SEARCH FOR DINEUTRON CORRELATION IN BORROMEAN HALO NUCLEI

A. Corsi

CEA Saclay

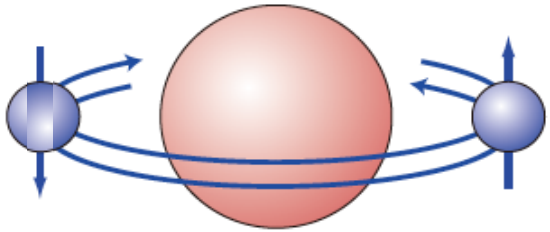
NS2016, Knoxville, 25-29th July 2016

Outline

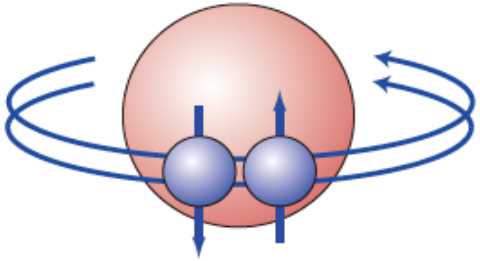
- Dineutron correlation in Borromean nuclei
- *(p,pn)* Quasi Free Scattering (QFS)
- Spectroscopy of unbound ^{10}Li
- Opening angle distributions: ^{11}Li, ^{14}Be
- Conclusions

DINEUTRON CORRELATION

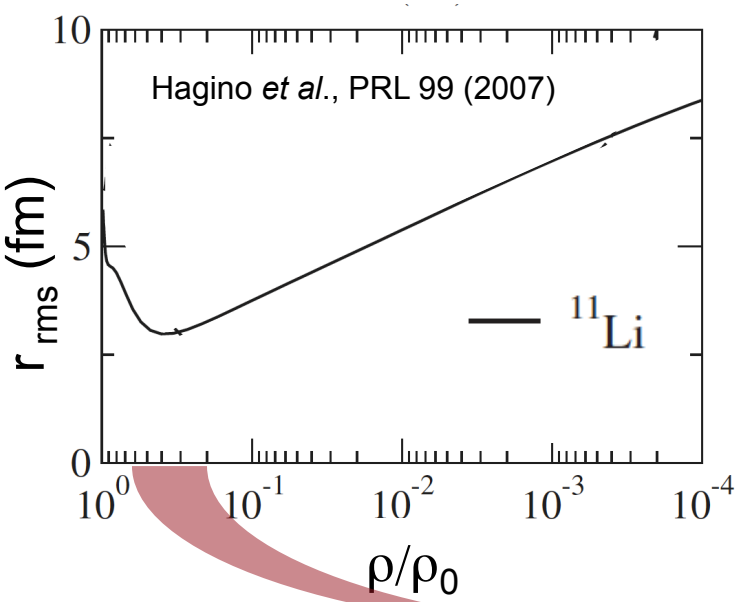
PAIRING (BCS LIKE)

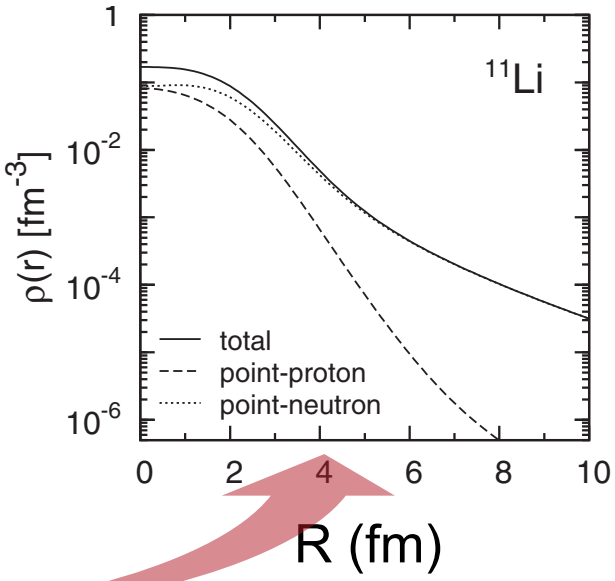


DI-NEUTRON



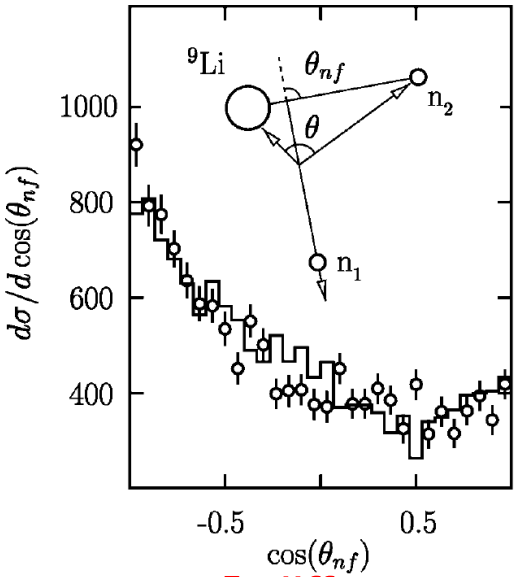
DECREASING DENSITY





HOW TO PROBE IT: THE CASE OF ^{11}LI

- C induced knockout Simon *et al.*, PRL 83 (1999)
- Coulomb breakup Nakamura *et al.*, PRL 96 (2006)
- H induced knockout Aksyutina *et al.*, PLB 718 (2013)



Asymmetry ➔different parity

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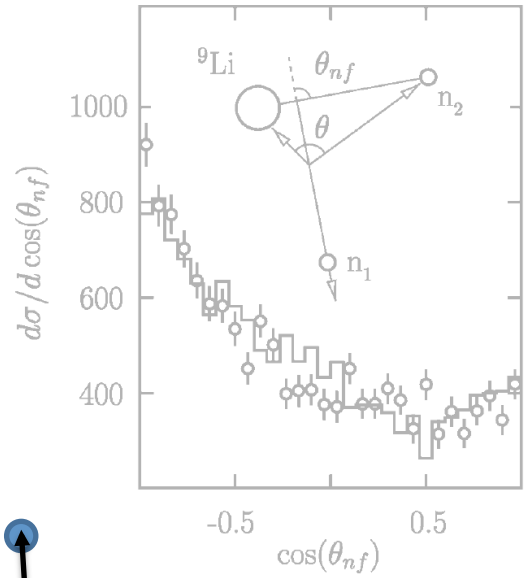

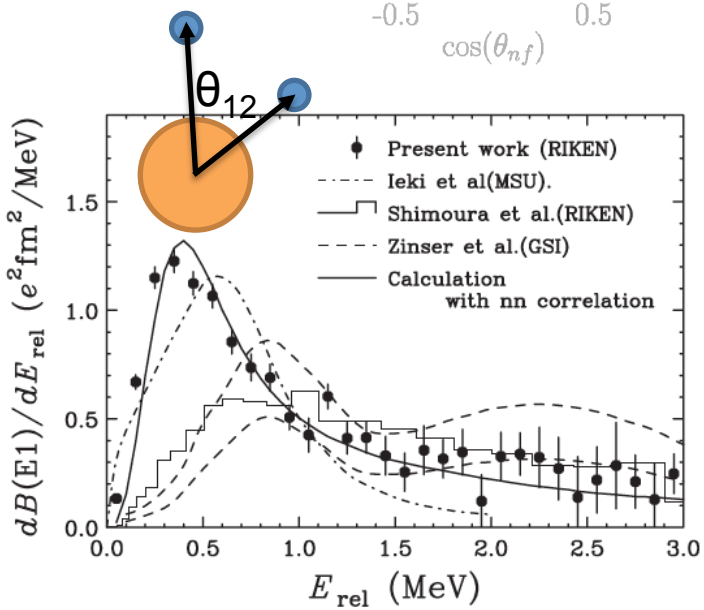

$B(E1) \sim \cos(\theta_{12}) \rightarrow \theta_{12} = 48^{+14}_{-18}{}^{\circ}$

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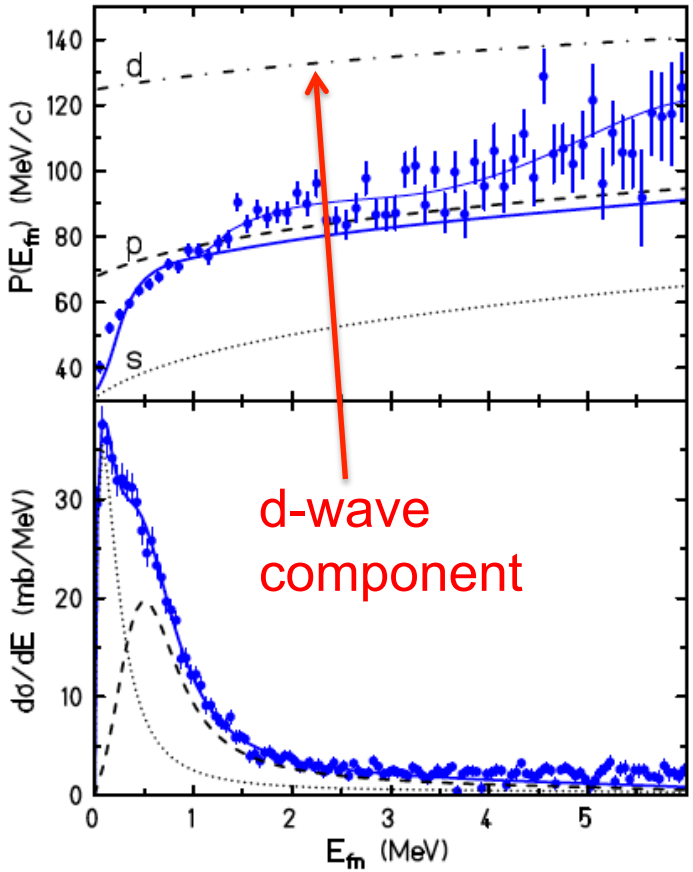

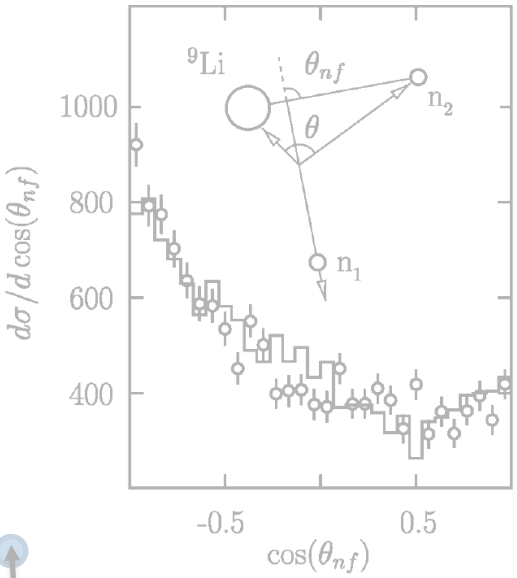

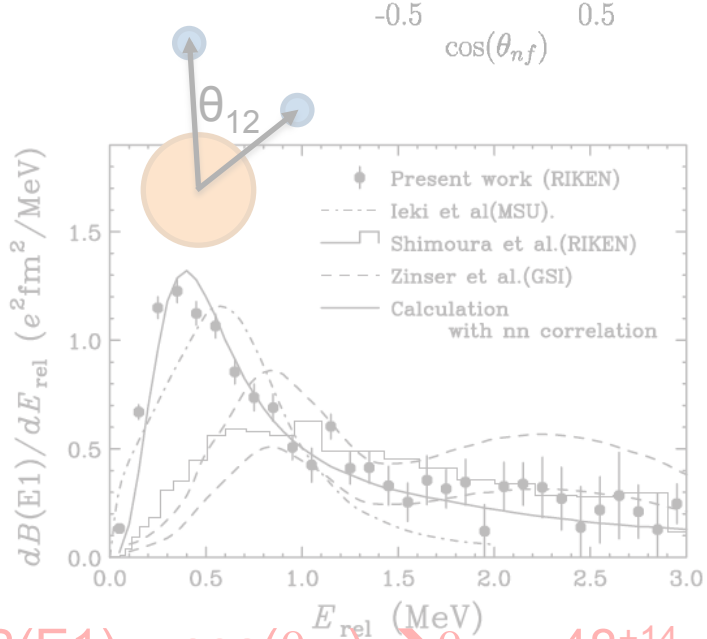

$B(E1) \sim \cos(\theta_{12}) \rightarrow \theta_{12} = 48^{+14}_{-18}$ °

CAVEATS

- Absorption by heavy ion target (C)
- Final State Interaction, model dependence to extract gs properties
- Core excitation

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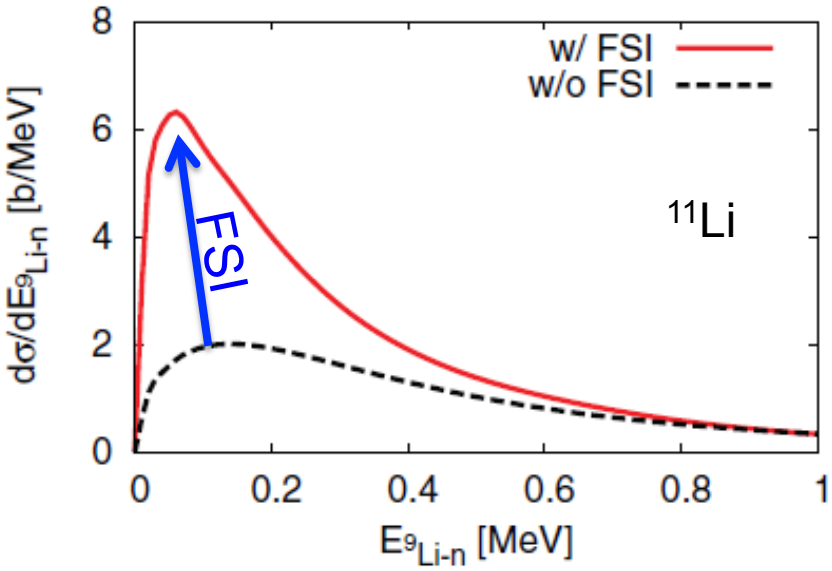

Kikuchi *et al.*, PRC 87 (2013)

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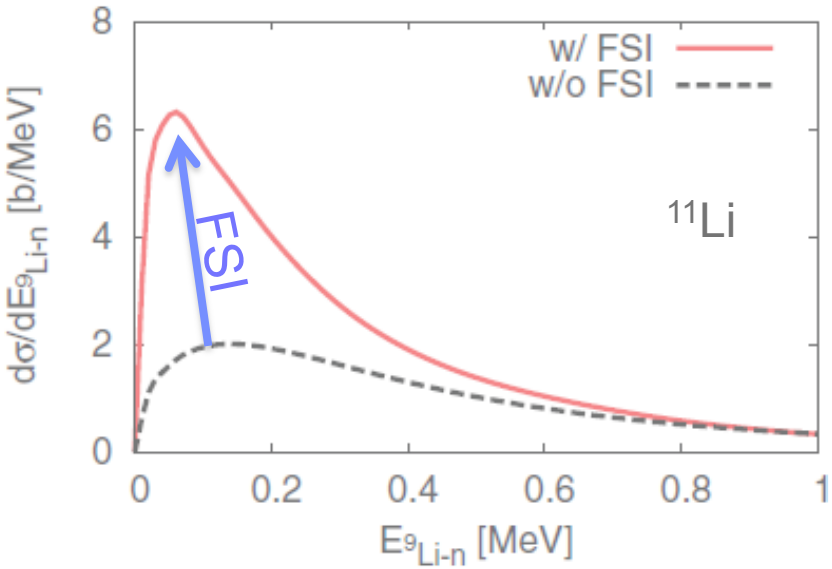
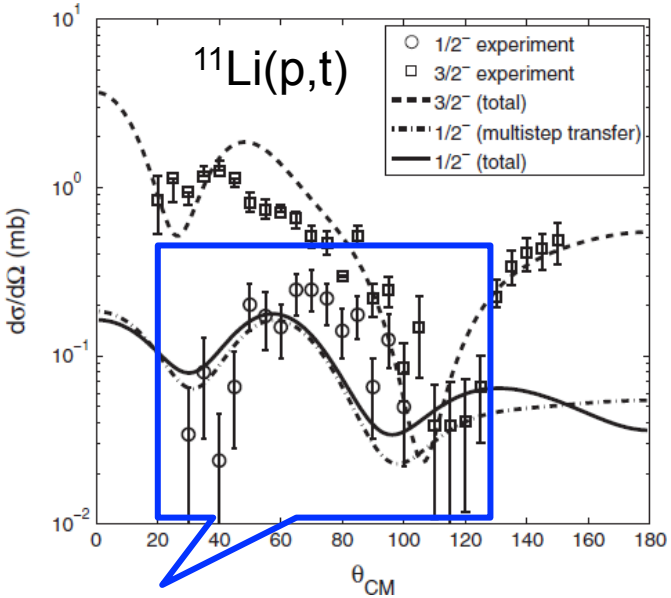


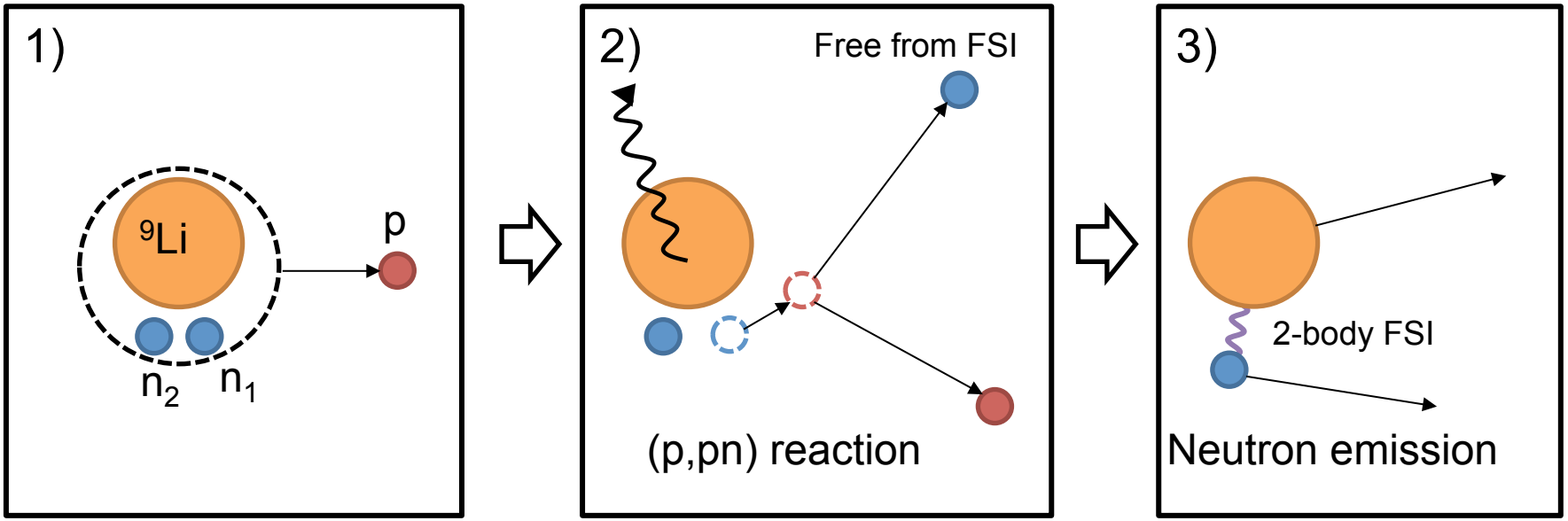
Kikuchi *et al.*, PRC 87 (2013)



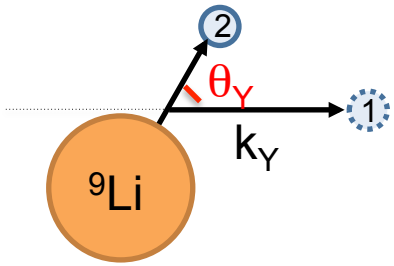
excited core/halo components

Tanihata *et al.*, PRL 100 (2008)
Potel *et al.*, PRL 105 (2010)

THIS EXPERIMENT



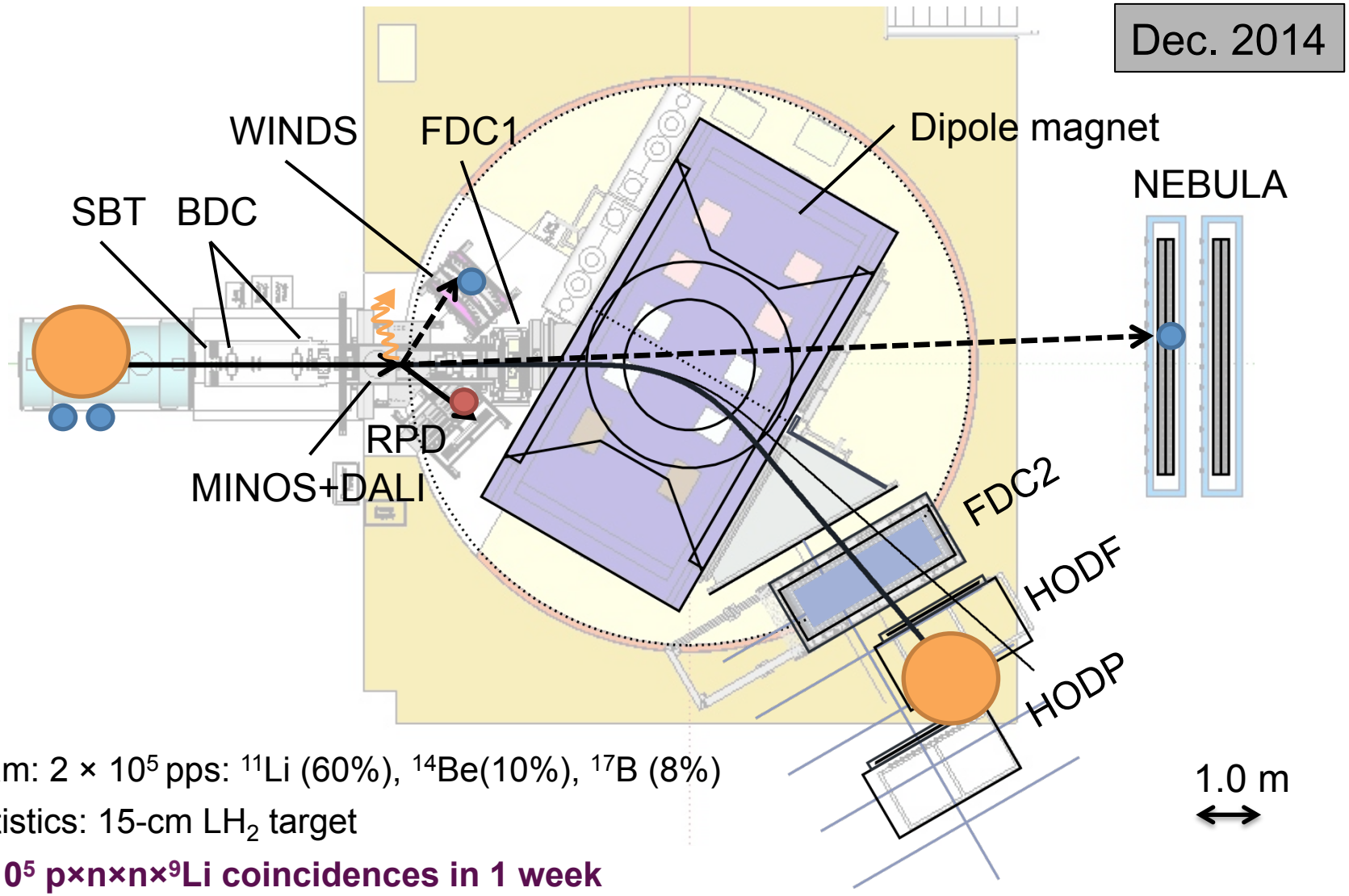
- QFS on Hydrogen to **minimize Final State Interaction (2)**
- **Kinematically complete** measurement
- Core excitation via γ **detection**
- **Observable sensitive to dineutron: θ_Y**



➔ Need high statistics : RIBF + MINOS thick target = x 100 in statistics

EXPERIMENTAL SETUP AT RIBF, RIKEN

Spokespersons: Y.Kubota (CNS, RNC) and A.Corsi (CEA Saclay)



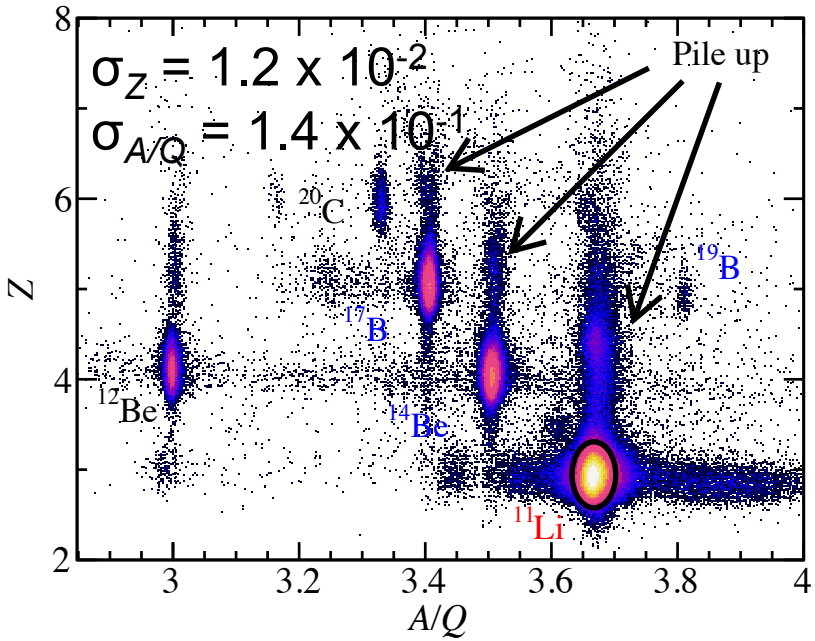
Beam: 2 × 10^5 pps: ^{11}Li (60%), ^{14}Be(10%), ^{17}B (8%)

Statistics: 15-cm LH_2 target

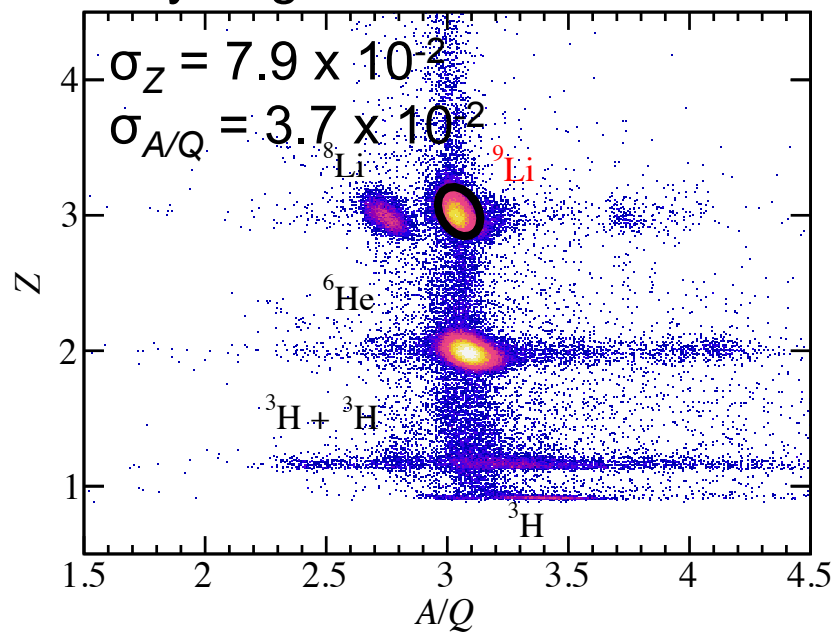
→10^5 p×n×n×^{9}Li coincidences in 1 week

NUCLEI OF INTEREST

Beam PID



Heavy fragment PID for ^{11}Li beam



^{11}Li $\xrightarrow{(p,pn)}$ ^{10}Li* $\longrightarrow$ ^{9}Li + *n* (Y.Kubota, RNC)

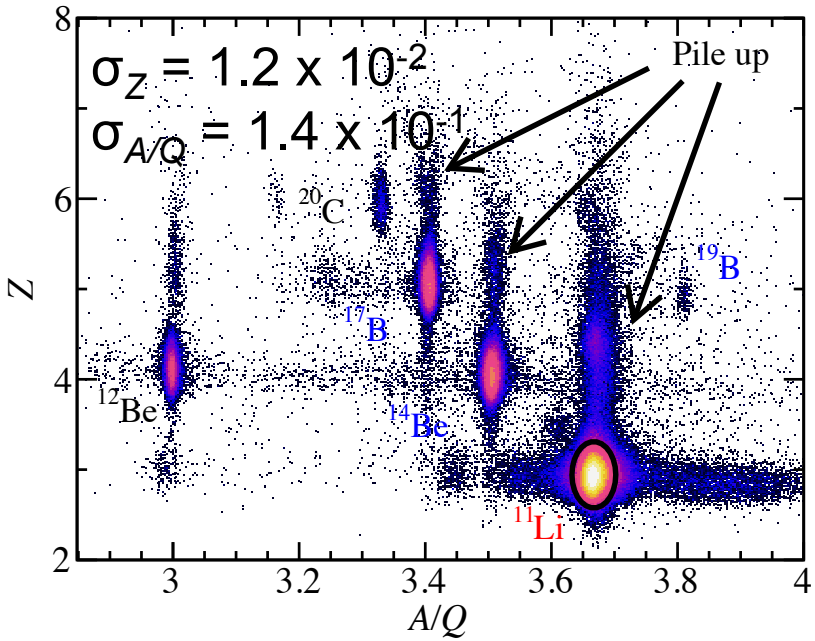
$\xrightarrow{(p,2p)}$ ^{10}He* $\longrightarrow$ ^{8}He + 2*n*, ^{6}He + 4*n* (S.Giraud, CEA Saclay)

^{14}Be $\xrightarrow{(p,pn)}$ ^{13}Be* $\longrightarrow$ ^{12}Be + *n* (A.Corsi, CEA Saclay)

^{17}B $\xrightarrow{(p,pn)}$ ^{16}B* $\longrightarrow$ ^{15}B + *n* (Y.Zaihong, RNC)

NUCLEI OF INTEREST

Beam PID



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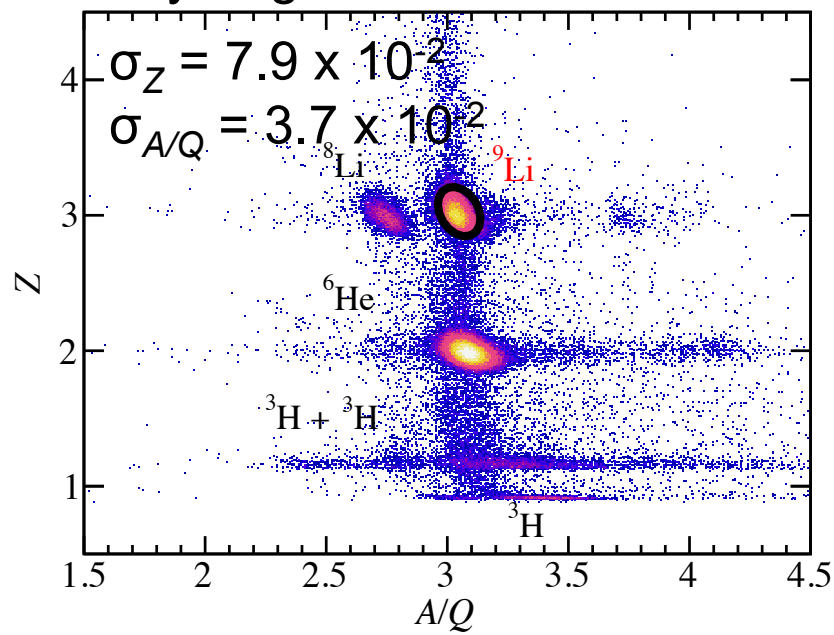
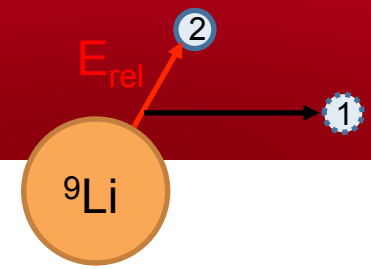
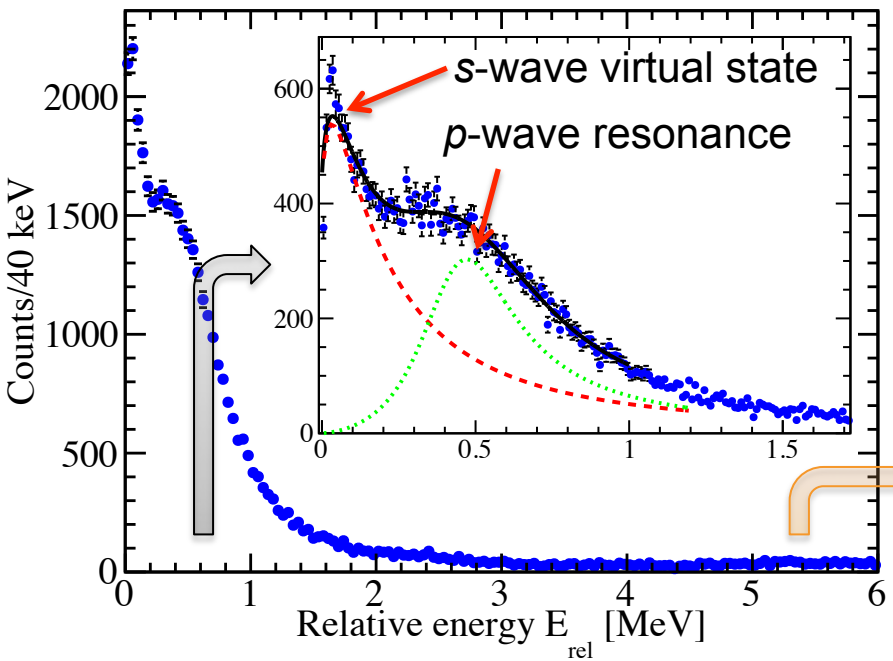
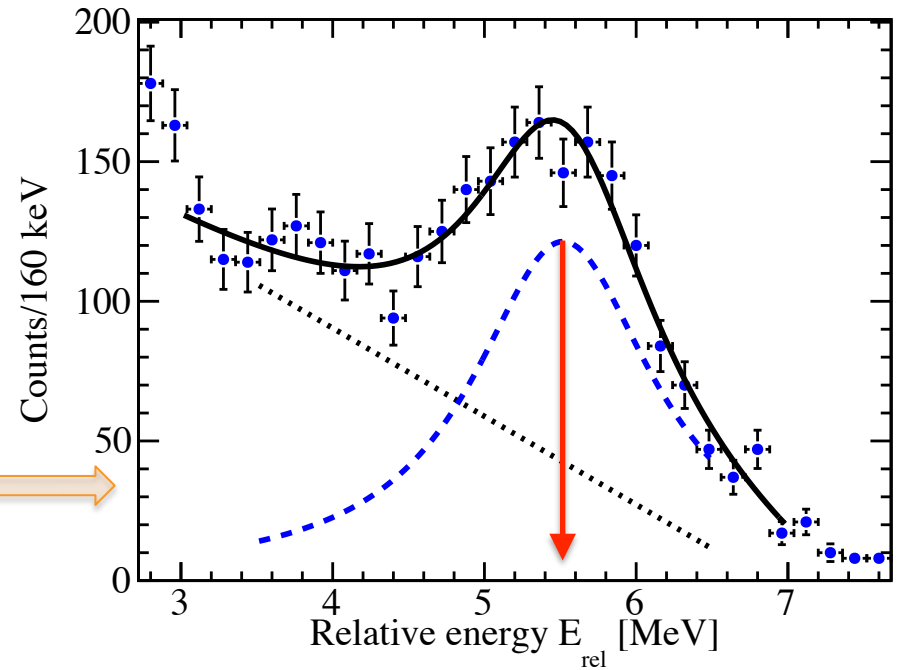


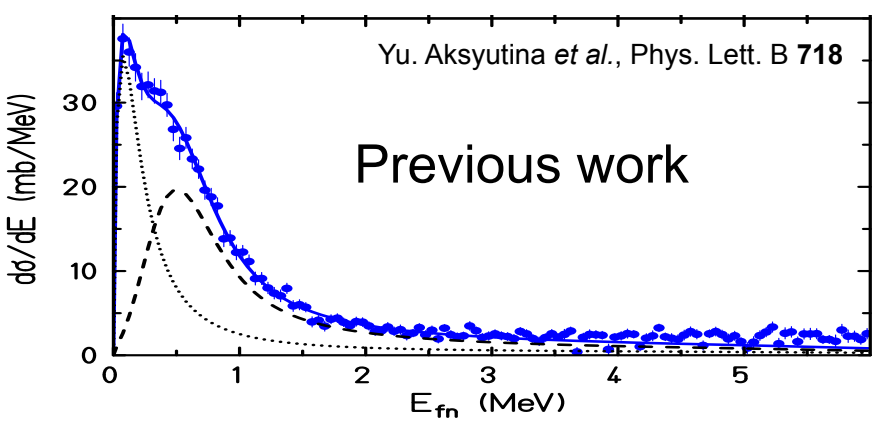
^{11}Li	$\xrightarrow{(p,pn)}$	^{10}Li*	$\longrightarrow$ ^{9}Li + n	(Y.Kubota, RNC)
	$\xrightarrow{(p,2p)}$	^{10}He*	$\longrightarrow$ ^{8}He + 2n, ^{6}He + 4n	(S.Giraud, CEA Saclay)
^{14}Be	$\xrightarrow{(p,pn)}$	^{13}Be*	$\longrightarrow$ ^{12}Be + n	(A.Corsi, CEA Saclay)
^{17}B	$\xrightarrow{(p,pn)}$	^{16}B*	$\longrightarrow$ ^{15}B + n	(Y.Zaihong, RNC)

^{10}LI INVARIANT MASS: A NEW RESONANCE







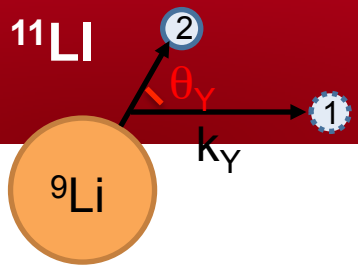


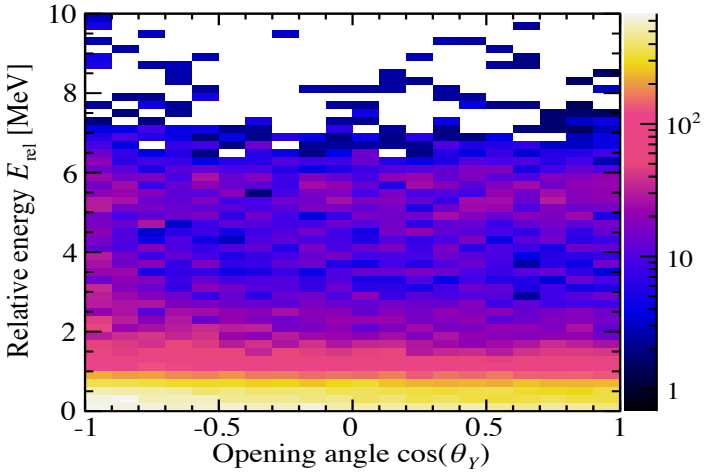
New resonance:

- E_r = 5.52±0.04 MeV
- Γ = 0.72±0.10 MeV
- *d*-wave resonance

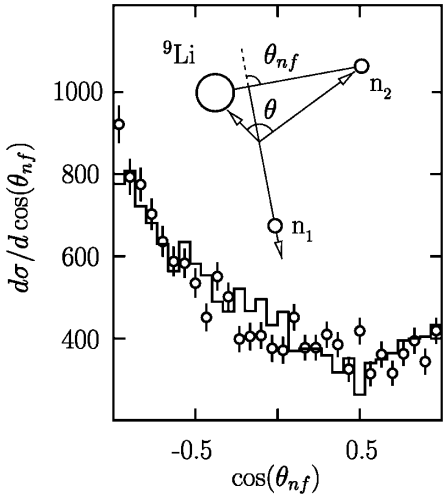
Courtesy: Y.Kubota, RNC

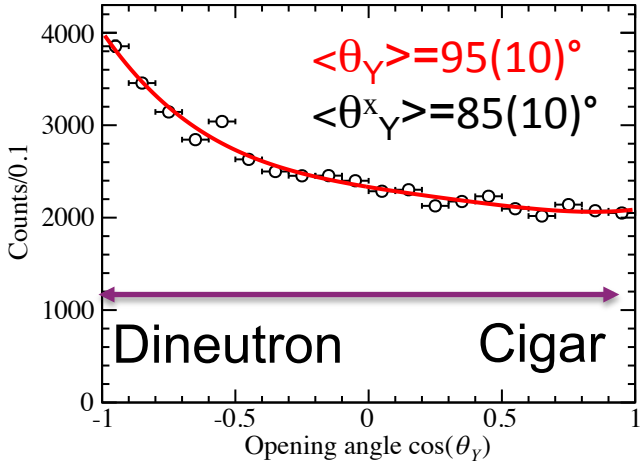
OPENING ANGLE: DINEUTRON CORRELATION IN ^{11}LI





$<\theta^x_Y>=76(2)°$

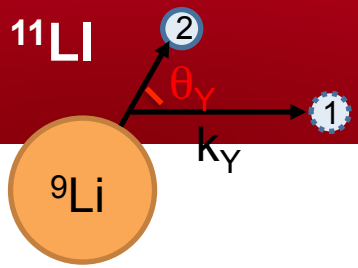


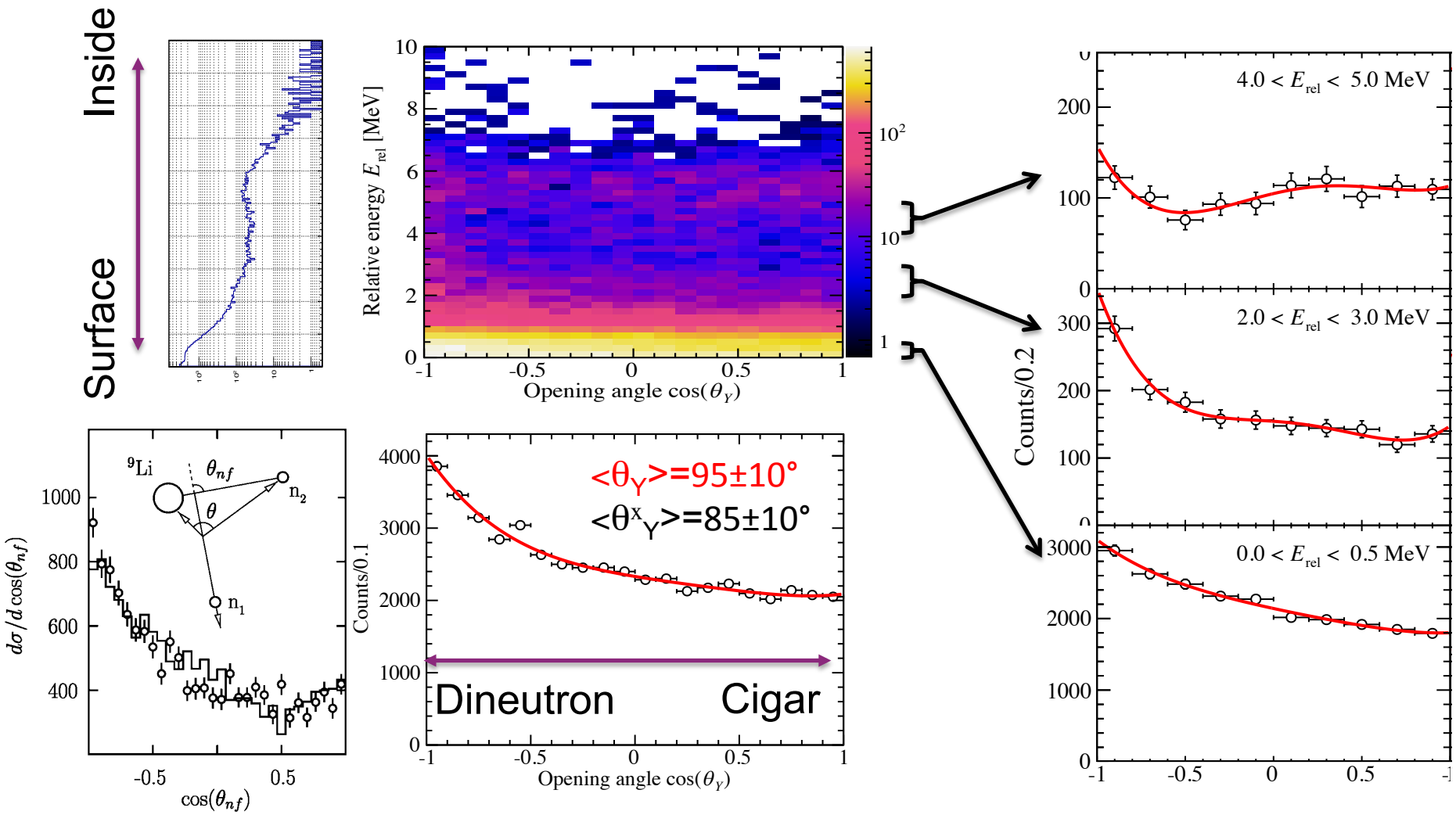


H. Simon et al, Phys. Rev. Lett. **83**, 496 (1999).

Courtesy: Y.Kubota, RNC

OPENING ANGLE: DINEUTRON CORRELATION IN ^{11}LI

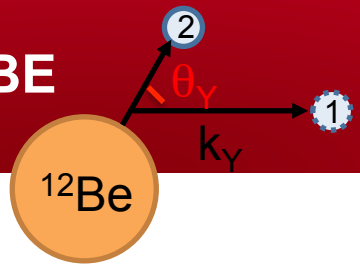


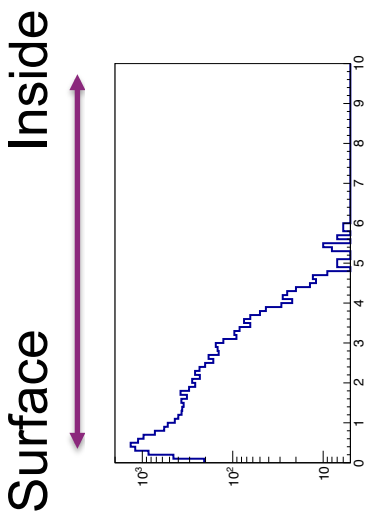


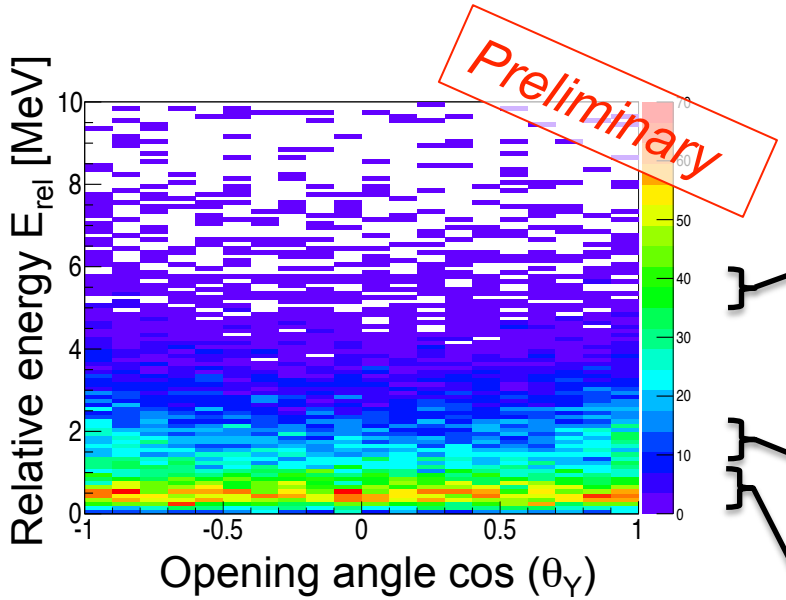
H. Simon et al, Phys. Rev. Lett. **83**, 496 (1999).

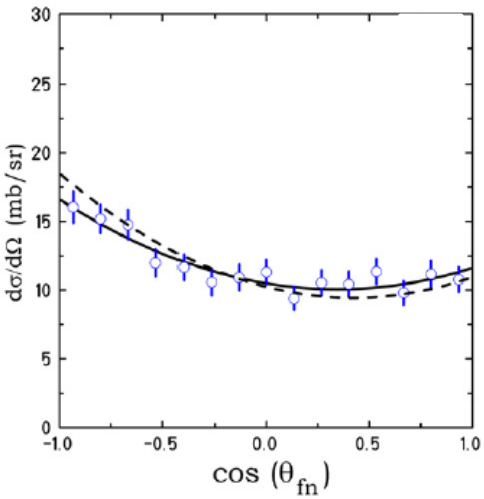
➔signature of dineutron at the surface

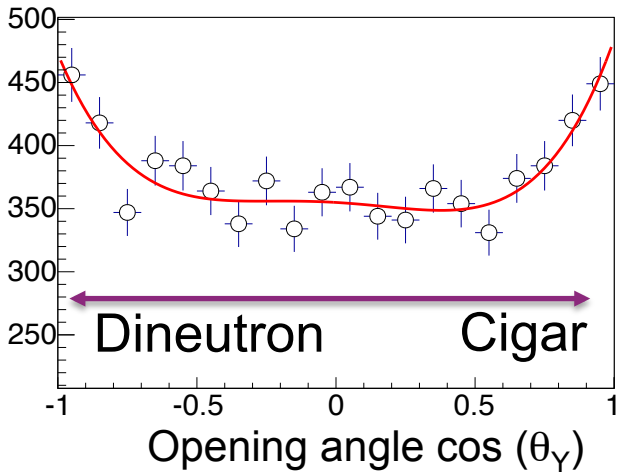
OPENING ANGLE: DINEUTRON CORRELATION IN ^{14}BE

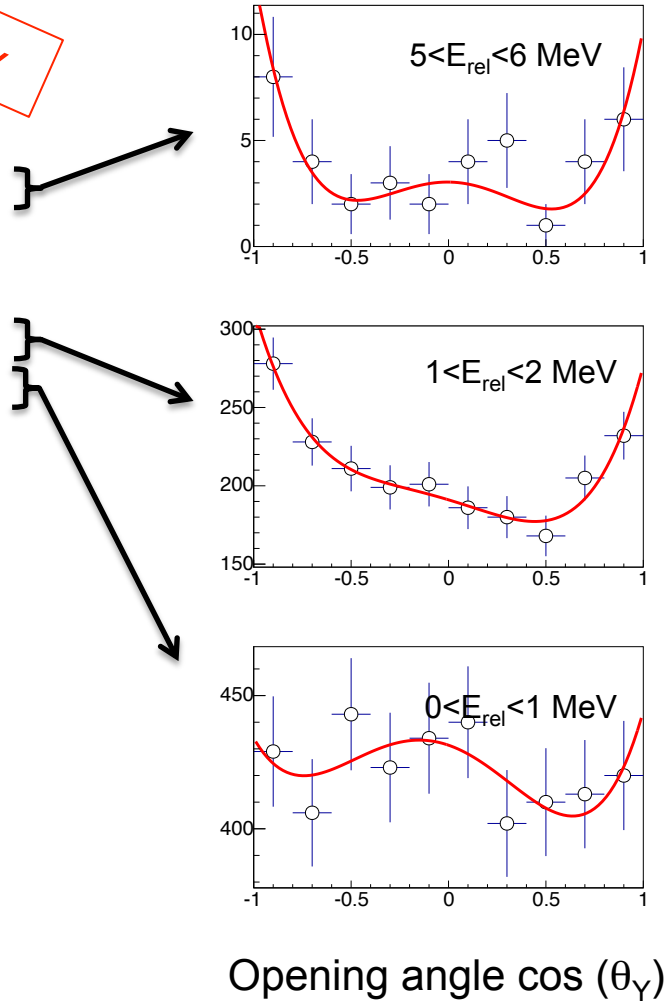












H.Simon *et al.*, NPA 791 (2007)

➔weaker/different nature of dineutron correlation

Summary and perspectives

- **Quasi-free (*p,pn*) measurement on Borromean nuclei** ^{11}Li, ^{14}Be, ^{17,19}B for the study of dineutron correlation
  - ✔ High luminosity
  - ✔ Kinematical complete measurement
  - ✔ Quasi-free (*p,pn*) → Minimum FSI

- New *d*-wave resonance in ^{10}Li at E_r = 5.52 MeV, Γ = 0.72 MeV.

- Integrated opening angle $\langle\theta^x_Y\rangle$ = 85±10° for ^{11}Li
  → **Indication of "weaker" dineutron correlation**

- Need for structure + reaction model for nuclei with A>11

Collaboration

Experimentalists:

Y.Kubota, M.Dozono, Y.Kiyokawa, M.Kobayashi, S.Ota (CNS); H.Baba, T.Isobe, T.Motobayashi, H.Otsu, V.Panin, M.Sako, M.Sasano, H.Sato, Y.Shimizu, L.Stuhl, T.Uesaka, K.Yoneda, J.Zenihiro (RNC); **A.Corsi**, G.Authelet, D.Calvet, A.Delbart, J.-M.Gheller, A.Gillibert, V.Lapoux, A.Obertelli, E.C.Pollacco, J.-Y.Roussé, C.Santamaria (CEA Saclay); C.Caesar, S.Paschalis (TU Darmstadt); J.Feng, Z.H.Yang (Peking Univ.); F.Flavigny (Orsay); J.Gibelin, F.M.Marqués, N.A.Orr (Caen); K.Hasegawa, T.Kobayashi, T.Sumikama (Tohoku); Y.Kanaya, S.Kawakami, Y.Maeda (Miyazaki); D.Kim (Ehwa Womans Univ.); N.Kobayashi, S.Koyama, T.Miyazaki (Tokyo); Y.Kondo, T.Nakamura, T.Ozaki, A.Saito, M.Shikata, Y.Togano, J.Tsubota (TITECH); Z.Korkulu (ATOMKI); N.Nakatsuka (Kyoto); Y.Nishio, A.Ohkura, S.Sakaguchi, Y.Shindo, M.Tabata, J.Yasuda (Kyushu); S.Reichert (TU Munich)

Theorists:

Y.Kikuchi (RNC); K.Ogata (RCNP)

BACKUP

^{11}LI: OPENING ANGLE AND CORRELATION

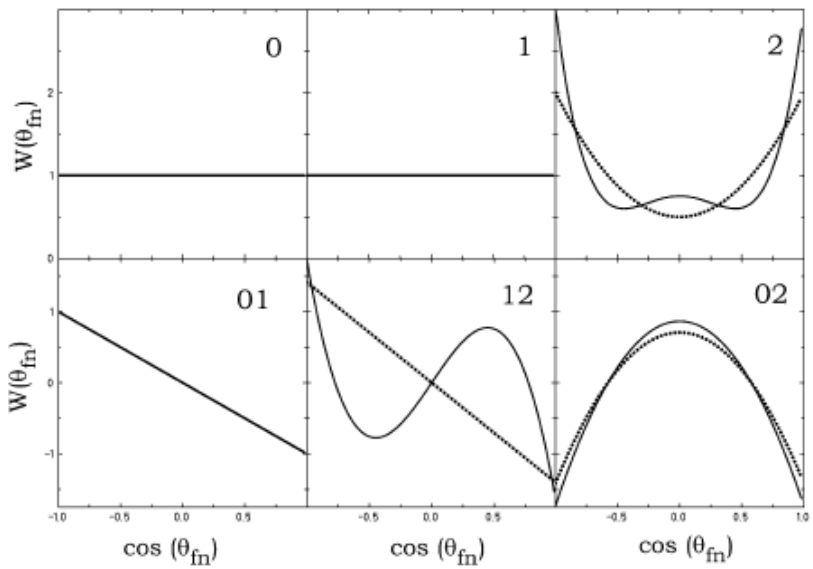
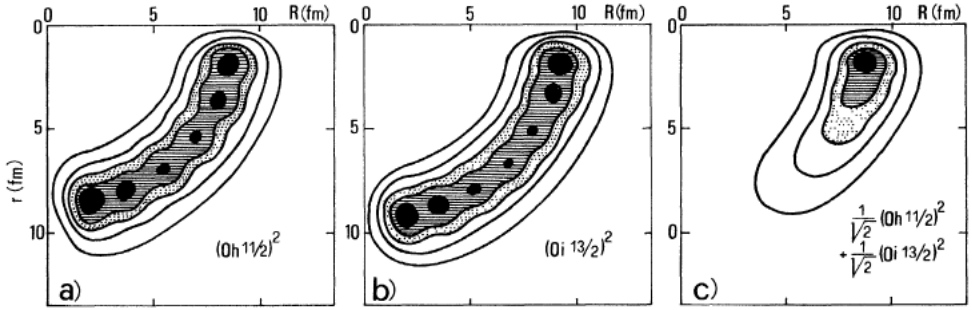


Fig. B.2. Angular dependence of direct and interference terms for the sequential fragmentation $^{14}Be \rightarrow {}^{13}Be + n \rightarrow {}^{12}Be + 2n$ for $s_{1/2}$-shell (panel 0), $p_{1/2}$-shell (panel 1) and $d_{5/2}$-shell (panel 2) neutrons. Interference terms are shown in panels: 01-(sp), 12-(pd) and 02-(sd). Dotted lines correspond to the case of $d_{3/2}$-shell.

H.Simon *et al.*, NPA 791 (2007)

^{11}Li

Probe	$\langle\theta_Y^x\rangle$ [deg.]	θ_{12} [deg.]	Reference
Coulomb breakup		48^{+14}_{-18}	Nakamura 2006
+ Core excitation		65 ± 11	
		$65.2^{+11.4}_{-13.0}$	Hagino 2016
Compilation	72.2	61.7	Shulgina 2009
Neutron removal	76.6(2.1)		Simon 1999
This work	85 ± 10		

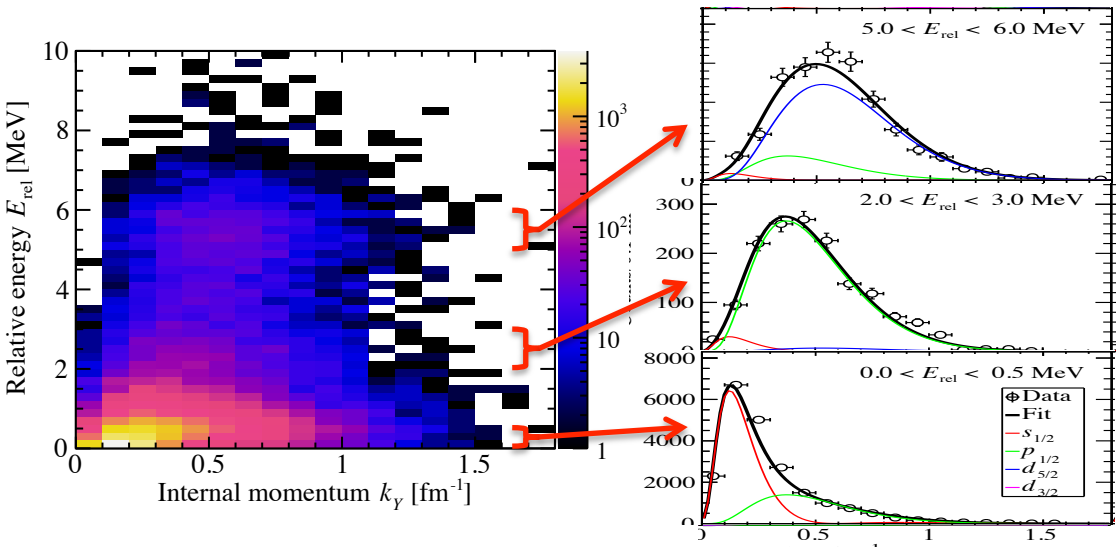


$$P(r,R) = \int |\Psi(\vec{r}_1, \chi_1; \vec{r}_2, \chi_2)|^2 r^2 R^2 d\hat{r}\, d\hat{R}\, d\chi_1 d\chi_2$$

^{206}Pb

Catara et al., PRC 29 (1984)

^{11}LI: ANGULAR MOMENTUM DETERMINATION



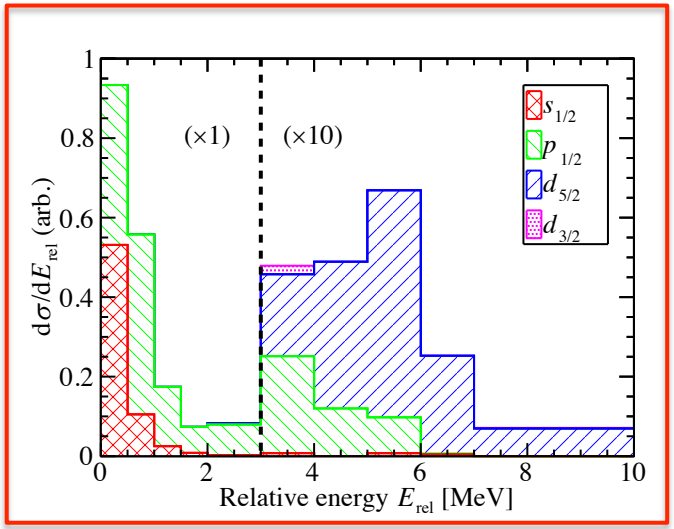
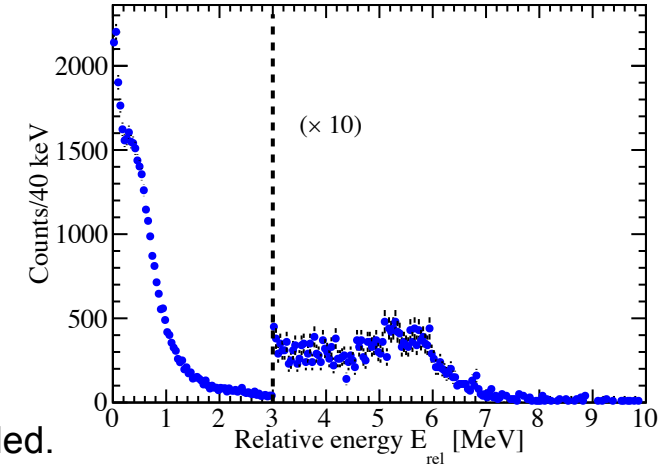


Table 5.5: The fraction S_{lj} of each multipole. The unit is percent (%).

	$(s_{1/2})^2$	$(p_{3/2})^2$	$(p_{1/2})^2$	$(d_{5/2})^2$	$(d_{3/2})^2$
This work	35 ± 4	$0^{(*1)}$	59 ± 1	6 ± 4	
Neutron removal Simon 1999	45 ± 10	3–5	55 ± 10		
Simon 2007	45 ± 10	3–5	45 ± 10	10 ± 8	
(*p*,*pn*) Aksyutina 2013				11 ± 2	
Kikuchi 2013	44.0	2.5	46.9	3.1	1.7
Fortune 2015	33 ± 6				
Ikeda 2010	46.9	2.5	42.7	4.1	1.9

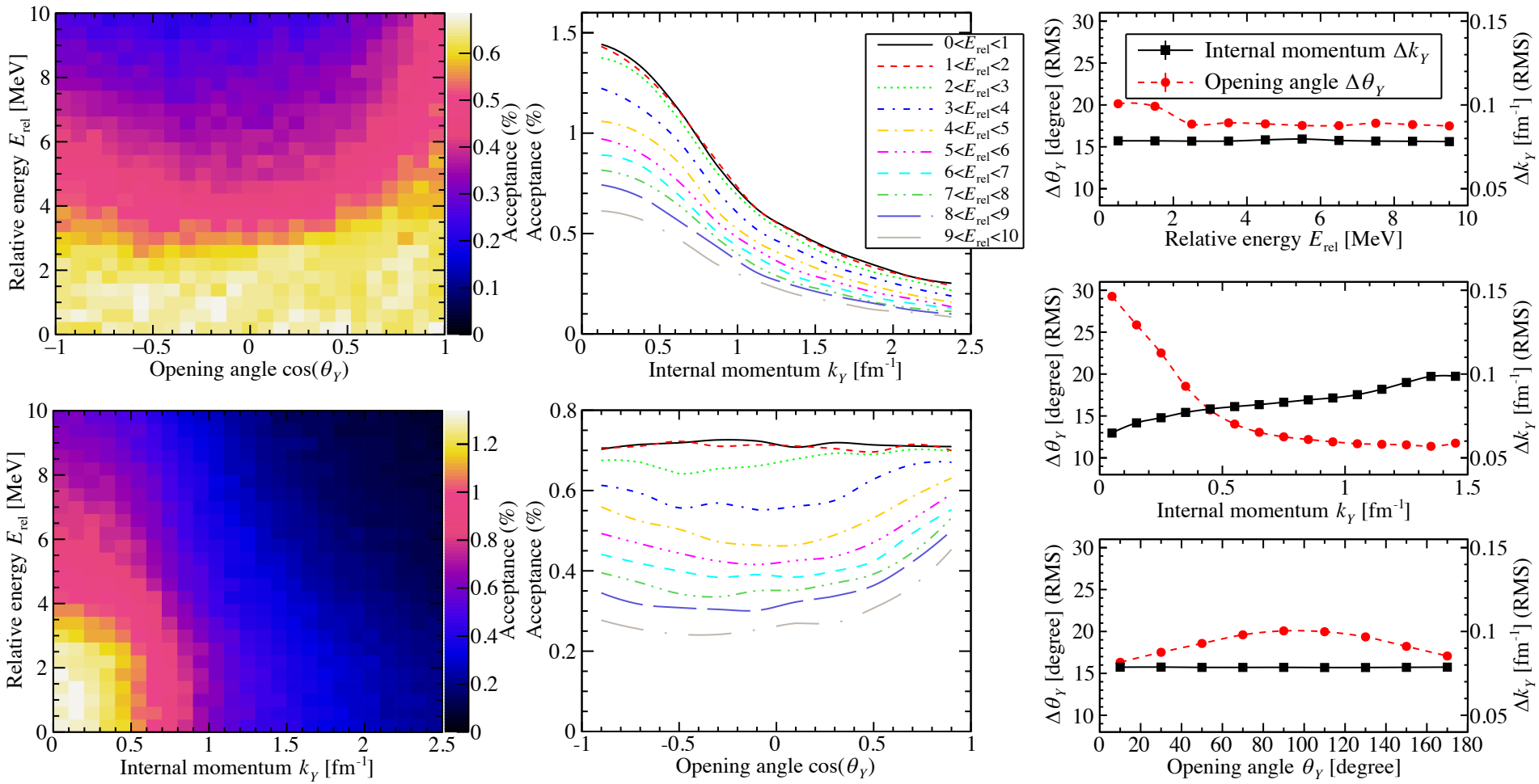
Exp.

Theor.



- Components with ℓ>2 are not taken account.
- Systematic uncertainty related to DWIA calculation is not included.

MONTE-CARLO SIMULATION FOR ACCEPTANCE/RESOLUTION EVALUATION



→ No singularity. No problem for “correlation study”.