Coulomb Breakup of Halo Nuclei

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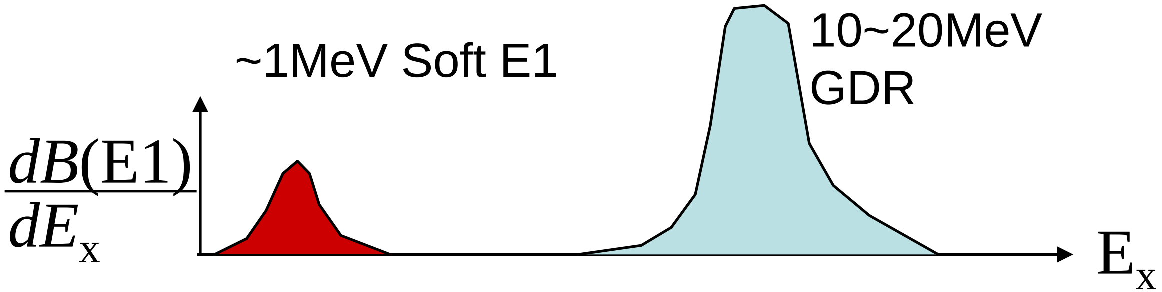
Contents

Introduction

Enhancement of E1 Strength at Low Excitation Energies



Unique properties
for Neutron Halo Nuclei

•Soft Dipole Excitation
—Structureless E1 Continuum due to Halo Structure

Questions

- Nuclear Halo --- Universal?
- How is nuclear structure at the drip line characterized?

Coulomb Breakup

- One neutron halo
- Two neutron halo

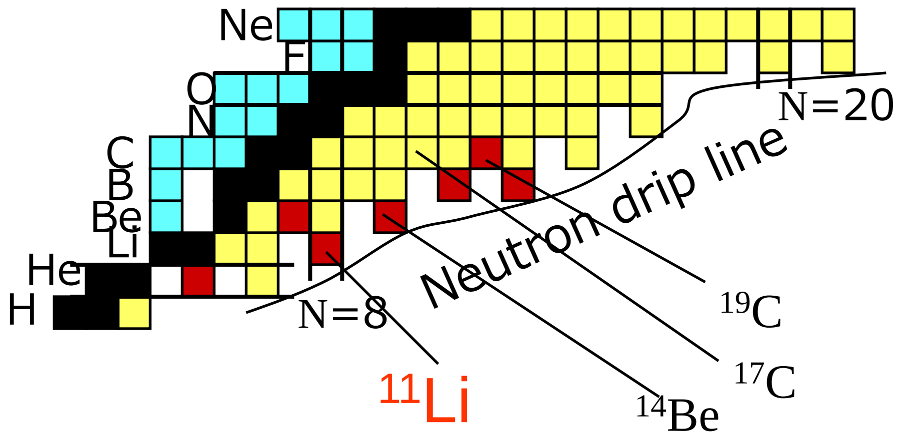
    How B(E1) can be related to halo structure?

    Di-neutron Correlation?

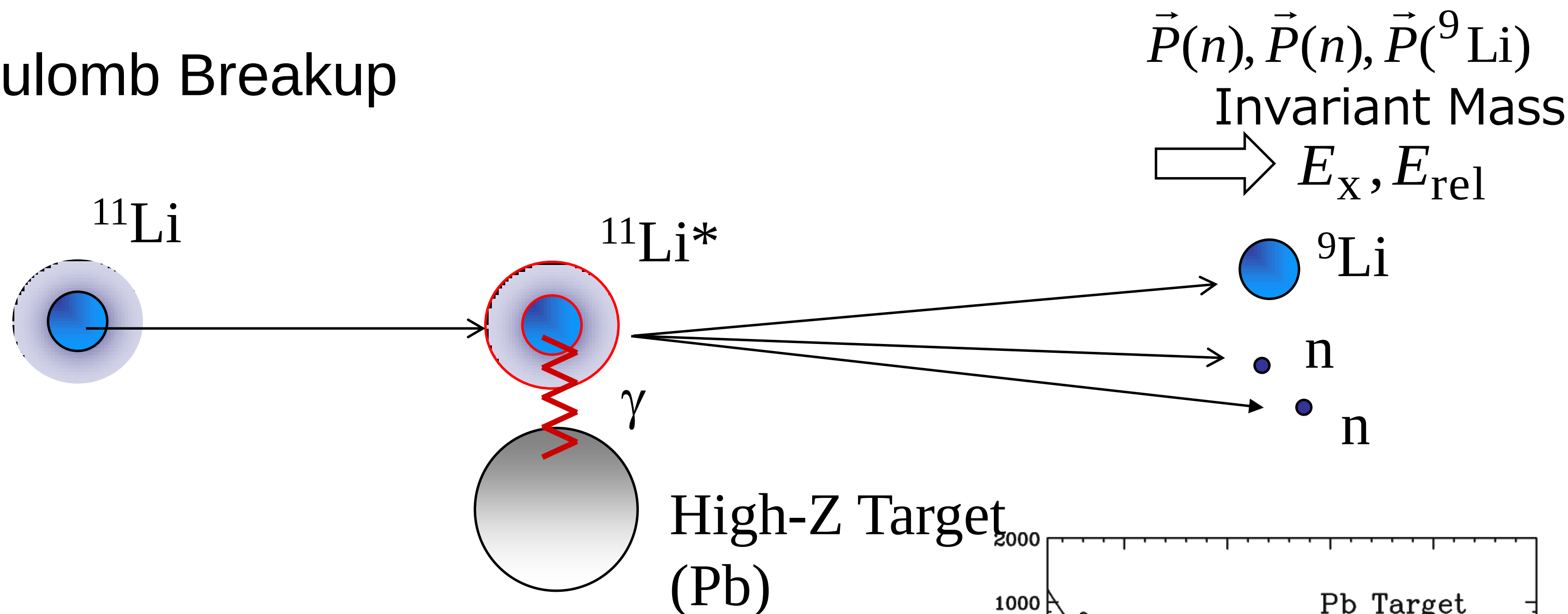
1 Coulomb Breakup of ^{11}Li

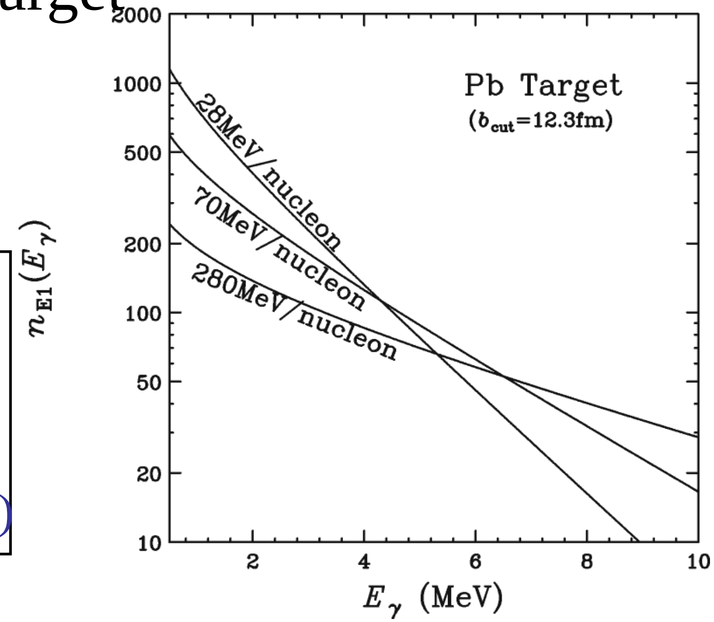
T. Nakamura, A.M.Vinodkumar et al.,

Phys. Rev. Lett. 96, 252502 (2006).



Coulomb Breakup





Equivalent Photon Method

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

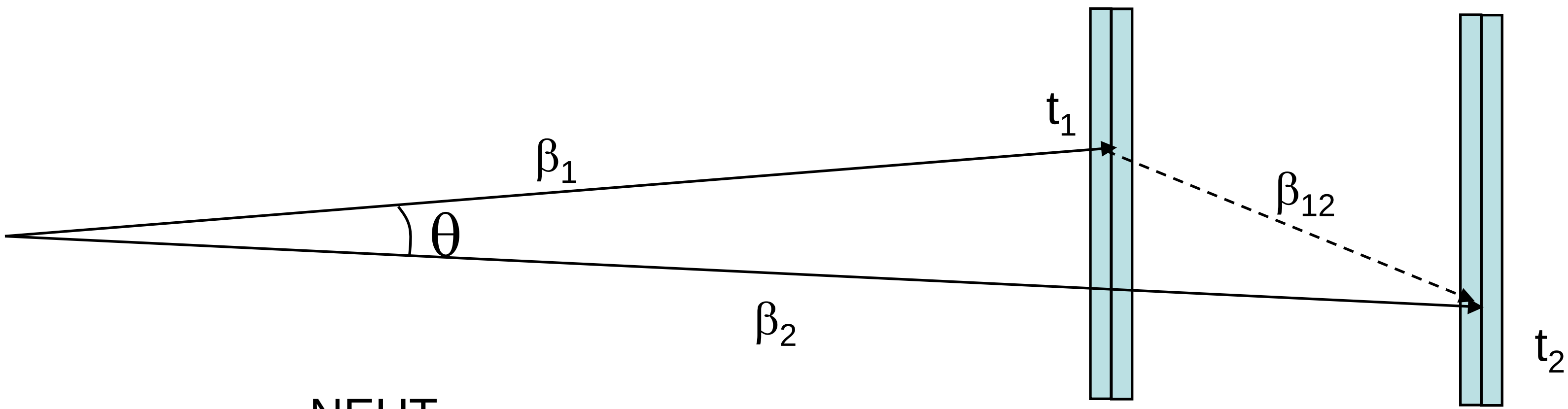
Cross section = (Photon Number)x(Transition Probability)

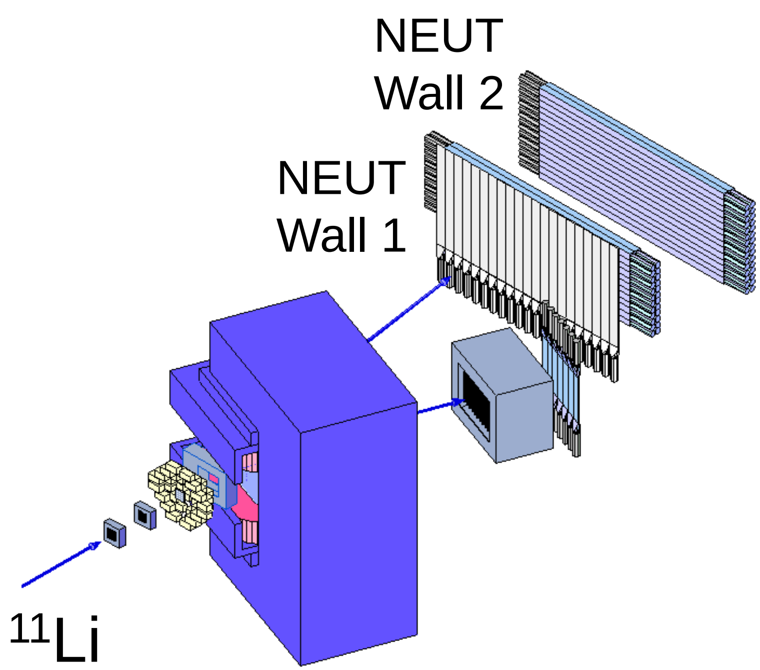
Elimination of Cross-Talk events

Examine Different Wall Events

Condition: $\beta_1 \leq \beta_{12}$

Almost no bias



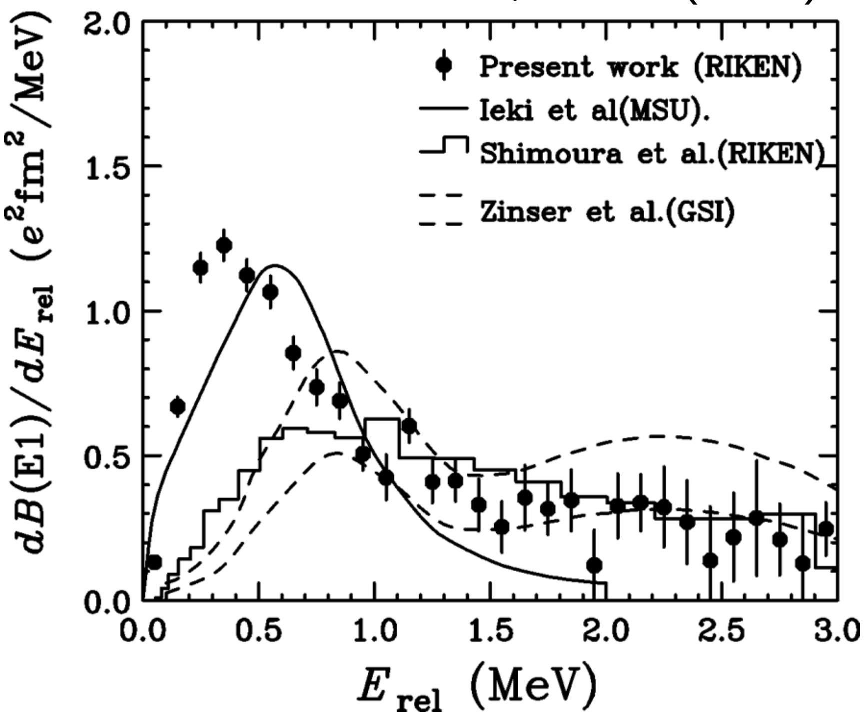


High detection sensitivity even at E_{rel}~0MeV (θ~0)

⇨ Precise measurement of B(E1) distribution of ^{11}Li

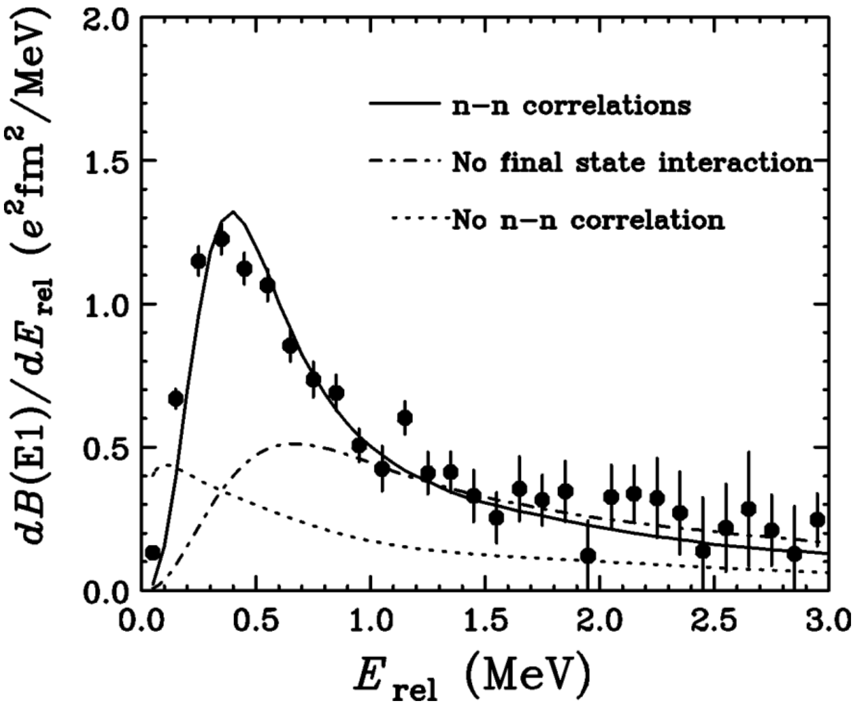
Experimental Results

TN et al. PRL96,252502(2006).



$$B(E1) = 1.42 \pm 0.18\, e^2\, fm^2 (E_{\mathrm{rel}} \leq 3\mathrm{MeV})$$
$$= 4.5(6)\ \mathrm{W.u}$$

Comparison with 3-body Theory-1



Calculation

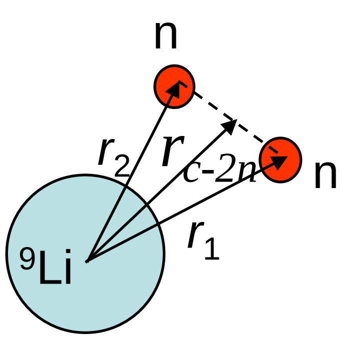
H.Esbensen and G.F. Bertsch
NPA542,310 (1992).

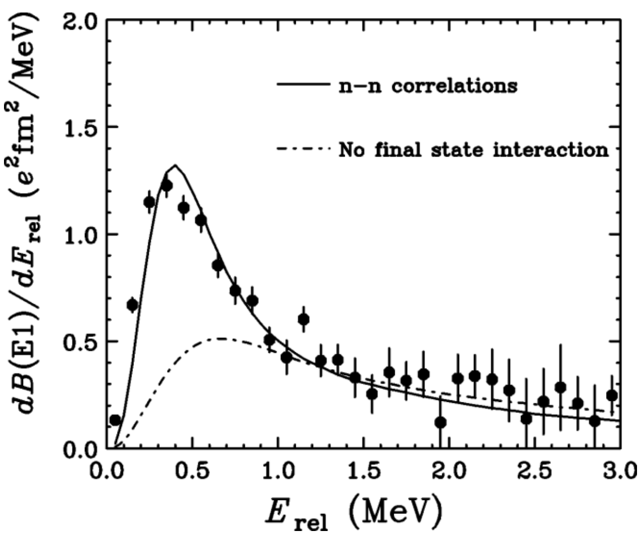
H.Esbensen et al.,
PRC76, 024302 (2007)

Non-energy weighted
E1 Cluster Sum Rule

$$B(E1) = \int_0^\infty \frac{dB(E1)}{dE_x} dE_x = \frac{3}{4\pi}\left(\frac{Ze}{A}\right)^2 \left\langle {r_1}^2 + {r_2}^2 + 2(\vec{r}_1 \cdot \vec{r}_2) \right\rangle$$

$$= \frac{3}{\pi}\left(\frac{Ze}{A}\right)^2 \left\langle {r_{c-2n}}^2 \right\rangle$$





$$\underline{B(E1) = 1.42 \pm 0.18\, e^2\, fm^2 (E_{\rm rel} \le 3\,{\rm MeV})}$$

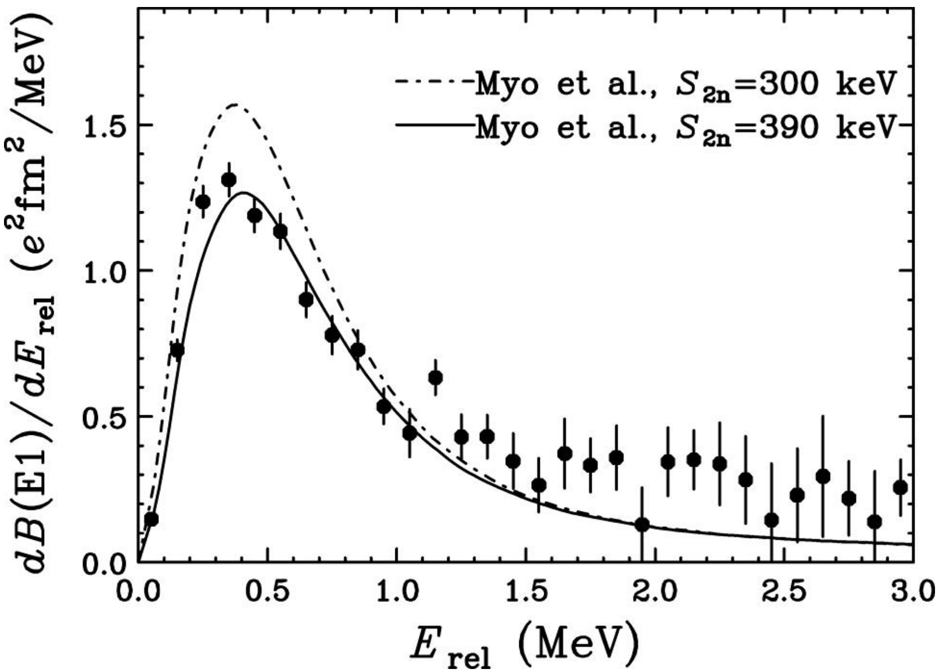
$\rightarrow 1.78(22)\, e^2\, fm^2$ (Extrapolated value)

$$\rightarrow \sqrt{\left\langle r_{c-2n} \right\rangle^2} = 5.01 \pm 0.32\ {\rm fm}$$

~70% larger than non-correlated strength $\left(\vec{r}_1 \cdot \vec{r}_2 = 0\right)$

$$\longrightarrow \left\langle \theta_{12} \right\rangle = 48^{+14}_{-18}\ {\rm deg}$$

Comparison with 3-body theory-2



Myo et al.,PRC76,024305 (2007).

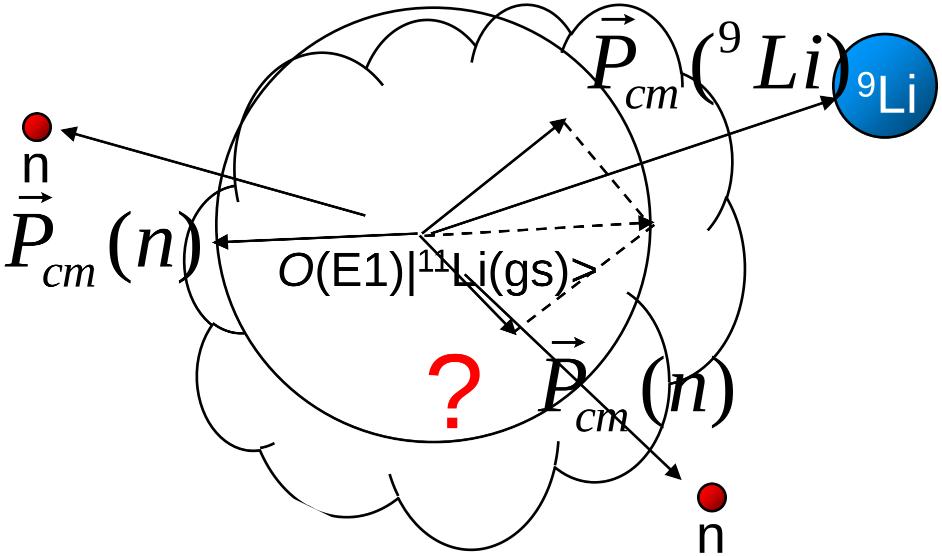
Core polarization

(Tensor correlation+Pauli Principle)

P(S^2)~ 40% $\sqrt{\langle r_{c-2n} \rangle^2} = 5.38\,\text{fm}$ $\langle \theta_{12} \rangle = 65\,\text{deg}$

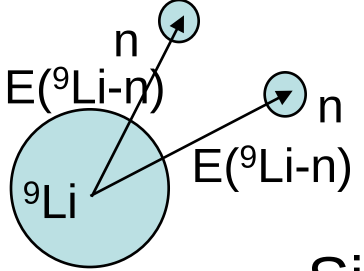
Both Charge distribution & B(E1) are reproduced.

2n Correlations can be studied by 3-body decay of $^{11}Li^*$?

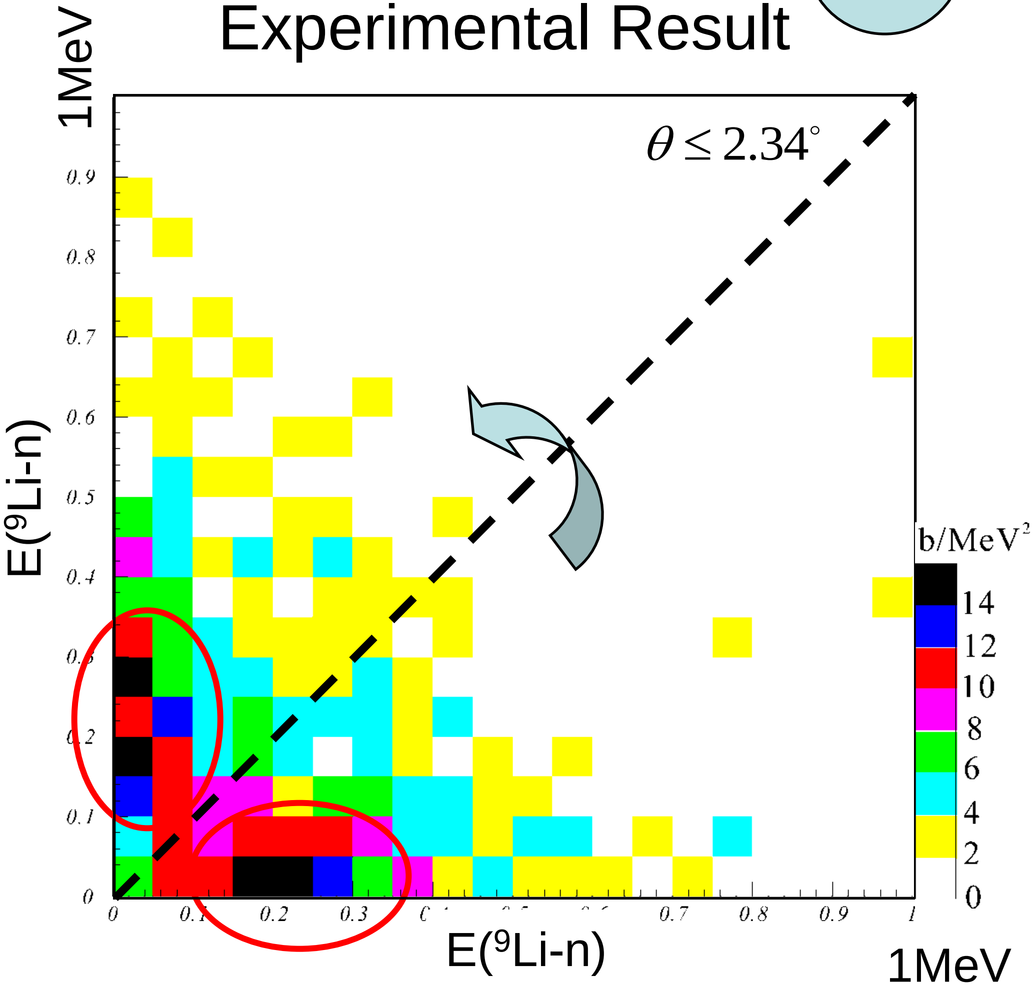


--Kinematically complete measurement

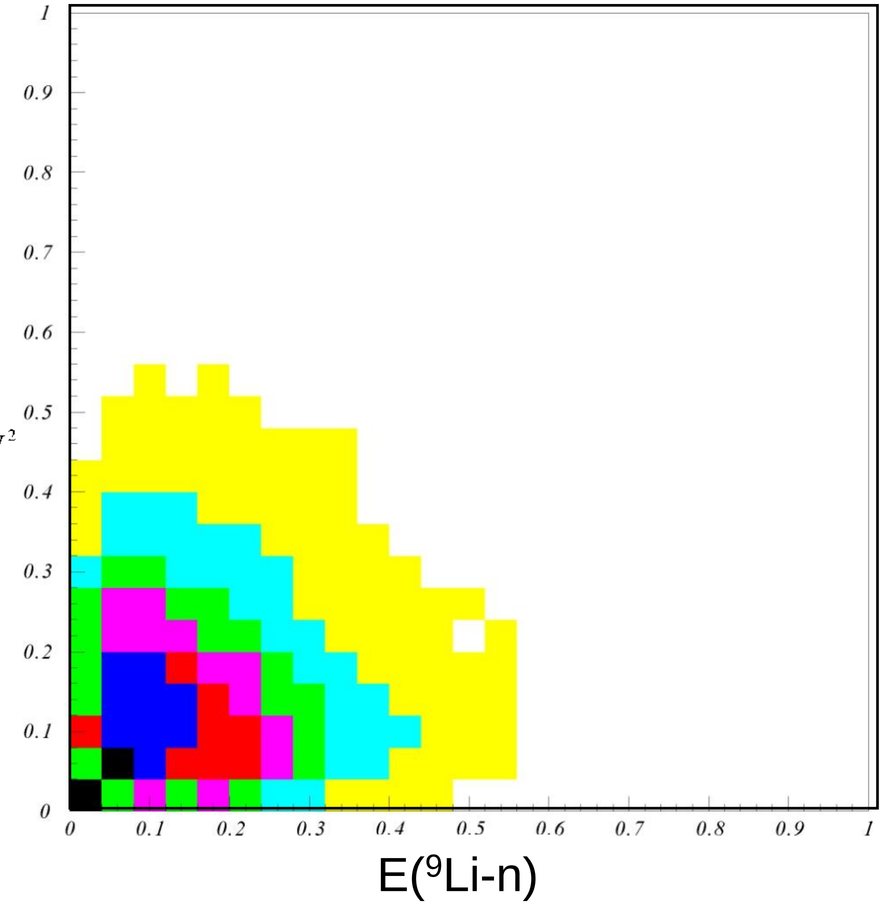
Further Correlation?

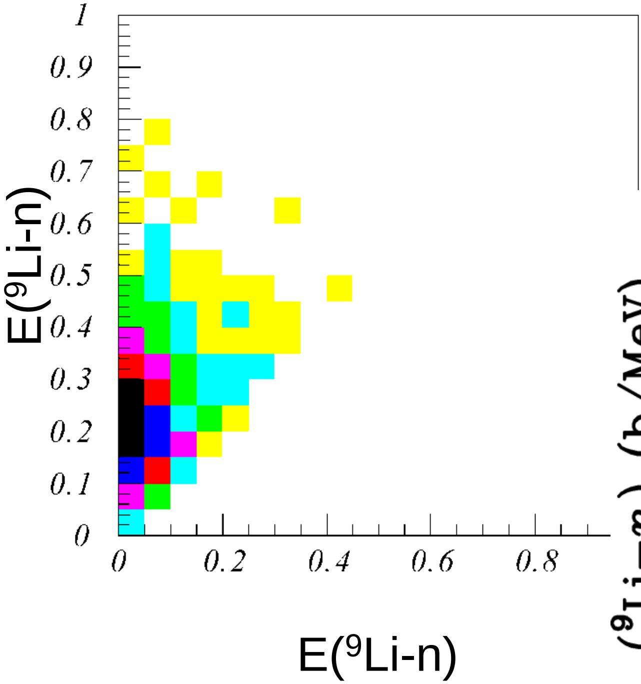


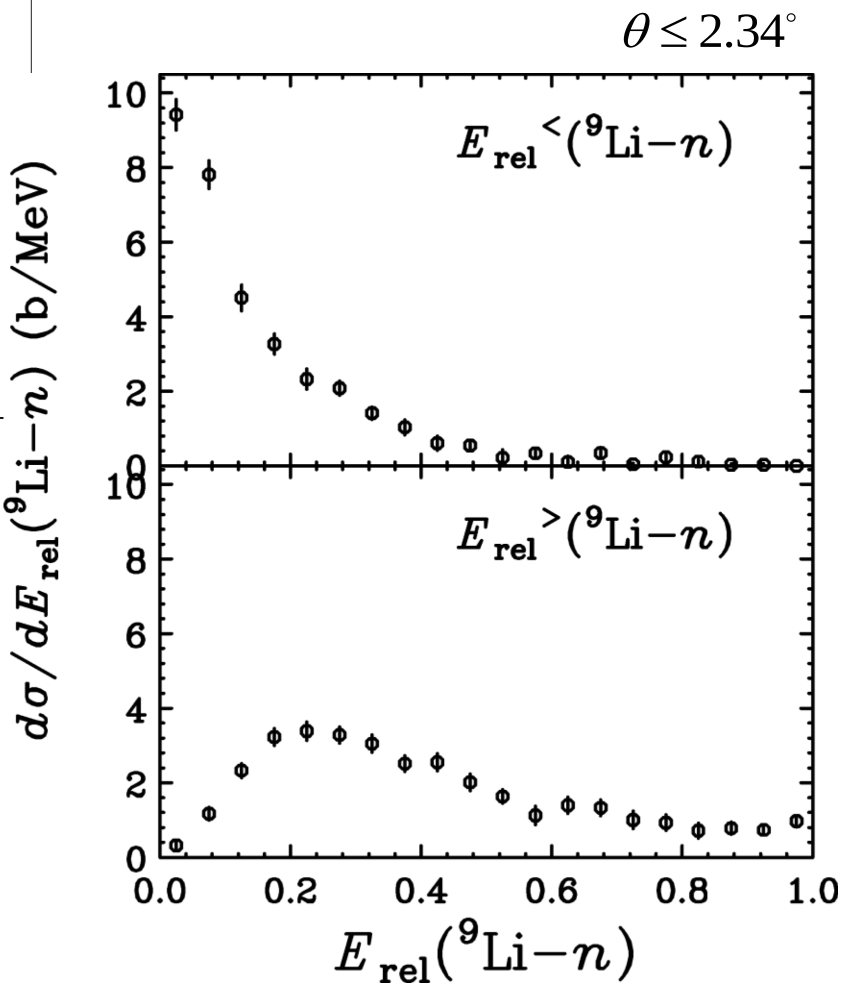
Experimental Result



Simulation (Phase Space)







^{10}Li s-wave
Virtual state

p-wave?

$$\left|\Phi(^{11}\mathrm{Li}_{gs})\right\rangle = \alpha\left|\Phi(^{9}\mathrm{Li}_{gs})\otimes(s_{1/2})^2\right\rangle + \beta\left|\Phi(^{9}\mathrm{Li}_{gs})\otimes(p_{1/2})^2\right\rangle + \dots$$

$$\left|O(E1)\,|\,\Phi(^{11}\mathrm{Li}_{gs})\right\rangle = \gamma\left|\Phi(^{9}\mathrm{Li}_{gs})\otimes(s_{1/2})^1(p_{1/2})^1\right\rangle + \dots$$

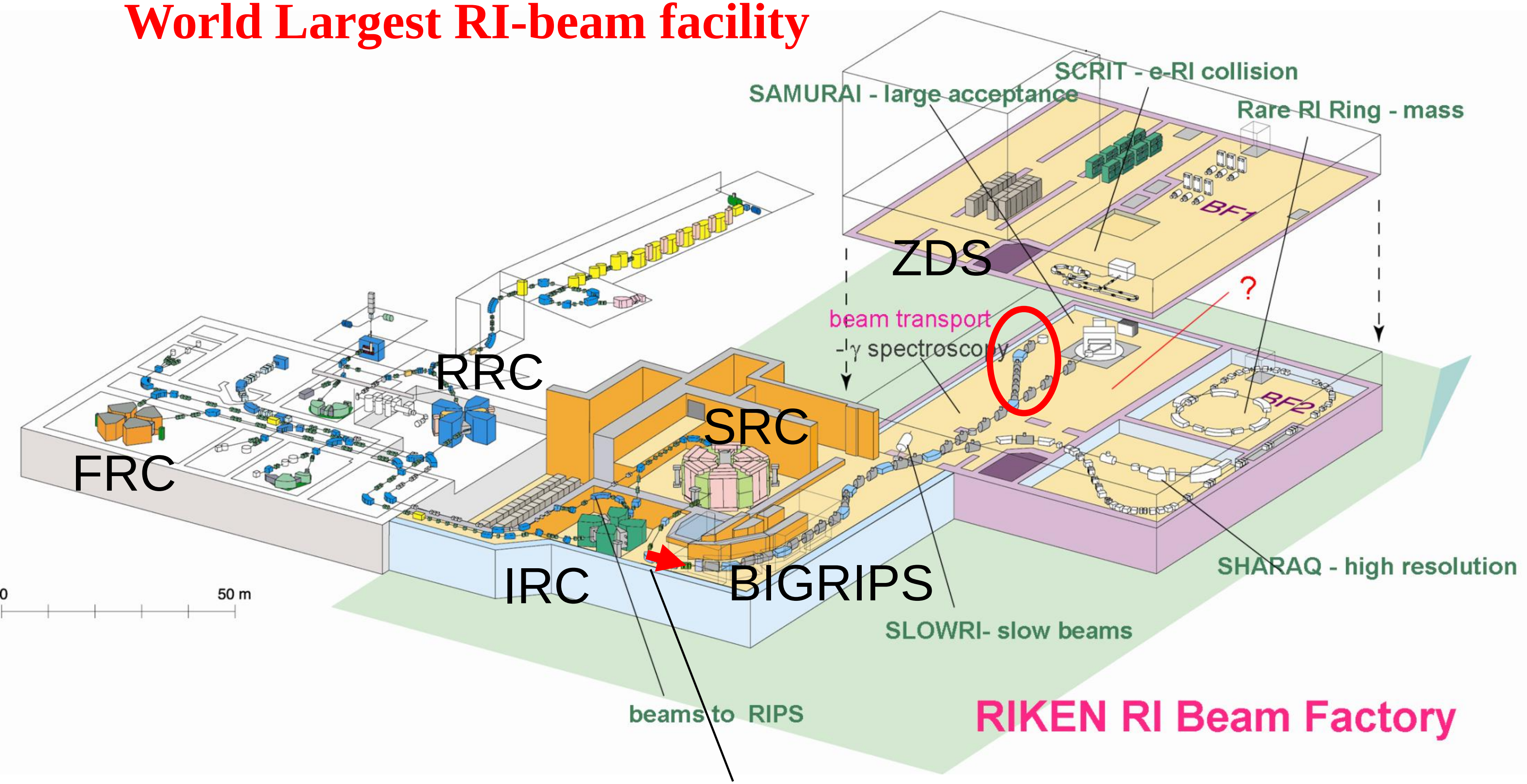
2

Inclusive Coulomb Breakup of ^{31}Ne and ^{22}C @ RIKEN RI BEAM FACTORY

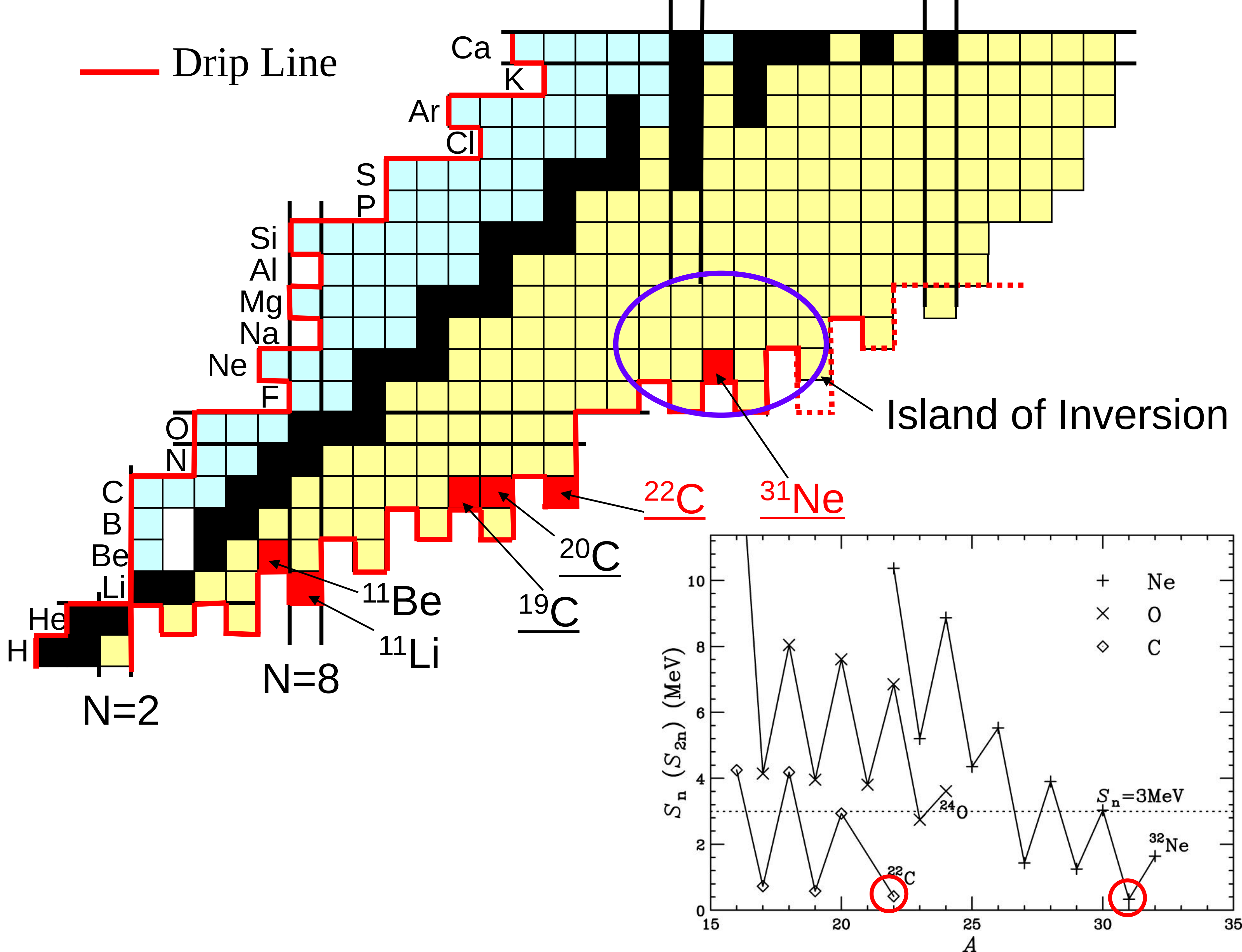
As an experiment for
Day-one ^{48}Ca beam campaign,
December 2008

RIKEN RI Beam Factory (RIBF)

Completed in 2007
World Largest RI-beam facility



^{48}Ca 345MeV/nucleon ~100pnA

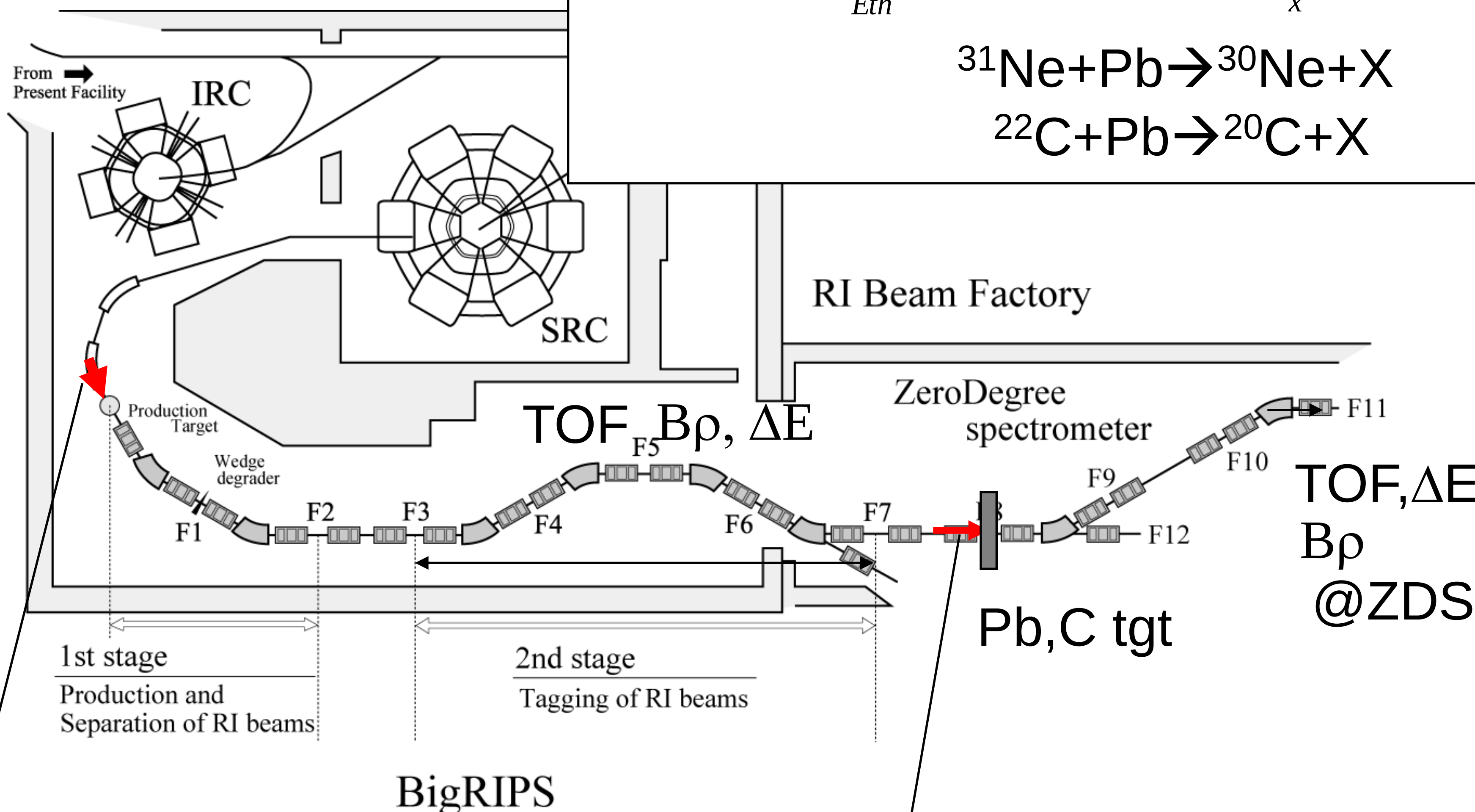

Drip Line
Ca
K
Ar
Cl
S
P
Si
Al
Mg
Na
Ne
F
O
N
C
B
Be
Li
He
H
N=2
N=8
11Be
11Li
19C
20C
22C
31Ne
Island of Inversion
Ne
O
C
S_n (S_{2n}) (MeV)
A
S_n=3MeV
24O
22C
32Ne

Inclusive Coulomb Breakup

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

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

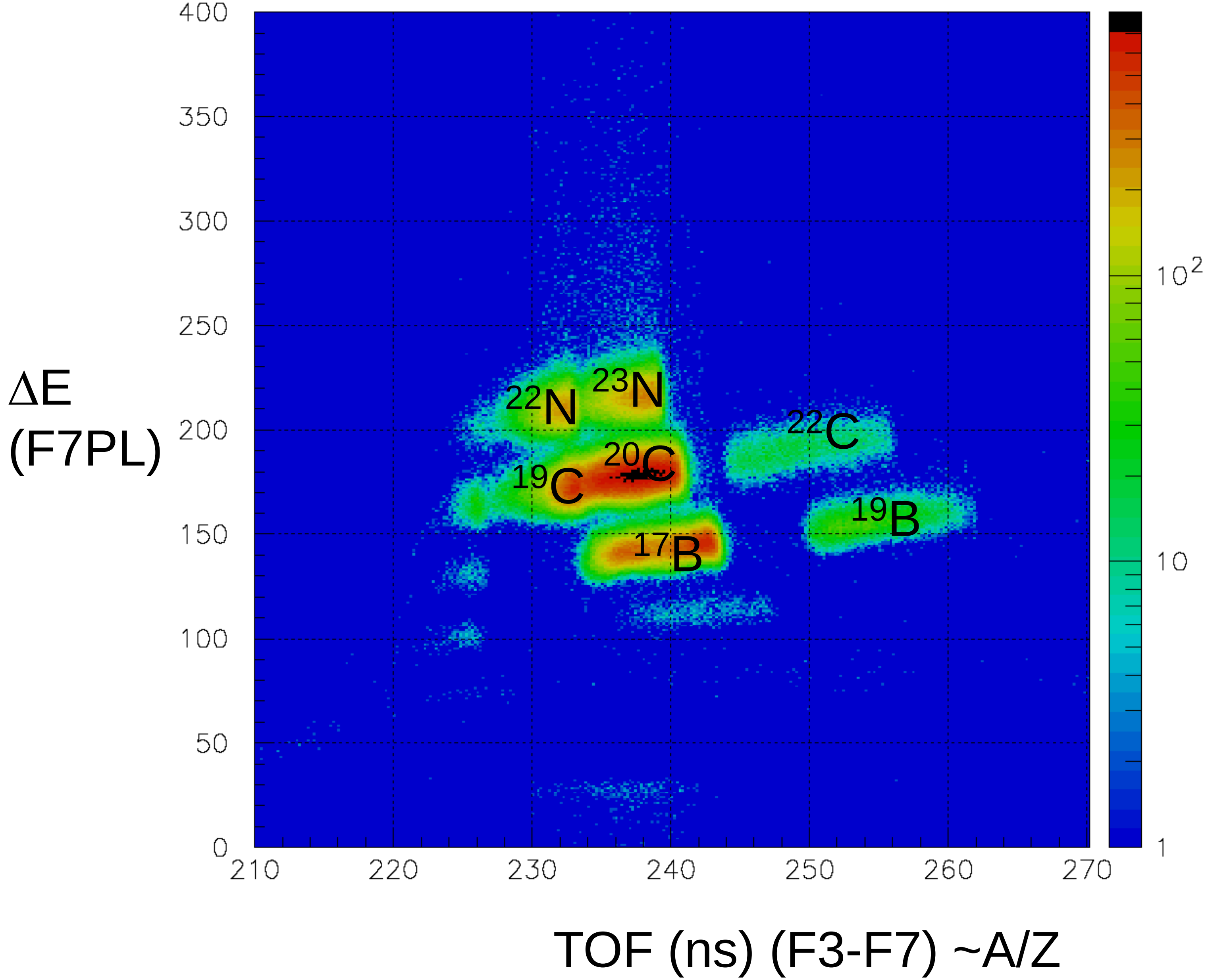
$^{22}C+Pb \rightarrow {}^{20}C+X$



^{48}Ca 345MeV/u

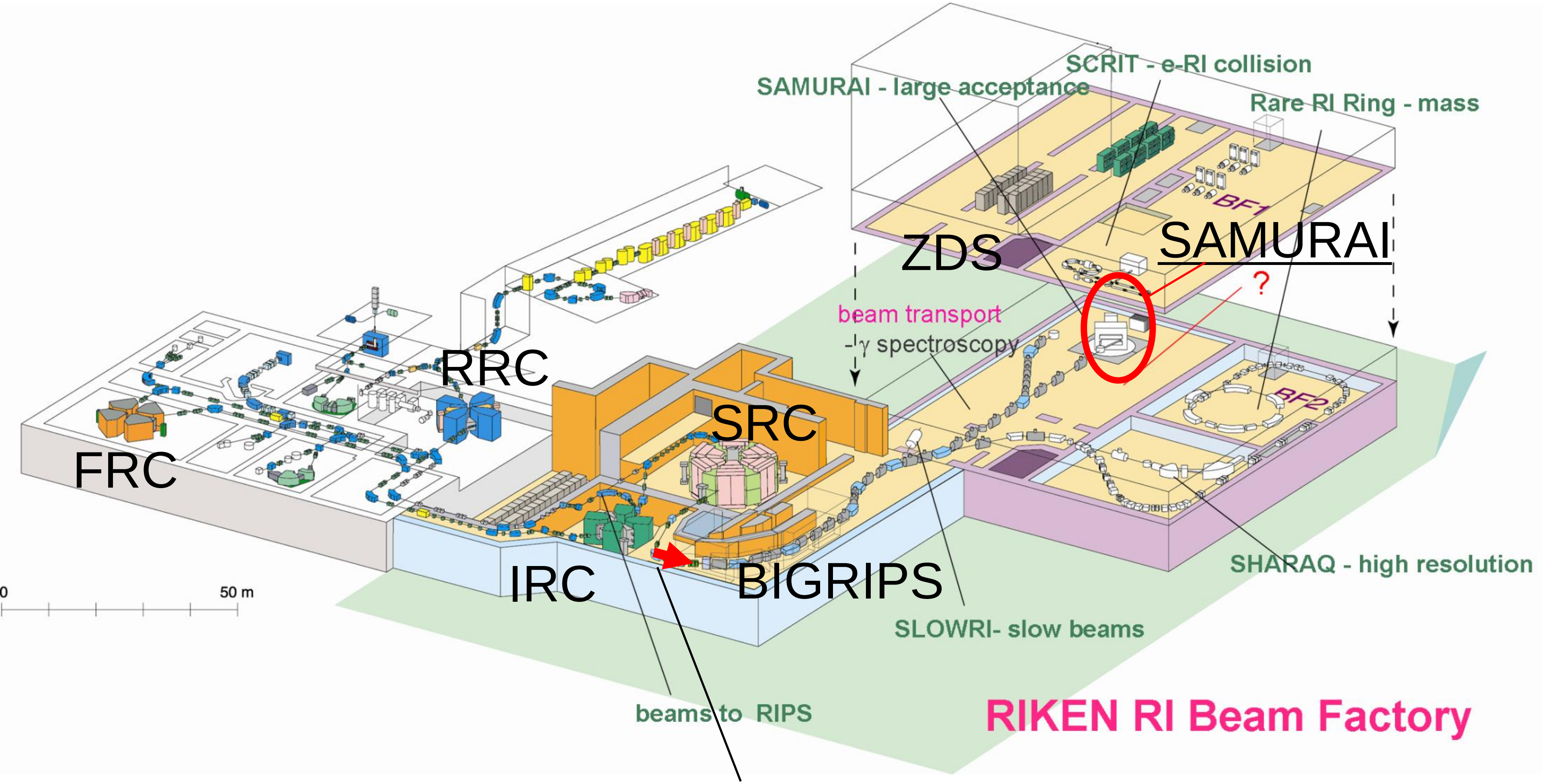
^{31}Ne ~230MeV/u

$^{22,20,19}C$ ~250MeV/u


ΔE
(F7PL)
TOF (ns) (F3-F7) ~A/Z
22N
23N
20C
19C
22C
19B
17B
400
350
300
250
200
150
100
50
0
210
220
230
240
250
260
270
10^2
10
1

3 SAMURAI / NEBULA PROJECT @ RIKEN RI BEAM FACTORY

RIKEN RI Beam Factory (RIBF)

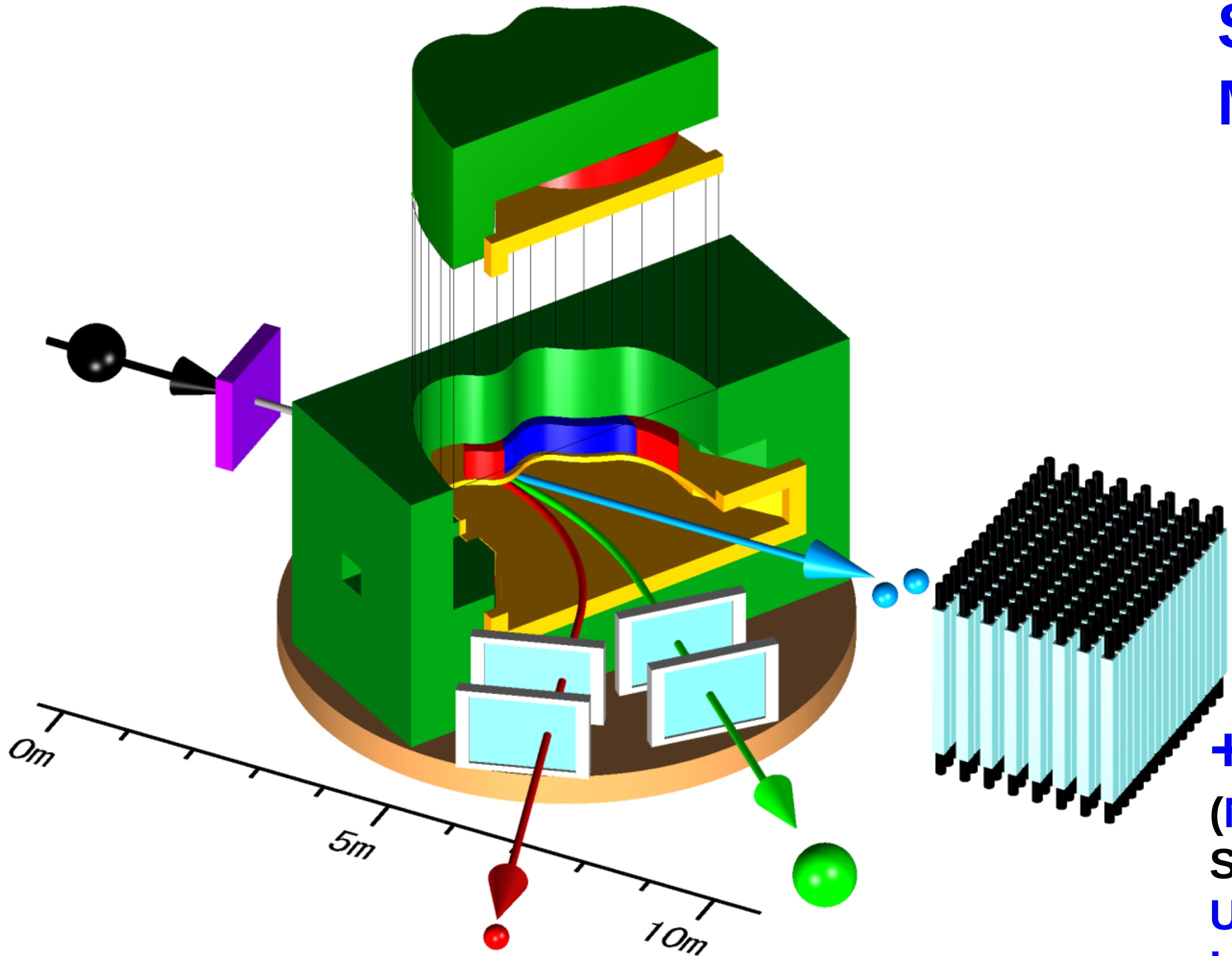


^{48}Ca 345MeV/nucleon ~100pnA

SAMURAI

Superconducting Analyser for MUlti-particles from RAdio-Isotope Beam

2008-2011 *1.5GJPY~16MUSD~13MEuro*



Superconducting Magnet

To let neutron(s) pass through the gap

Sweep Beam and Charged Fragments

Good Mass Resolution for PID @ A~100

+NEBULA

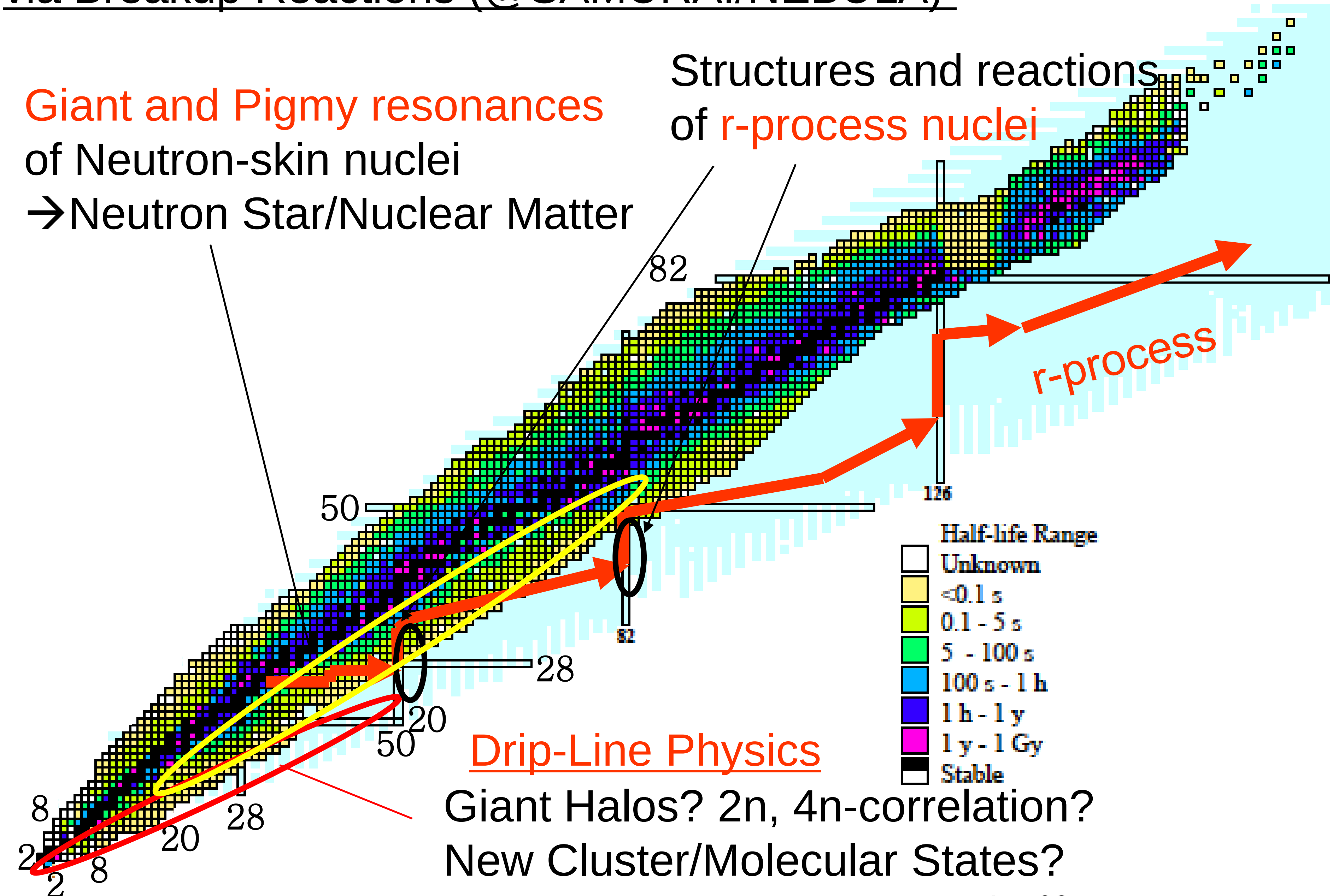
(NEutron Detection System for Breakup of Unstable Nuclei with Large Acceptance)

Bending Power
BL=7Tm (B=3Tesla, 60deg bending)

Physics of Neutron-rich Nuclei via Breakup Reactions (@SAMURAI/NEBULA)

Giant and Pigmy resonances of Neutron-skin nuclei
→Neutron Star/Nuclear Matter

Structures and reactions of r-process nuclei



Drip-Line Physics

Giant Halos? 2n, 4n-correlation?
New Cluster/Molecular States?
States beyond drip-lines? (^{4}n, ^{28}O, and more)

Summary

1 Coulomb Breakup of ^{11}Li and two-neutron correlation

T. Nakamura, A.M.Vinodkumar et al., Phys. Rev. Lett. 96, 252502 (2006).

$$B(E1) = 1.42 \pm 0.18 e^2 fm^2 (S_{2n} = 300\text{keV})$$

- Strong B(E1) at very low excitation energy
- neutron-neutron spatial correlation from E1 sum rule

  θ_{nn}~50deg
- 3body correlation in the decay of the dipole halo state

2 Inclusive Coulomb Breakup of ^{22}C and ^{31}Ne

Accumulated about ~1000 1n removal events

Promising results

3 SAMURAI/NEBULA Project

Collaborators

Coulomb Breakup of ^{11}Li (PRL96,252502(2006))

T.Nakamura, A.M.Vinodkuar, T.Sugimoto, Y.Kondo, N. Aoi, H. Baba, D. Bazin, N. Fukuda, T. Gomi, H. Hasegawa, N. Imai, M. Ishihara, T.Kobayashi, T. Kubo, M. Miura, T. Motobayashi, H. Otsu, A.Saito, H.Sakurai, S. Shimoura, K. Watanabe, Y.X. Watanabe, T. Yakushiji, Y. Yanagisawa, K. Yoneda

Inclusive Coulomb Breakup of ^{31}Ne and ^{22}C as an experiment in RIBF DayOne Campaign

T.Nakamura, N.Kobayashi(Duracell), Y.Satou, Y.Kondo, K.Tanaka, Y.Kawada, N.Tanaka, S.Deguchi,N.Aoi,K.Yoneda,H.Baba, S.Takeuchi, T.Ohnishi,T.Kubo, A.Saito, S.Shimoura, H.Sakurai, M.Ishihara, N.Orr, M.Takechi,T.Sumikama, Y.Togano, E.Takeshita, H.Takeda,A.Yoshida,K.Yoshida,K.Kusaka, Y.Yoshinaga,K.Miyashita

東工大物理GCOE　研究員募集中（1月27日締切）
www.phys.titech.ac.jp を参照下さい。