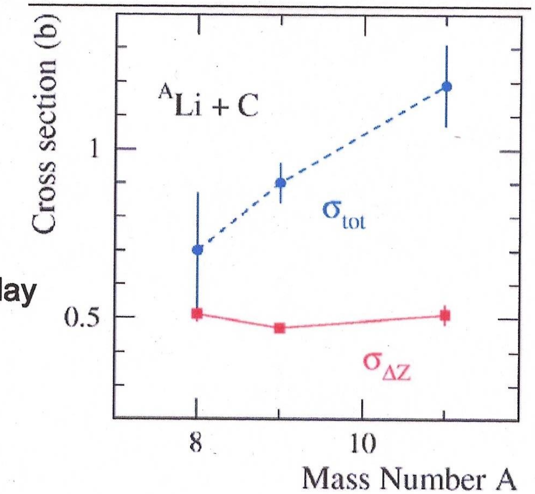


$I/I_O = e^{-\sigma\rho t}$

$\sigma_I = \pi[R_I(P) + R_I(T)]^2$

Bevalac@LBL, I. Tanihata et al.,
PRL 55 (1985) 2676, PLB 206 (1988) 592

Charge-changing cross sections



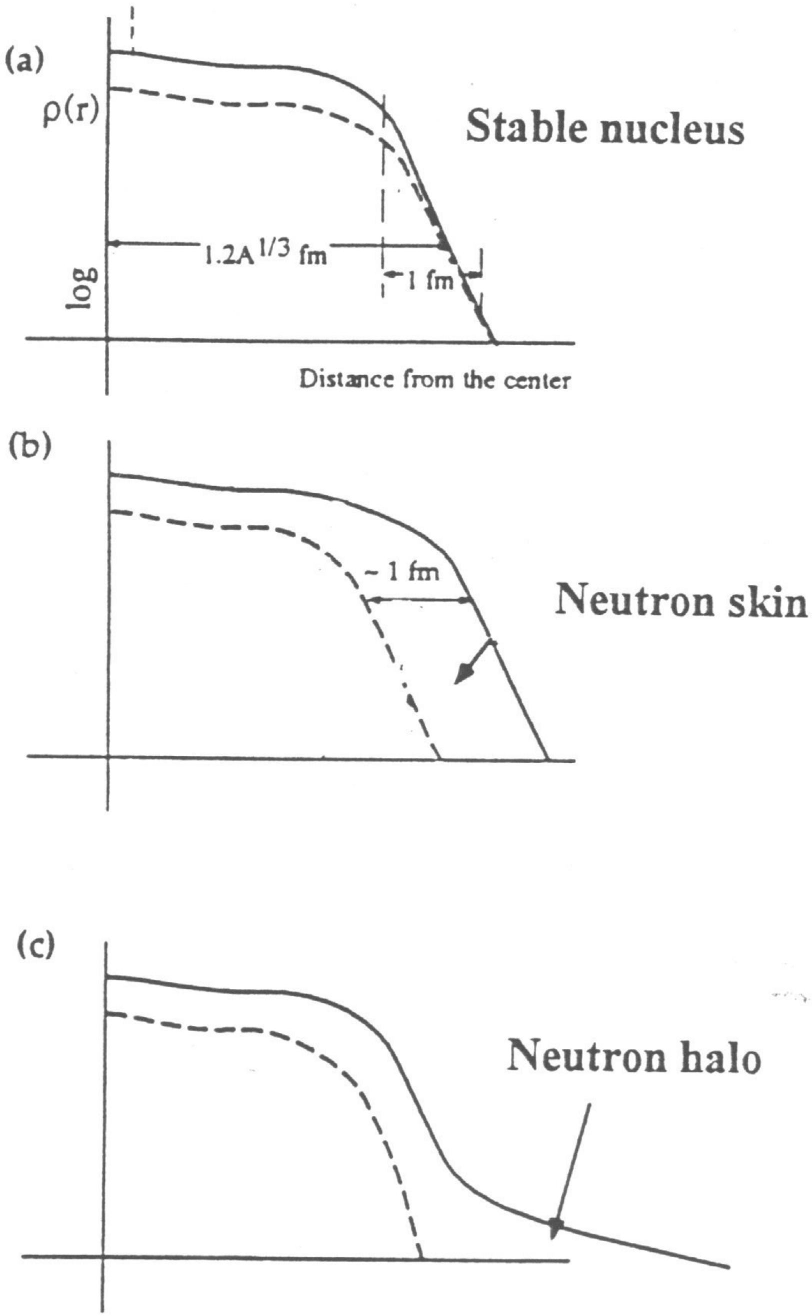
SATURNE@Saclay
B. Blank et al.,
Z.Phys. A 343
(1992) 375

Quadrupole moments

$Q(^{11}Li) \approx Q(^{9}Li)$

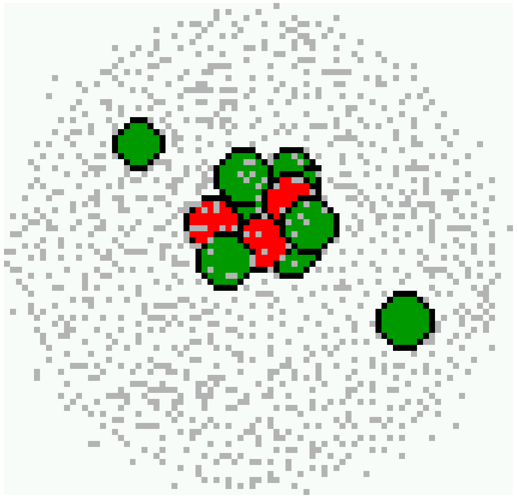
ISOLDE@CERN,
E. Arnold et al., Phys. Lett. B 281 (1992) 16

⇒ Large neutron tail (Halo)



Europhys.Lett. 4, 409 (1987)
P.G.Hansen, B.Jonson

Exotic Structure of 2-n Halo Nuclei



^{11}Li

Z=3

N=8

Radius ~3.2 fm

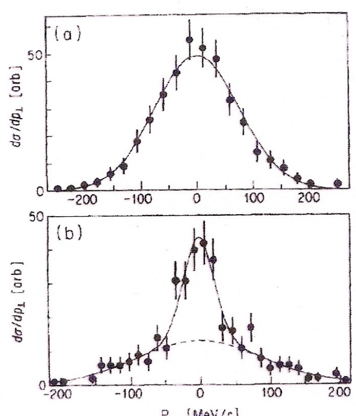
Striking Features:

- Extremely small separation energy S_n or S_{2n}
- Very large matter radius
- Narrow momentum distribution of fragments
- Borromean property of many two neutron halos(^6He, ^{11}Li, ^{14}Be)

Structure	Nucleus	S_n(kev)	S_{2n}(keV)
1n-halo	^{11}Be	504 ± 6	7317 ± 6
	^{19}C	160 ± 120	4350 ± 110
2n-halo	^6He	1864 ± 1	974 ± 1
	^{11}Li	330 ± 30	300 ± 30
	^{14}Be	1850 ± 120	1340 ± 110
	^{19}B	1030 ± 900	500 ± 430

Conditions for halo formation

- Small binding energy
- Small orbital angular momentum (most likely in s & p-state)
- Coulomb barrier hinders the formation of halo.
  (p-halos are less pronounced than n-halo)



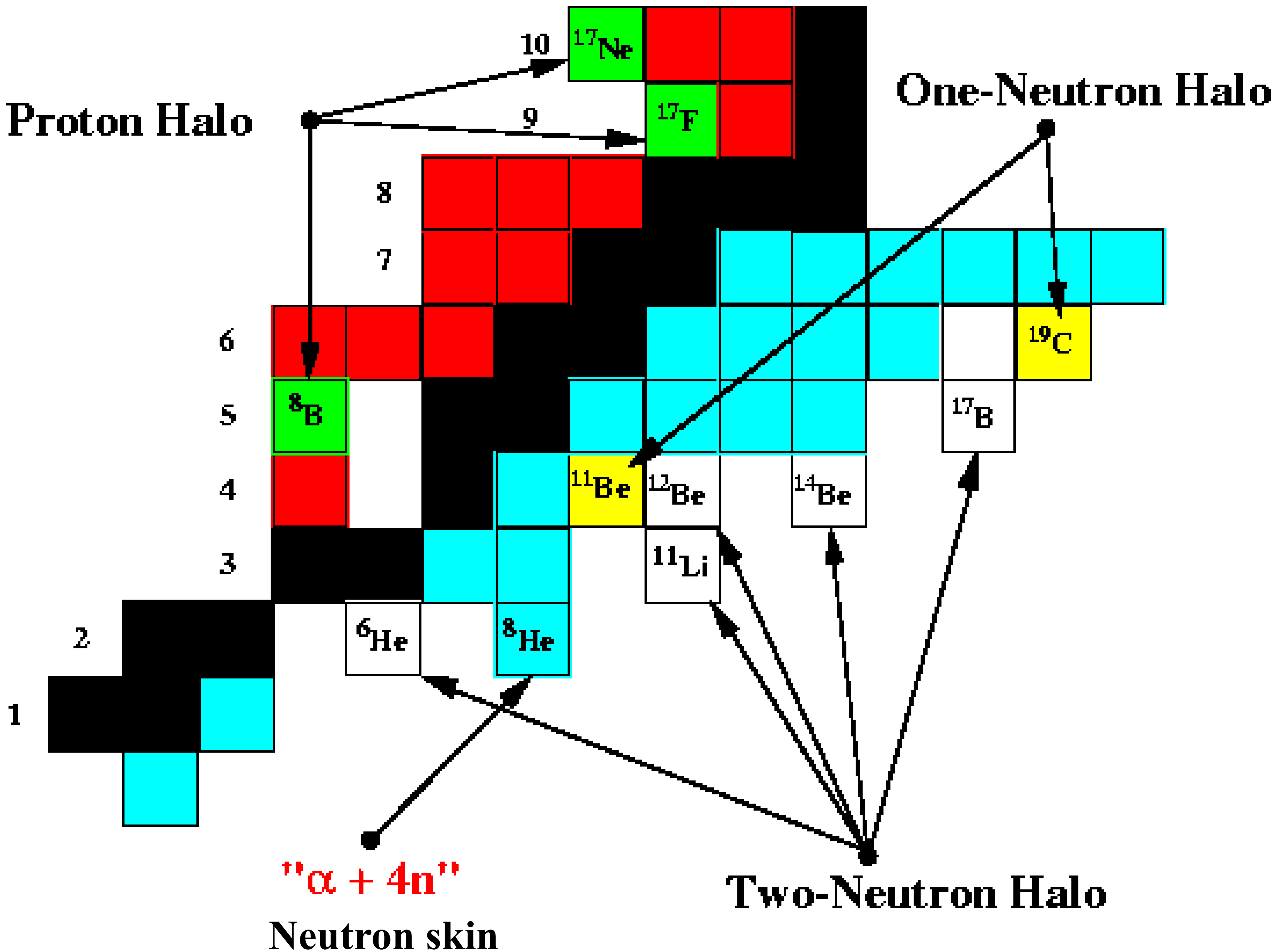
Major RIB facilities

- GSI, Darmstadt
- RIKEN, Japan
- MSU, USA
- GANIL, France
- RIA, (?) USA

Fragmentation projectile/ target

Recall talk by M. marques

Typical experimental momentum distribution of halo nuclei from fragmentation reaction


Proton Halo
One-Neutron Halo
Two-Neutron Halo
"α + 4n"
Neutron skin
1
2
3
4
5
6
7
8
9
10
17Ne
17F
8B
19C
11Be
12Be
14Be
17B
11Li
6He
8He

Theoretical Models

- Shell Model *Bertsch et al. (1990) PRC 41,42*
- Cluster model
- Three-body model (for 2n halo nuclei)
- RMF model
- EFT *Braaten & Hammer, Phys. Rep. 428 (2006)*

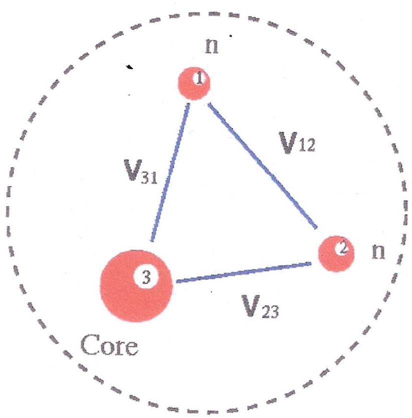
The Formalism

The 2-neutron halo nucleus ^{11}Li is modeled as a three-body system consisting of a compact core of ^{9}Li and two valence neutrons forming a halo around the core. We label the two neutrons and the core as 1,2,3 with momenta $\boldsymbol{P_1}$, $\boldsymbol{P_2}$, $\boldsymbol{P_3}$ respectively. Assuming the core to be a structureless and spinless object, we write the Schrodinger equation in momentum space as

$$(T - E)\psi = -(V_{12} + V_{23} + V_{31})\psi$$

Where E is the total energy (= - binding energy, B.E.) and T represents the kinetic energy such that

$$T - E = p^2_1/2m + p^2_2/2m + p^2_3/2m_3 - E$$
$$= p^2_{ij}/2\mu_{ij} + p^2_k/2\mu_{ij\text{-}k} - E$$



For the two-body interactions we consider non-local, separable potentials of the Yamaguchi form and assume *s-state interactions* both for n-n and n-^{9}Li systems.

Dasgupta, Mazumdar, Bhasin, Phys. Rev C50,550

The three body bound state wave function in momentum space using the binary separable potentials

$V_{12} = -\frac{\lambda_n}{2\mu_{12}} g(p_{12}) g(p'_{12})$,

$V_{23} = -\frac{\lambda_c}{2\mu_{23}} g(p_{23}) g(p'_{23})$,

$V_{31} = -\frac{\lambda_c}{2\mu_{31}} g(p_{31}) g(p'_{31})$ is

$$\psi(\vec{p}_{12}, \vec{p}_3; E) = D^{-1}(\vec{p}_{12}, \vec{p}_3; E)[g(p_{12})F(\vec{p}_3) + f(p_{23})G(\vec{p}_1) + f(p_{31})G(\vec{p}_2)] \quad (1)$$

$g(p) = 1/(p^2 + \beta_n^2)$, $f(p) = 1/(p^2 + \beta_c^2)$, $\lambda_{n,c}$, $\beta_{n,c}$

reproduce spin singlet scattering length and effective range.

The spectator functions F(p) and G(p) satisfy the homogeneous coupled integral equations

$$[\Lambda_n^{-1} - h_n(p)]F(\vec{p}) = 2\int d\vec{q} K_1(\vec{p}, \vec{q}) G(\vec{q}) \quad (2)$$

$$[\Lambda_c^{-1} - h_c(p)]G(\vec{p}) = \int d\vec{q} K_2(\vec{p}, \vec{q}) F(\vec{q}) + \int d\vec{q} K_3(\vec{p}, \vec{q}) G(\vec{q}) \quad (3)$$

After the angular integration, the two couple equation reduce to an integral equation in one variable. These equations are numerically computed as an eigenvalue problem.

We Calculate

- 2-n separation energy
- Momentum distribution of n & core
- Root mean square radius

Inclusion of p-state in n-core interaction

β-*decay of* ^{11}Li

TABLE I. Parameters of the input two body (n-n and n-^{9}Li) potentials. Given the ^{11}Li binding energy, the strength parameter λ_c as obtained from the three-body equation is matched with the corresponding value obtained from the two-body analysis.

B.E. of ^{11}Li (MeV)	β/α	λ_n/α^3	β_1/α	λ_c/α^3	λ_c/α^3 three-body
0.34	5.8	18.6	5.0	10.32	12.92
	6.255	23.4	5.0	10.32	12.91
	5.8	18.6	5.5	14.0	17.01
0.20	5.8	18.6	5.0	10.32	12.39
	5.8	18.6	5.5	14.00	16.38

TABLE II. Values of the root mean square radii of neutron-neutron and neutron-^{9}Li separations calculated using Eqs. (18) and (19) for different binding energies of ^{11}Li.

B.E. of ^{11}Li (MeV)	$\bar{r}_{nn}$ (fm)	$\bar{r}_{nn}$ (fm) (from other model calculations [4])	$\bar{r}_{nc}$ (fm)	$\bar{r}_{nc}$ (fm) (from other model calculations [4])
0.20	10.63		10.93	
0.25	9.9		9.86	
0.315	8.93	6.24 to 7.80	8.87	5.47 to 6.40

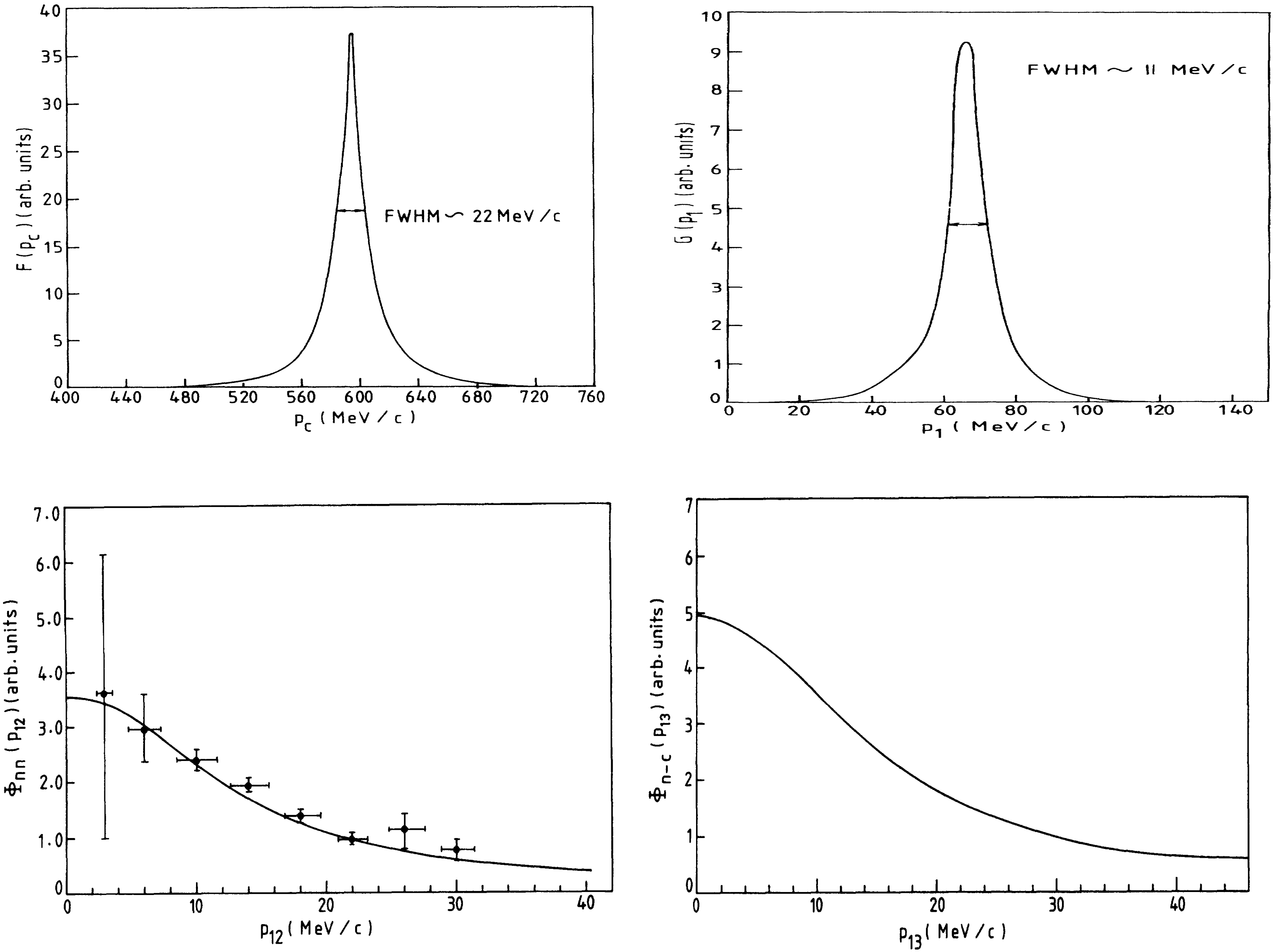
The rms radius r_{matter} calculated is ~ 3.6 fm

$$\langle r^2\rangle_{matter} = A_c/A\langle r^2\rangle_{core} + 1/A\langle\rho^2\rangle$$

$$\rho^2 = r^2_{nn} + r^2_{nc}$$

Fedorov et al (1993)

Garrido et al (2002) (3.2 fm)



Dasgupta, Mazumdar, Bhasin, PRC 50, R550

Data: *N. Orr et al., PRL69 (1992) , K. Ieki et al. PRL 70, (1993)*

Kumar & Bhasin,
Phys. Rev. C65 (2002)

Incorporation of both *s* & *p* waves in n-^{9}Li potential

- ***Ground state energy and 3 excited states above the 3-body breakup threshold were predicted***
- ***The resulting coupled integral equations for the spectator functions have been computed using the method of rotating the integral contour of the kernels in the complex plane.***
- ***Dynamical content of the two body input potentials in the three body wave function has also been analyzed through the three-dimensional plots.***

E_r ∀	E_r (Ex)	Γ (T)
0.038	0.03(0.04)	0.056
1.064	1.02(0.07)	0.050
2.042	2.07(0.12)	0.500

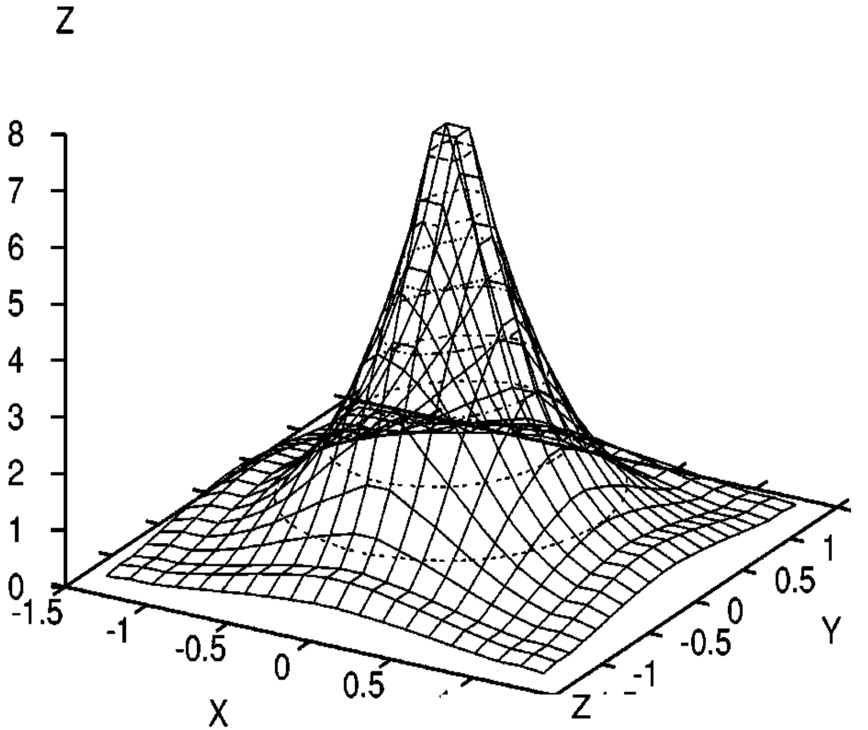
Data from
Gornov et al. PRL81 (1998)

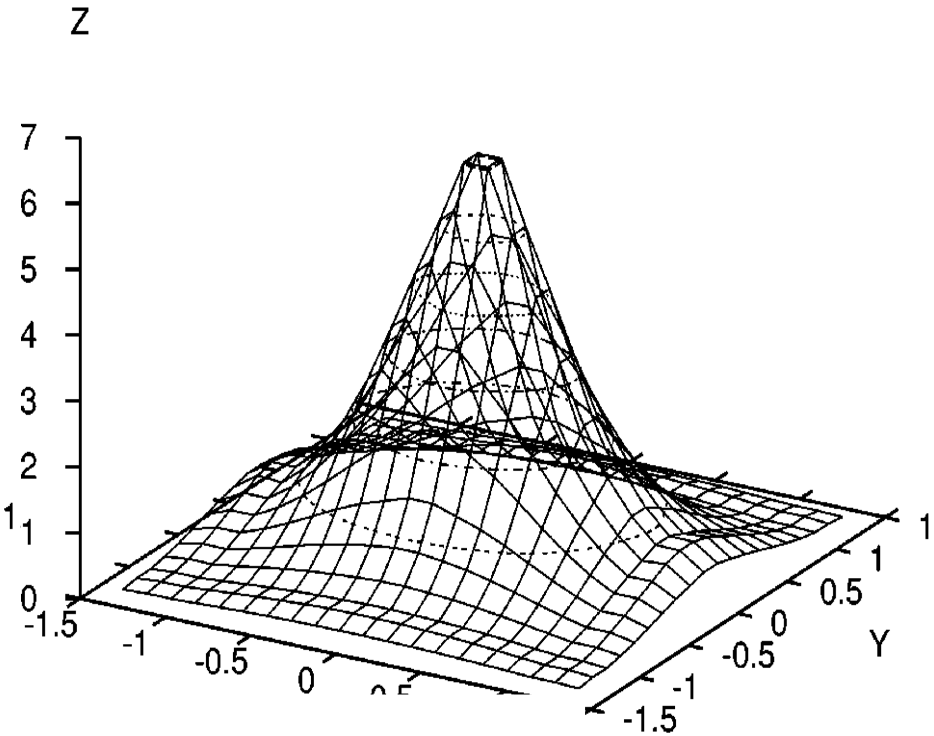
β-decay to two channels studied:

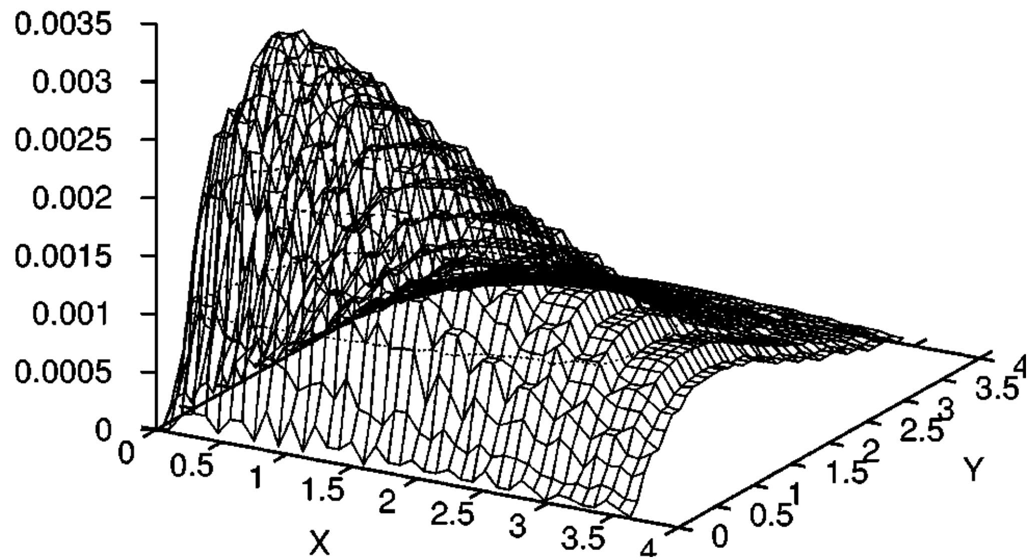
^{11}Li to high lying excited state of ^{11}Be → **18.3 MeV, bound (^{9}Li+p+n) system**
Gamow-Teller β-decay strength calculated

^{11}Li to ^{9}Li + deuteron channel → ***Branching ratio (1.3X10^{-4}) calculated***

Mukha et al (1997), Borge et al (1997)







Kumar & Bhasin
PRC65, (2002)

Efimov Effect

" A three-body system can support infinite bound states when none of the three pairs are bound, or one or two pairs are barely bound."

V. Efimov, Phys. Lett. B 33, 563 (1970); Comments Nucl. Part. Phys. 19, 271 (1990), Amado & Noble, Phys. Lett. B 35, 25 (1971)

Universality:

Independent of the details of the 2-body interaction

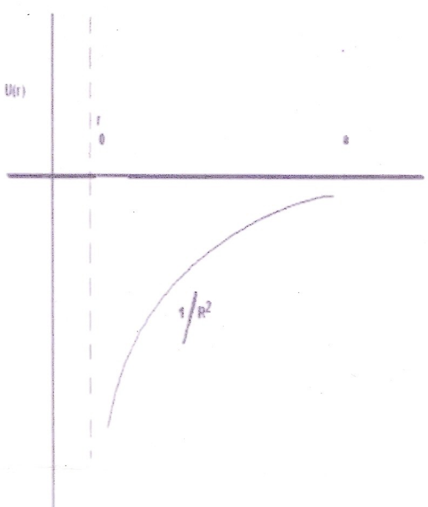
Adjacent energy levels are related by $\frac{E_{N+1}}{E_N} = e^{-2\pi}$

Size of the Nth state is $R_{size} \sim r_0 e^{N\pi}$

The number of states decreases with increasing 2-body strength

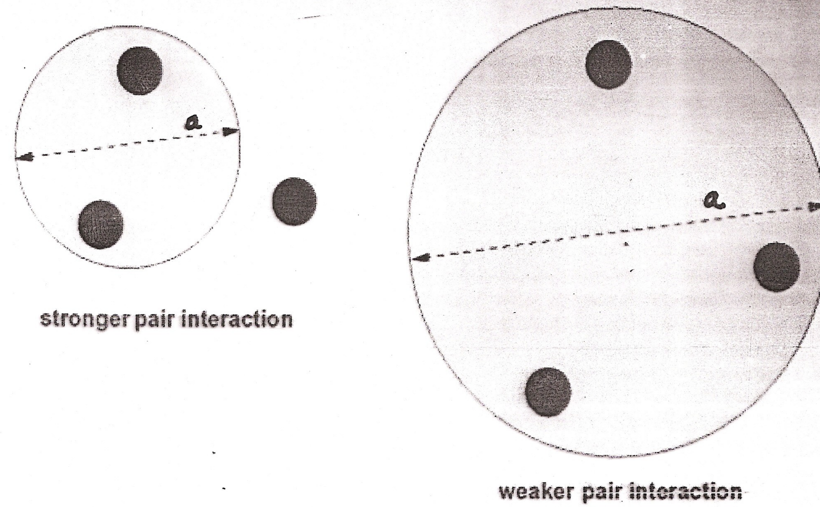
Necessary Conditions:

- Low energy requirement
- Large scattering length



The Efimov Effect

(A Simple Visualisation)



This scenario was predicted for three-body systems with

$a \gg r_0$	where	a = two-body scattering length r_0 = two-body effective range

Note: modern helium pair potentials have $a \approx 104$ Å, $r_0 \approx 11$ Å

Artificially weakening the pair interaction introduces up to infinitely many three-body bound states.

V. Efimov; Phys. Lett. **33B**, 563 (1970)

V. Efimov; Comments Nucl. Part. Phys. **19**, 271 (1990)

V. Efimov:

Sov. J. Nucl. Phys 12, 589 (1971)
Phys. Lett. 33B (1970)
Nucl. Phys A 210 (1973)
Comments Nucl. Part. Phys.19 (1990)

Amado & Noble:

Phys. Lett. 33B (1971)
Phys. Rev. D5 (1972)

Fonseca *et al*.

***Nucl. PhysA320, (1979*)**

Adhikari & Fonseca

Phys. Rev D24 (1981)

Theoretical searches in Atomic Systems

T.K. Lim *et al*. PRL38 (1977)

Cornelius & Glockle, J. Chem Phys. 85 (1986)

T. Gonzalez-Lezana et al. PRL 82 (1999),
This workshop

The case of He trimer

Diffraction experiments with transmission gratings

Carnal & Mlynek, PRL 66 (1991)
Hegerfeldt & Kohler, PRL 84, (2000)

Three-body recombination in ultra cold atoms

First Observation of Efimov States

Letter

Nature **440**, 315-318 (16 March 2006) |

Evidence for Efimov quantum states in an ultracold gas of caesium atoms

T. Kraemer, M. Mark, P. Waldburger, J. G. Danzl, C. Chin, B. Engeser, A. D. Lange, K. Pilch, A. Jaakkola, H.-C. Nägerl and R. Grimm

Magnetic tuning of the two-body interaction

- For Cs atoms in their energetically lowest state the *s*-wave scattering length *a* varies strongly with the magnetic field.

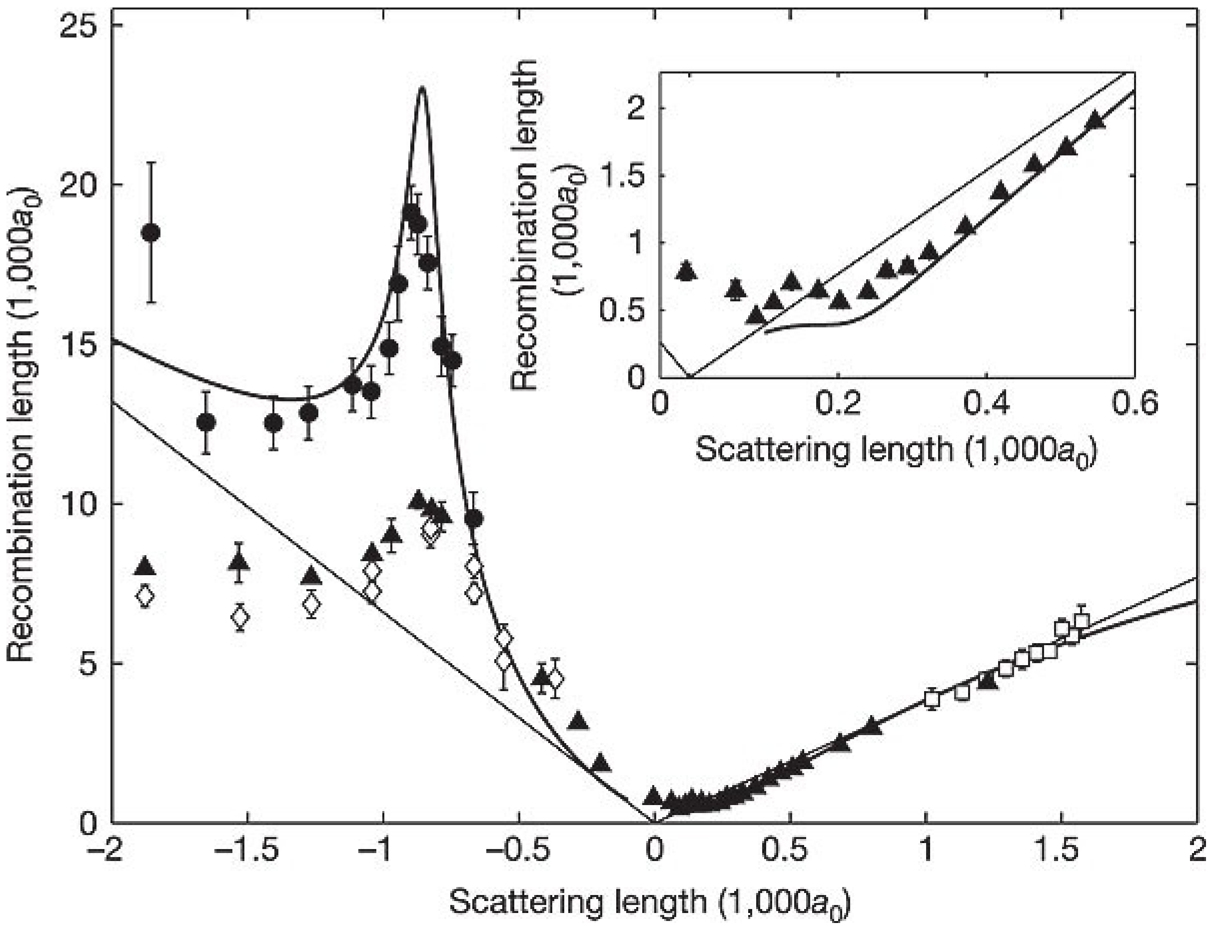
Trap set-ups and preparation of the Cs gases

- All measurements were performed with trapped thermal samples of caesium atoms at temperatures *T* ranging from 10 to 250 nK.

- In set-up A they first produced an essentially pure Bose–Einstein condensate with up to 250,000 atoms in a far-detuned crossed optical dipole trap generated by two 1,060-nm Yb-doped fibre laser beams

- In set-up B they used an optical surface trap in which they prepared a thermal sample of 10,000 atoms at *T*   250 nK via forced evaporation at a density of *n*0 = 1.0   1012 cm-3. The dipole trap was formed by a repulsive evanescent laser wave on top of a horizontal glass prism in combination with a single horizontally confining 1,060-nm laser beam propagating along the vertical direction

T. Kraemer et al. Nature 440, 315



Recall talks by
F. Ferlaino, J. D’Incao,
L. Platter

Can we find Efimov Effect in the atomic nucleus?

Unlike cold atom experiments we have no control over the scattering lengths.

The discovery of 2-neutron halo nuclei, characterized by very low separation energy and large spatial extension are ideally suited for studying Efimov effect in atomic nclei.

Fedorov & Jensen
PRL 71 (1993)

Fedorov, Jensen, Riisager
PRL 73 (1994)

Conditions for occurrence of Efimov states in 2-n halo nuclei.

P. Descouvement
PRC 52 (1995), Phys. Lett. B331 (1994)

$\tau_n^{-1}(p)F(p) \equiv \varphi(p)$ **and** $\tau_c^{-1}(p)G(p) \equiv \chi(p)$

Where

The basic structure of the equations in terms of the spectator functions F(p) and G(p) remains same. But for the sensitive computational details of the Efimov effect we recast the equations in dimensionless quantities.

$$\tau_n^{-1}(p) = \mu_n^{-1} - [\, \beta_r (\beta_r + \sqrt{p^2/2a + \varepsilon^3})^2 \,]^{-1}$$

$$\tau_c^{-1}(p) = \mu_c^{-1} - 2a[\, 1 + \sqrt{2a(p^2/4c + \varepsilon 3)} \,]^{-2}$$

where $\mu_n = \pi^2\lambda_n/\beta_1^2$ **and** $\mu_c = \pi^2\lambda_c/2a\beta_1^3$

are the dimensionless strength parameters. Variables p **and** q **in the final integral equation are also now dimensionless,**

$$p/\beta_1 \rightarrow p \;\&\; q/\beta_1 \rightarrow q$$

and

$$-mE/\beta_1^3 = \varepsilon_3, \;\; \beta_r = \beta/\beta_1$$

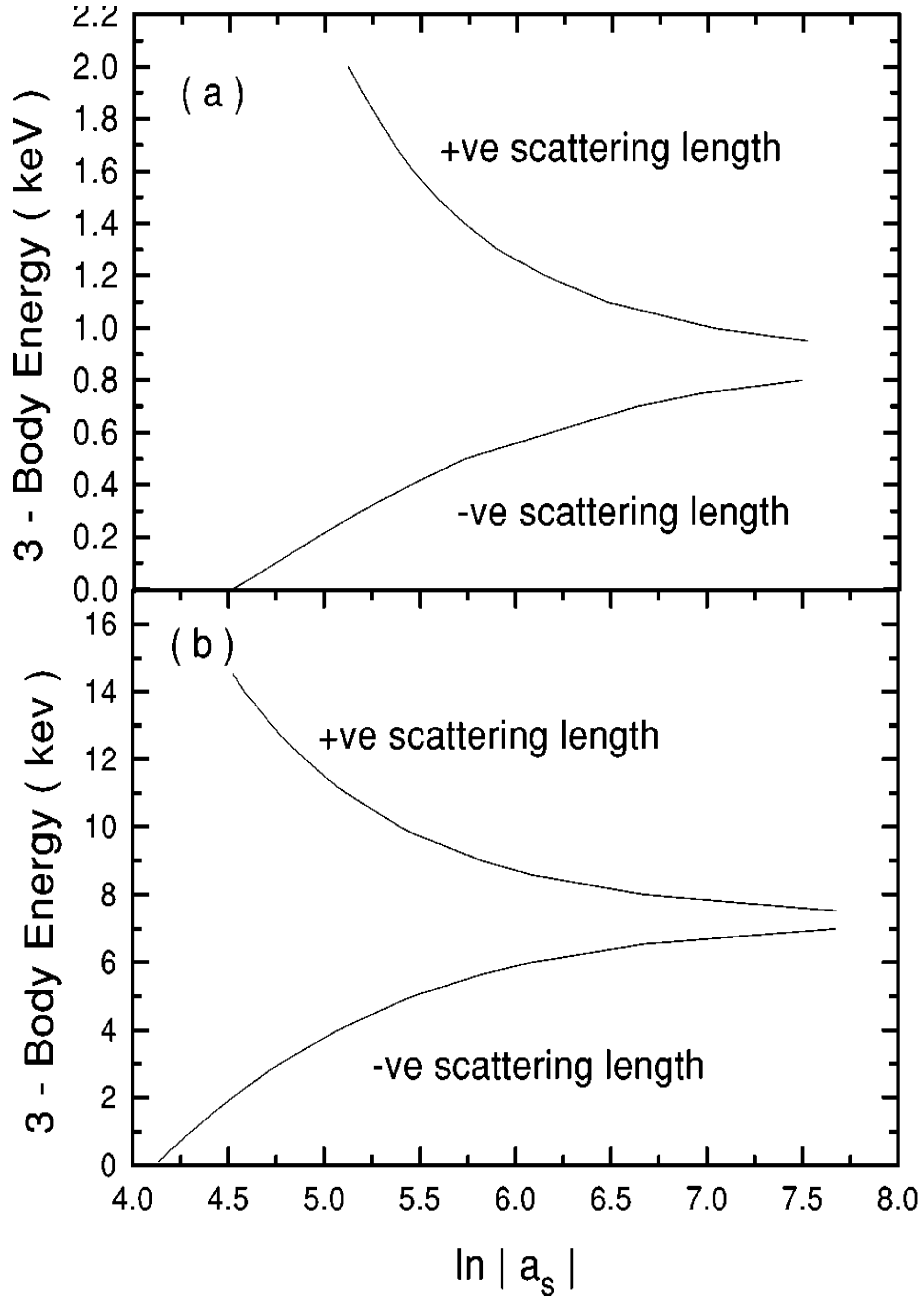
Factors τ_n^{-1} *and* τ_c^{-1} *appear on the left hand side of the spectator functions F(p) and G(p) and are quite sensitive. They blow up as* $p \rightarrow 0$ *and* ε_3 *approaches extremely small value.*

TABLE I. ^{14}Be ground and excited states three-body energy for different two-body input parameters.

n-^{12}Be Energy keV	λ1	a_s fm	ϵ_0 keV	ϵ_1 keV	ϵ_2 keV
50	11.71	−21	1350		
5.8	12.32	−61.6	1408	.053	
2	12.46	−105	1450	2.56	0.061
1	12.52	−149	1456	3.8	0.22
0.1	12.62	−483	1488	6.1	0.62
0.05	12.63	−658	1490	6.4	0.68
0.01	12.65	−1491	1490	6.9	0.72

Mazumdar and Bhasin, PRC 56, R5

Thoennessen, Yokoyama, Hansen
PRC 63 (2000)
Observation of low lying s-wave strength
With scattering legth < -10 fm

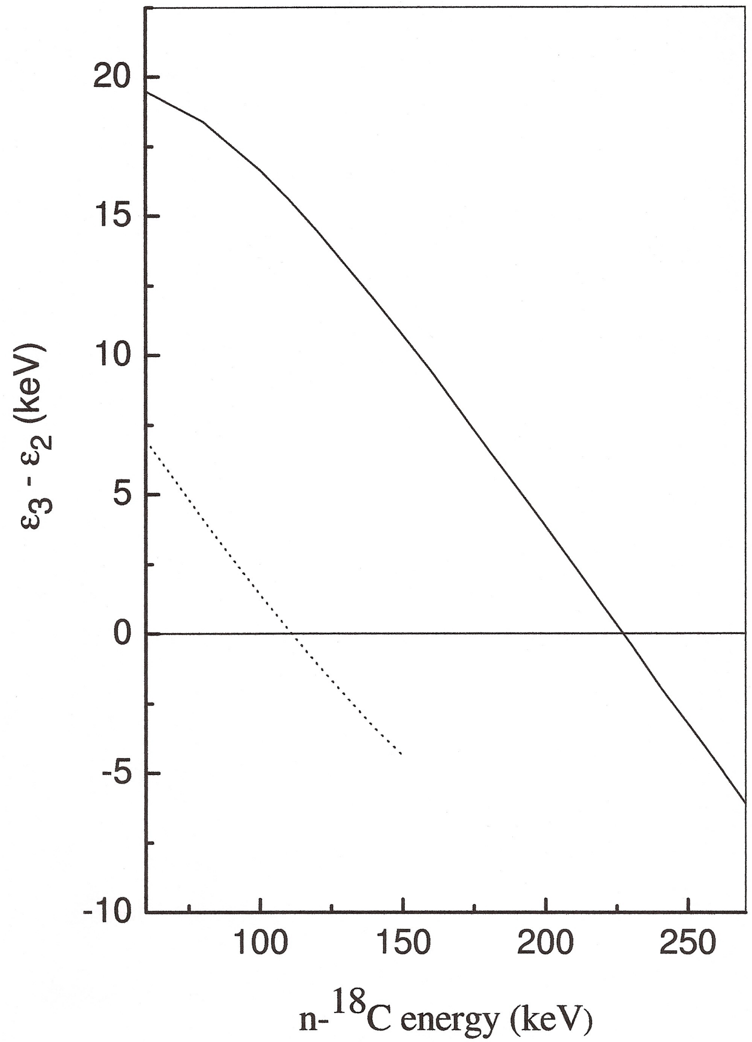


Search for Efimov states in ^{19}B, ^{22}C, and ^{20}C

n-^{17}B energy (keV)	λ_c/α^3	a_s (fm)	ε_0 (keV)	ε_1 (keV)	ε_2 (keV)
514.8	8.49	-6.515	500		
135.3	9.5	-12.71	728		
48	10.0	-21.16	851		
7.7	10.5	-53.2	978	0.16	
0.67	10.75	-179.6	1042	5.4	0.36

n-^{20}C energy (keV)	λ_c/α^3	a_s (fm)	ε_0 (keV)	ε_1 (keV)	ε_2 (keV)
319	9.82	-8.23	1120		
127	10.5	-13.02	1287		
48.8	11.0	-21.0	1410		
9.3	11.5	-48.2	1540 0	0.122	
1.46	11.75	-121.5	1608	4.74	0.198

n-^{18}C energy (keV)	λ_c/α^3	a_s (fm)	ε_0 (keV)	ε_1 (keV)	ε_2 (keV)	
60	15.51	20.38	3188.03	78.87	65.8	1.01
100	15.89	16.05	3291.54	115.72	100.09	0.94
113.2	16.0	15.15	3317.35	127.41	111.76	0.92
139.60	16.2	13.77	3371.24	150.32	135.29	0.89
168.59	16.4	12.64	3426.03	175.34	163.48	0.86
200	16.6	11.71	3482.95	202.15	194.15	0.84



Mazumdar, Arora Bhasin
Phys. Rev. C 61, 051303(R)

- Amorim, Frederico, Tomio PRC 56 (1997) R2378
- Delfino, Frederico, Hussein, Tomio PRC 61 (2000)

- ***The feature observed can be attributed to the singularity in the two body propagator*** $[\Lambda_C^{-1} - h_c(p)]^{-1}$.

- ***There is a subtle interplay between the two and three body energies.***

- ***The effect of this singularity on the behaviour of the scattering amplitude has to be studied.***

In order to analyze the effect of this singularity on the behavior of the scattering amplitude for n-^{19}C elastic scattering the function G(p) describing the dynamics of the neutron in the presence of (n-^{18}C) system, must be subject to the boundary condition, viz,

$$G(\vec{p}) = (2\pi)^3\delta(\vec{p}-\vec{k}) + \frac{4\pi a_k(\vec{p})}{p^2-k^2-\iota\epsilon} \qquad (5)$$

The scattering amplitude is normalized such that, for the s-wave scattering,

$$a_k(\vec{p})_{|\vec{p}|=|\vec{k}|} \equiv f_k = \frac{e^{\iota\delta}sin\delta}{k} \qquad (6)$$

Before applying the boundary condition, we rewrite Eq.(3) substituting Eq.(2) for F(p) and finally get the equation for the off-shell scattering amplitude as

$$4\pi(\frac{a}{d})h(p^2,k^2;\alpha_2^2)a_k(\vec{p}) =$$
$$(2\pi)^3K_3(\vec{p},\vec{k}) + 4\pi\int\frac{d\vec{q}K_3(\vec{p},\vec{q})a_k(\vec{q})}{q^2-k^2-\iota\epsilon} + (2\pi)^3\int d\vec{q}K_3(\vec{p},\vec{q})K_1(\vec{q},\vec{k})\tau_n(q) +$$
$$(8\pi)\int d\vec{q}K_3(\vec{p},\vec{q})\tau_n(q)\int d\vec{q}'\frac{K_1(\vec{q},\vec{q}')a_k(\vec{q}')}{q'^2-k^2-\iota\epsilon} \qquad (7$$

This integral equation needs to be solved numerically for the scattering amplitude.

Arora, Mazumdar Bhasin (2004)

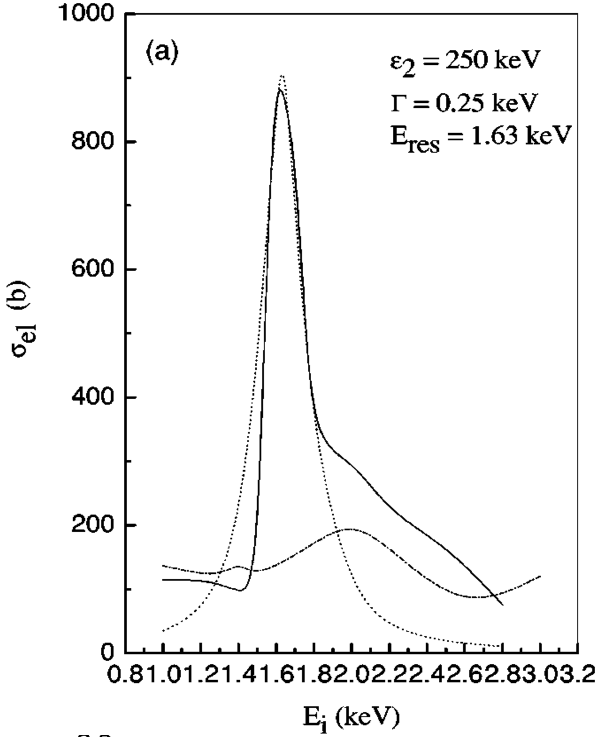
For k → 0, the singularity in the two body cut Does not cause any problem. The amplitude has only real part. The off-shell amplitude is computed By inverting the resultant matrix , which in the limit $a_o(p)_{p\to 0}$ → -a, the n-^{19}C scattering length.

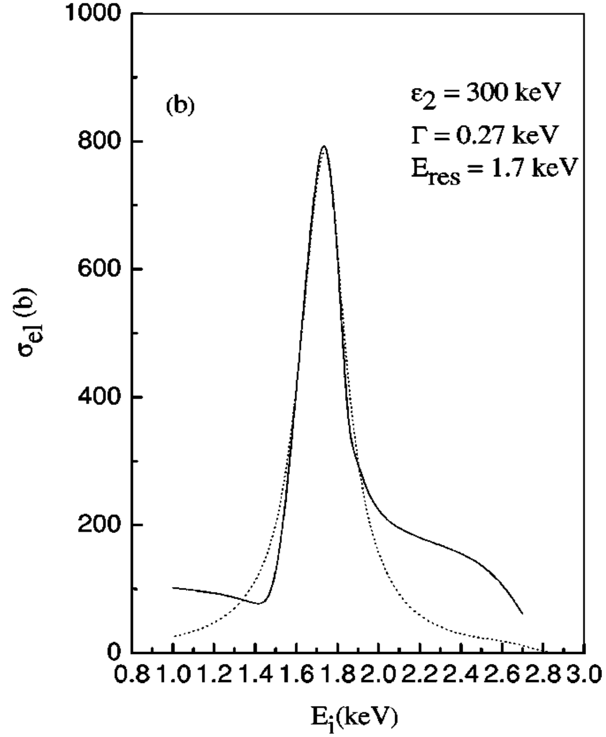
For non-zero incident energies the singularity in the two body propagator is tackled by the CSM.

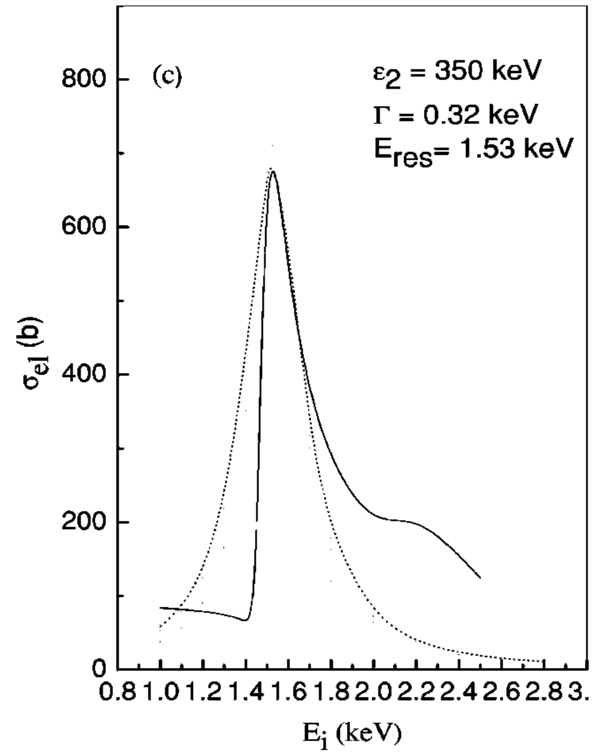
P → ***$p_1e^{-i\varphi}$ and q → $qe^{-i\varphi}$***

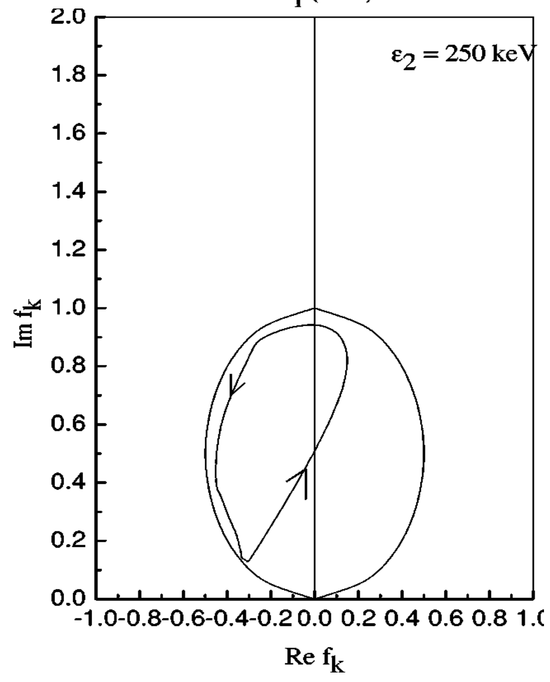
The unitary requirement is the Im($f^1{}_k$) = -k

Balslev & Combes (1971)
Matsui (1980)
Volkov et al. This workshop





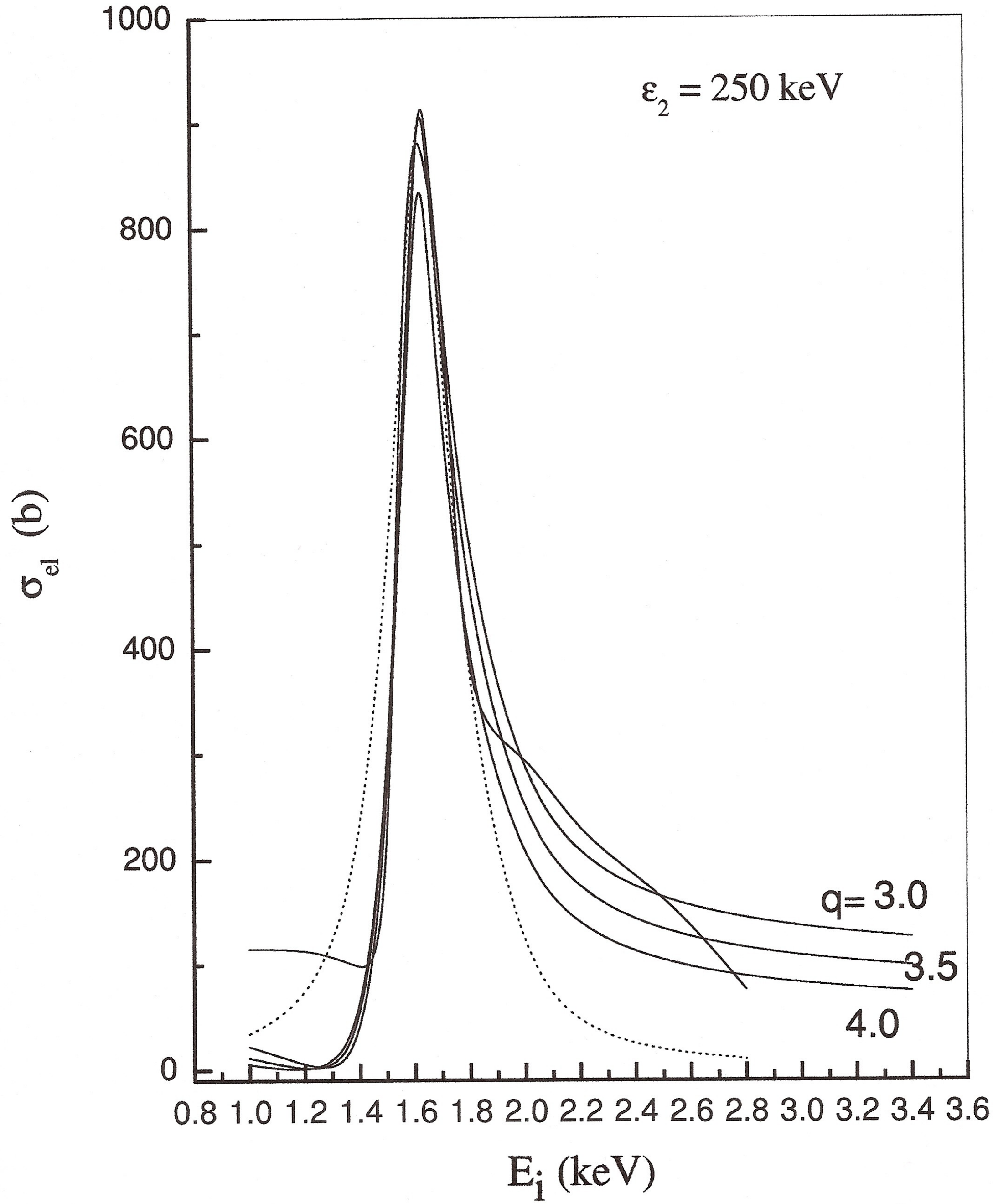




n-^{18}C Energy (keV)	$\varepsilon_3(0)$ (MeV)	$\varepsilon_3(1)$ (keV)	$\varepsilon_3(2)$ (keV)
4	3.00	79.5	66.95
100	3.10	116.6	101.4
6	3.18	152.0	137.5
7	3.25	186.6	-----
8	3.32	221.0	-----
9	3.35	238.1	-----
250	3.37	-----	-----
300	3.44	-----	-----

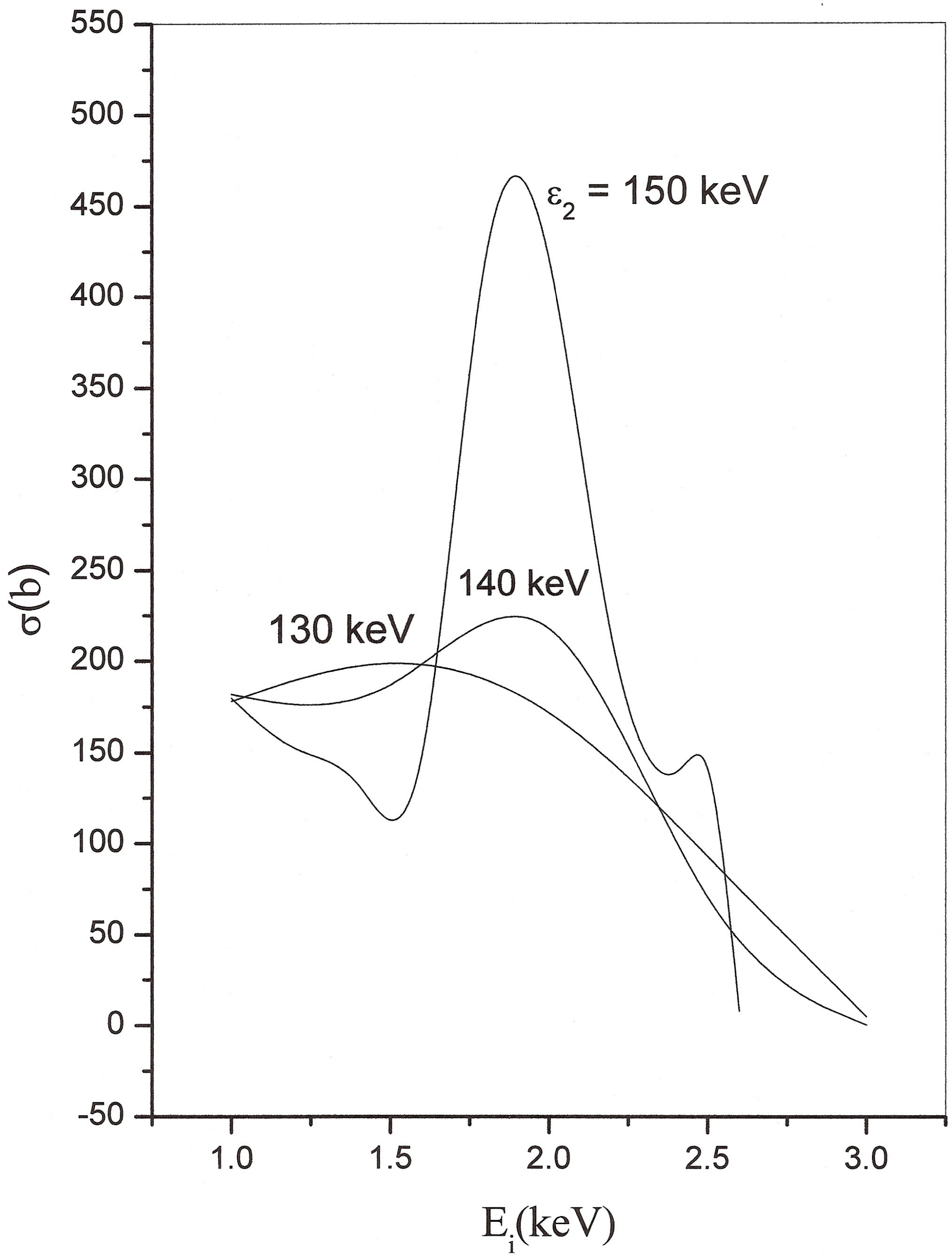
For all the values of n-^{18}C the zero energy scattering length retains a positive value through out.

Arora, Mazumdar, Bhasin, PRC 69, 061301

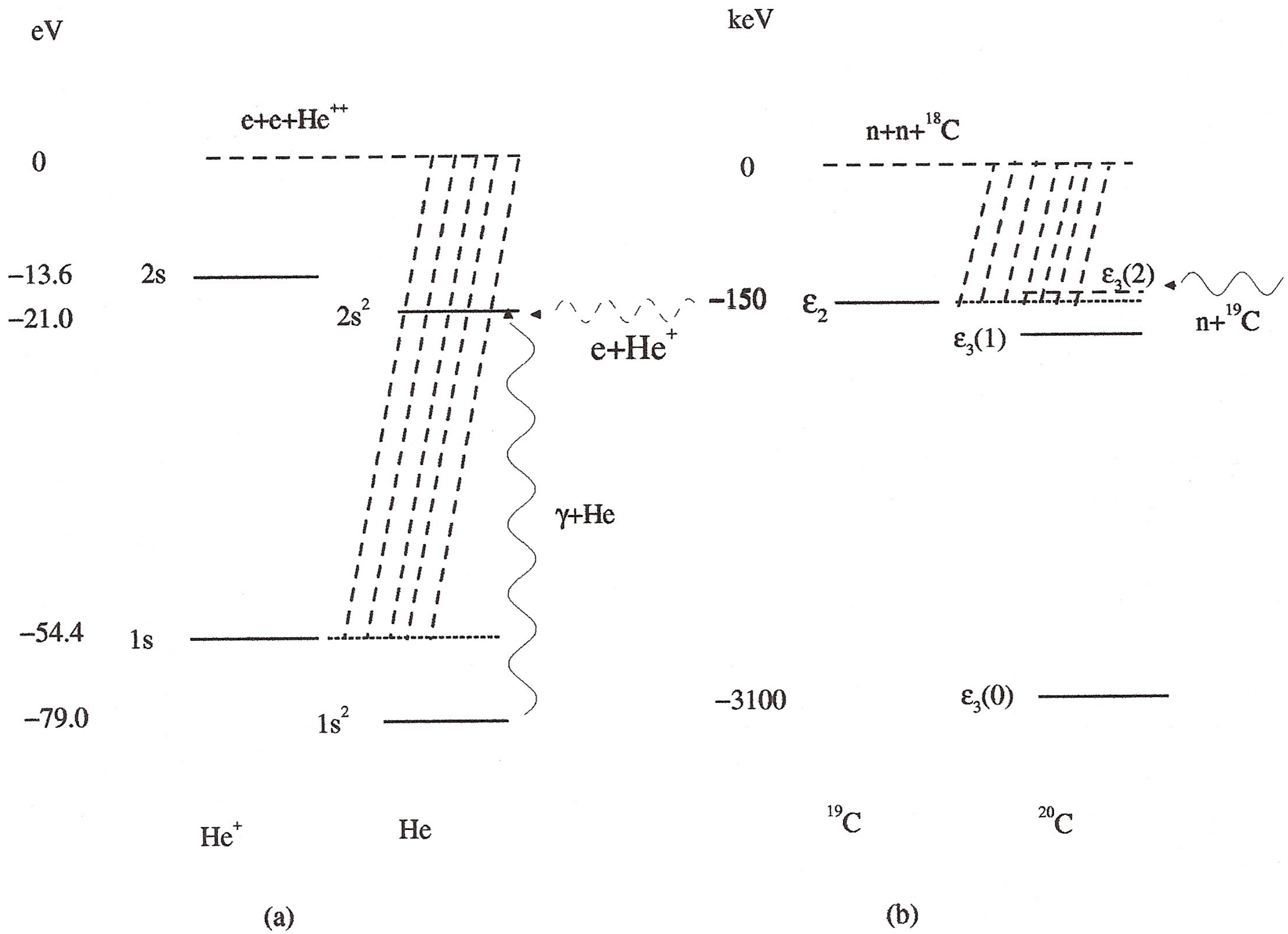


Fitting the Fano profile to the N-^{19}C elastic cross section for n-^{18}C BE of 250 keV

Mazumdar, Rau, Bhasin
Phys. Rev. Lett. 97 (2006)



The resonance due to the <u>second excited Efimov state</u> for n-^{18}C BE 150 keV. The profile is fitted by <u>same value of *q*</u> as for the 250 keV curve.



Comparison between He and ^{20}C as three body Systems in atoms and nuclei

Discussion

Our results are at variance with
Yamashita, Frederico, Tomio

- **We emphasize the cardinal role of channel coupling.**

    There is also a definite role of mass ratios as observed numerically.

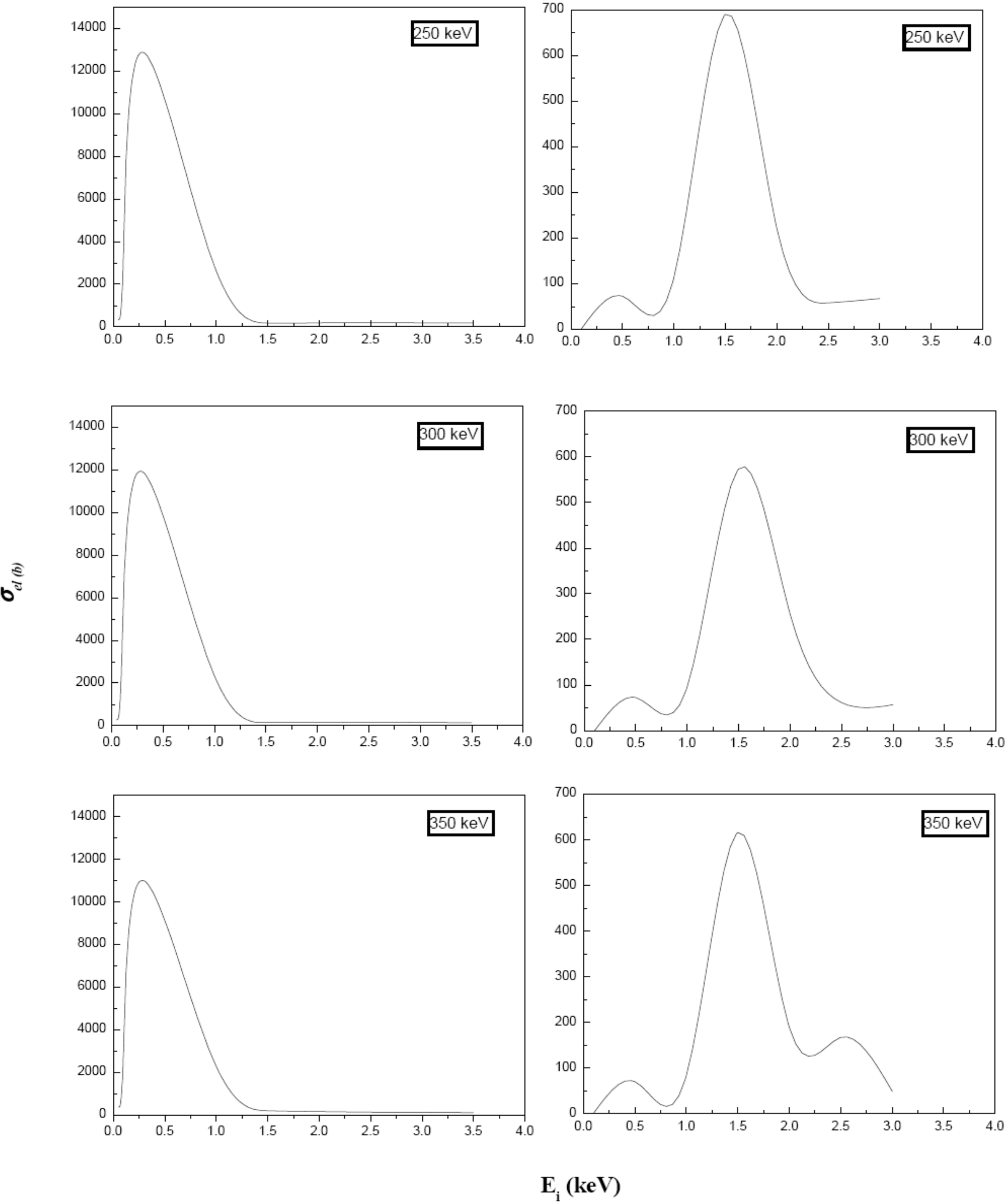
- **However, channel coupling is an elegant and physically plausible scenario.**

- **The difference can also arrive between zero range and realistic finite range potentials in non-Borromean cases.**

    Note, that for n-^{18}C binding energy of 200 keV, the scattering length is about 10 fm while the interaction range is about 1 fm.

- **The extension of zero range to finer details of Efimov states in non-Borromean cases may not be valid.**

- ***The discrepancy observed in the resonance vs virtual states in ^{20}C clearly underlines the sensitive structure of the three-body scattering amplitude derived from the binary interactions.***



ε_o (keV)	Equal (keV)	Heavy Core (keV)
250	455	4400
300	546	4470
350	637	4550

Ground states for the two cases

Mazumdar & Bhasin (Communicated)

A possible experimental proposal to search for Efimov State in 2-neutron halo nuclei.

- **Production of ^{20}C secondary beam with reasonable flux**
- **Acceleration and Breakup of ^{20}C on heavy target**
- **Detection of the neutrons and the core in coincidence**
- **Measurement of γ-rays as well**

The Arsenal:

- ***Neutron detectors array***
- ***Gamma array***
- ***Charged particle array***

Summary

- **A three body model with s-state interactions account for most of the gross features of ^{11}Li in a reasonable way.**

- **Inclusion of *p*-state in the n-^{9}Li contributes marginally.**

- **A virtual state of a few keV (2 to 4) energy corresponding to scattering length from -50 to -100 fm for the n-^{12}Be predicts the ground state and excited states Of ^{14}Be.**

- **^{19}B, ^{22}C and ^{20}C are investigated and it is shown that Borromean type nuclei are much less vulnerable to respond to Efimov effect.**

- **^{20}C is a promising candidate for Efimov states at energies below the n-(nc) breakup threshold.**

- ***The bound Efimov states in ^{20}C move into the continuum and reappear as Resonances with increasing strength of the binary interaction.***

- ***Asymmetric resonances in elastic n+^{19}C scattering are attributed to Efimov states and are identified with the Fano profile. The conjunction of Efimov and Fano phenomena my lead to the experimental realization in nuclei.***

Future scope of Work:

- Resonant states above the three body breakup threshold in ^{20}C.
- Fano resonances of Efimov states in ^{16}C, ^{19}B, ^{22}C and analytical derivation of the Fano index q.
- Role of Efimov states in Bose-Einstein condensation.
- Studying the proton halo (^{17}Ne) nucleus. (Neff, This workshop)
- Reanalyze profiles of GDR on ground states for its asymmetry.
- **Experiment for breakup of ^{20}C is being planned.**

Epilogue

“ the richness of understanding reveals even greater richness of ignorance”

D.H. Wilkinson


THANK YOU