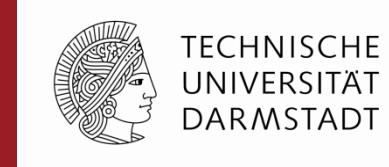


One nucleon removal from ^{14}O at ~100 MeV/nucleon with a thin hydrogen target



DREB Conference 2022

Thomas Pohl, Yelei Sun, Alexandre Obertelli

for the SAMURAI31 Collaboration

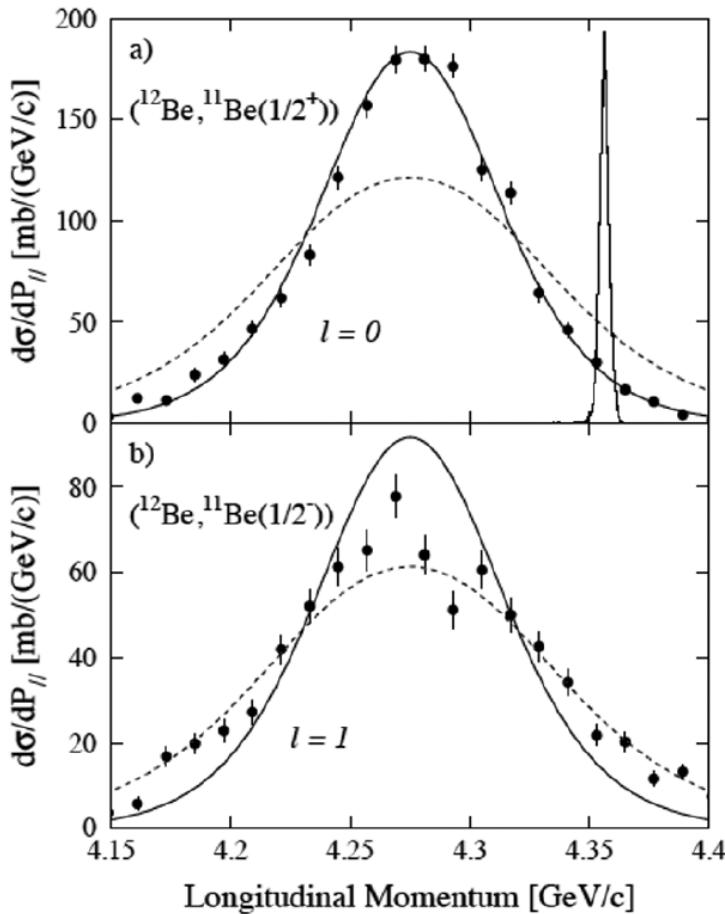
TU Darmstadt

Institut für Kernphysik

Momentum Distribution as tool to investigate the shell structure



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- Knockout of loosely bound nucleons sensitive to orbital angular momentum by measuring the PMD
- Fantastic results from the beginning of the 90's and used intensivly at NSCL, GANIL, GSI
- SE approximation to describe symmetric momentum distribution

Data from NSCL with ${}^9\text{Be}$ target and beam energy 78 MeV/nucleon

A. Navin et al., PRL 85, 266 (2000)

Nucleon removal with asymmetric PMD

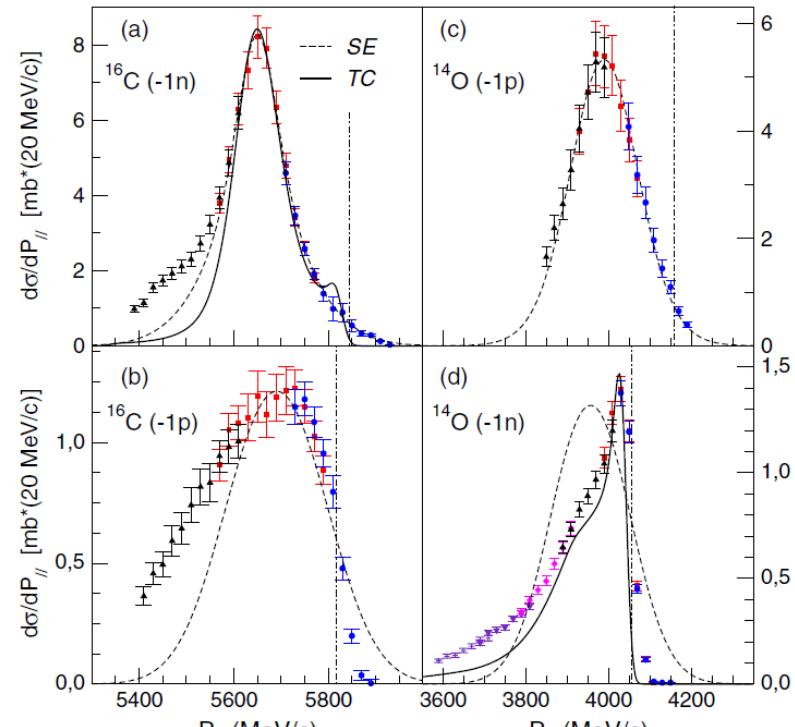


^{16}C Beam at 75 MeV/nucleon with ^9Be target

- (a) Neutron removal $S_n = 4.25$ MeV
- (b) Proton removal $S_p = 22.6$ MeV

^{14}O Beam at 53 MeV/nucleon with ^9Be target

- (c) Proton removal $S_p = 4.63$ MeV
- (d) Neutron removal $S_n = 23.2$ MeV



F. Flavigny et al., PRL 108, 252501 (2012)

- Symmetric distribution for loosely bound nucleon removal
- Energy conservation cut-off on the high momentum side and tail in the low momentum part for deeply bound nucleon removal

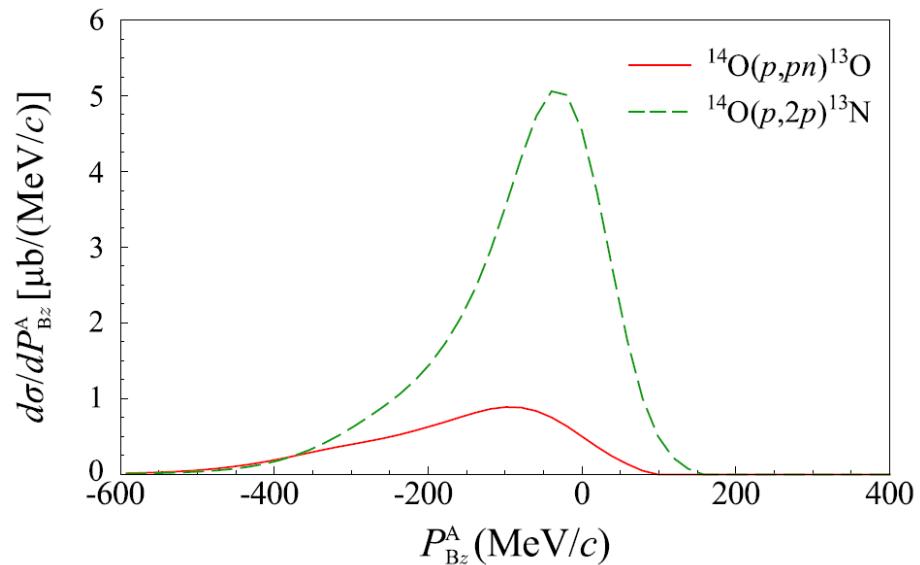
Proton induced nucleon removal from ^{14}O



Distorted wave impulse approximation

(DWIA) calculations:

- ^{14}O nucleon removal reaction at 100 MeV/nucleon
- Structureless hydrogen target is used
→ **Similar asymmetric PMD is predicted**
- **low momentum side:** momentum shift of outgoing particles due to residual potential (FSI)

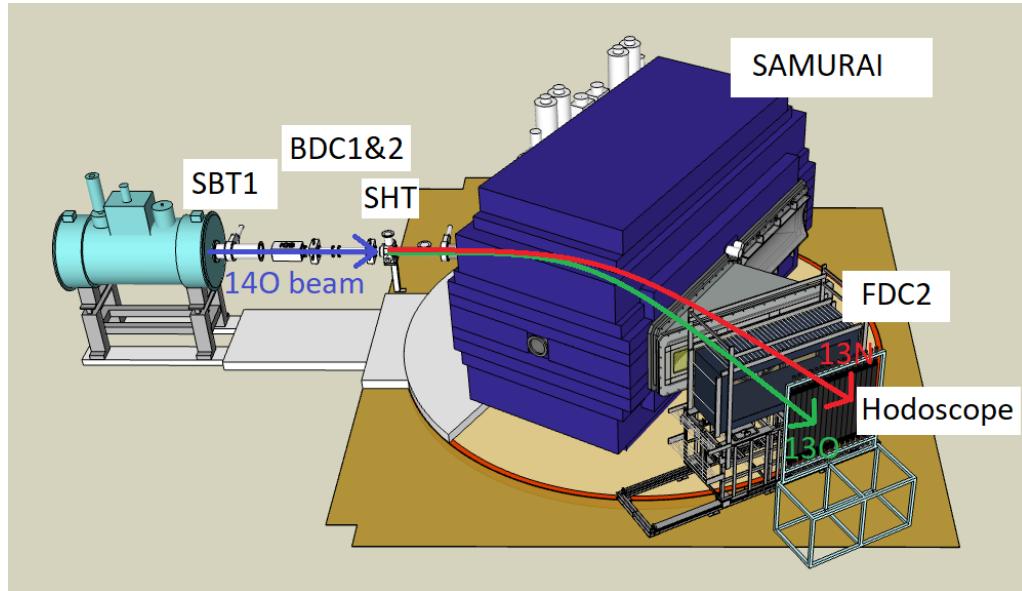


Ogata et al., Phys. Rev. C 92, 034616 (2015)

Experimental Setup



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T. Kobayashi et al., INSTRUM METH B 317, 252501 (2013)

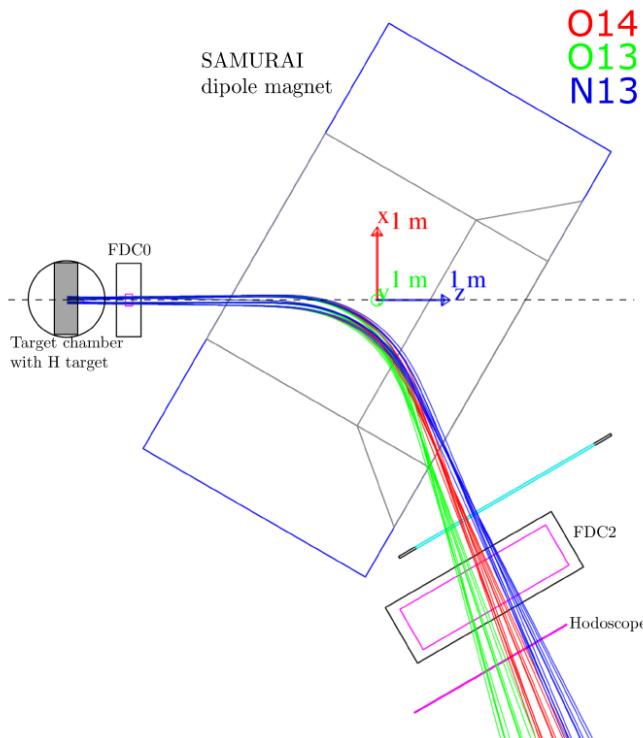
SHT target



Y. Matsuda et al., INSTRUM METH A 643, 252501 (2011)

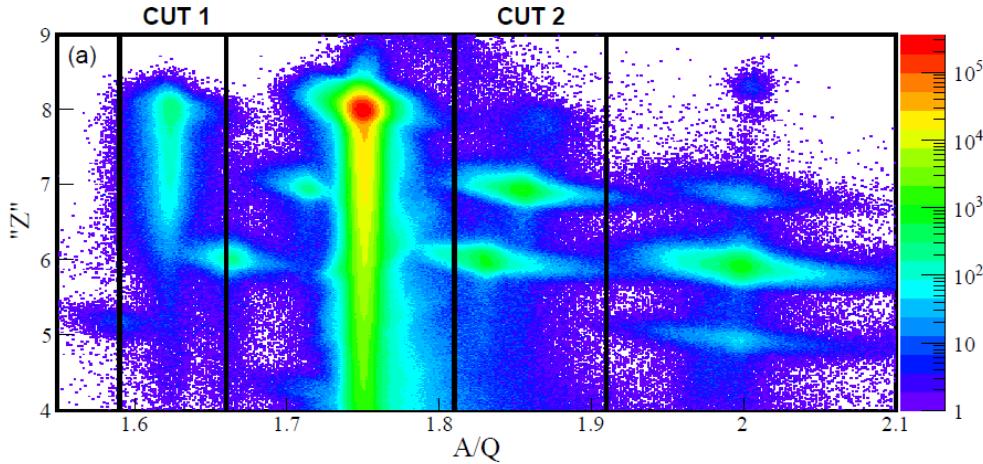
- ^{14}O beam at ~ 100 MeV/nucleon, 9000 particles/s, purity of 78 %
- 2 mm solid hydrogen target
- SBT1 and Hodoscope plastic scintillator for dE and TOF measurement
- BDC1,2 and FDC0,2 for position measurement

$B\rho$ and L calculation

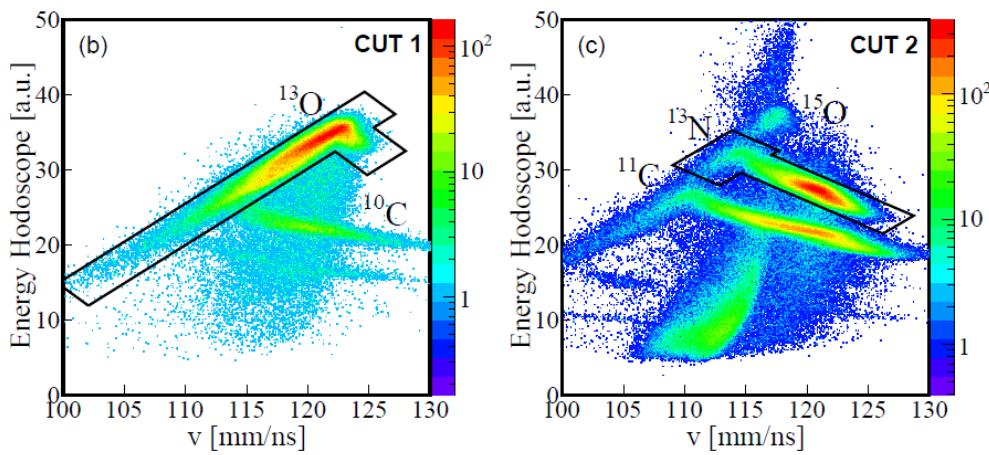


- Use of the position measurement with DC
- Simulate *Geant4* trajectories with *smsimulator* from *TiTech* (Courtesy Y. Kondo)
- Create two functions with dependence on FDC0 (x, θ_x, y, θ_y) and FDC2 (x, θ_x)
- Calculate $B\rho$ and L with experimental data

Particle Identification



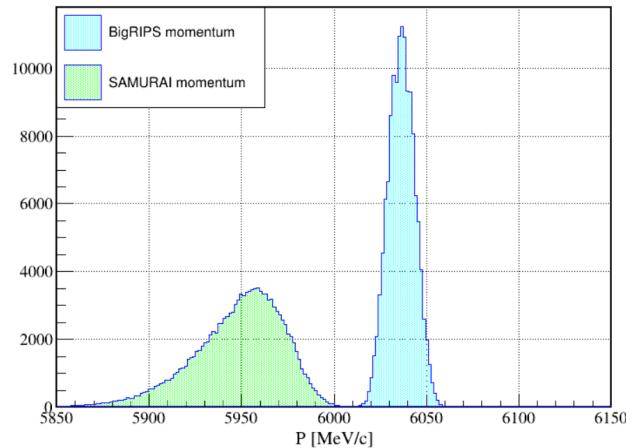
- $Bp - dE - TOF$ method
- **Tails** due to **residues stopping** in the plastic and due to the **interaction** with the plastic
- Apply dE over v for selection
- Particle stops in hodoscope: $dE \sim v^2$
- Particle traverse hodoscope: $dE \sim 1/v^2$



Comparison of unreacted beam momentum

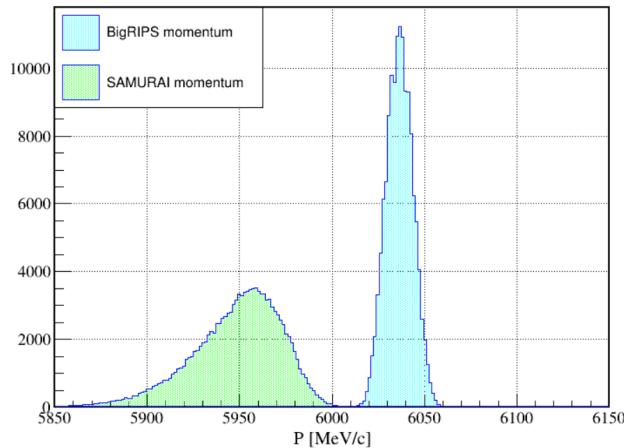


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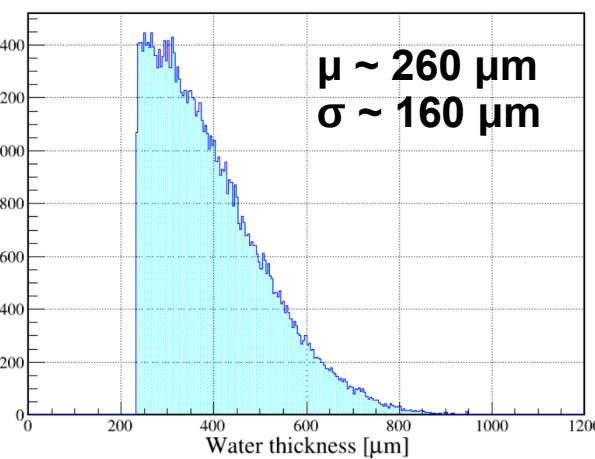
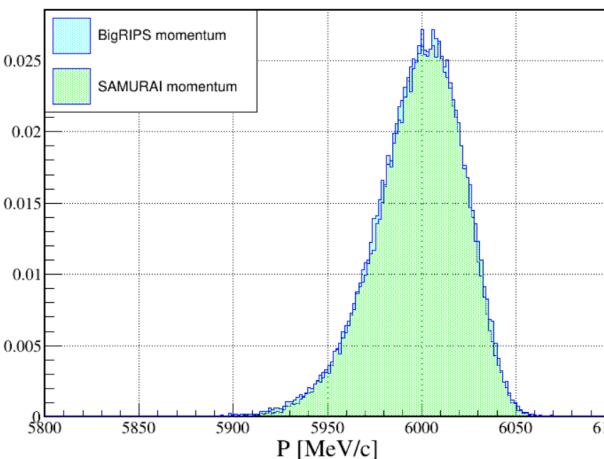


During experiment water was observed on the target window

Comparison of unreacted beam momentum



During experiment water was observed on the target window



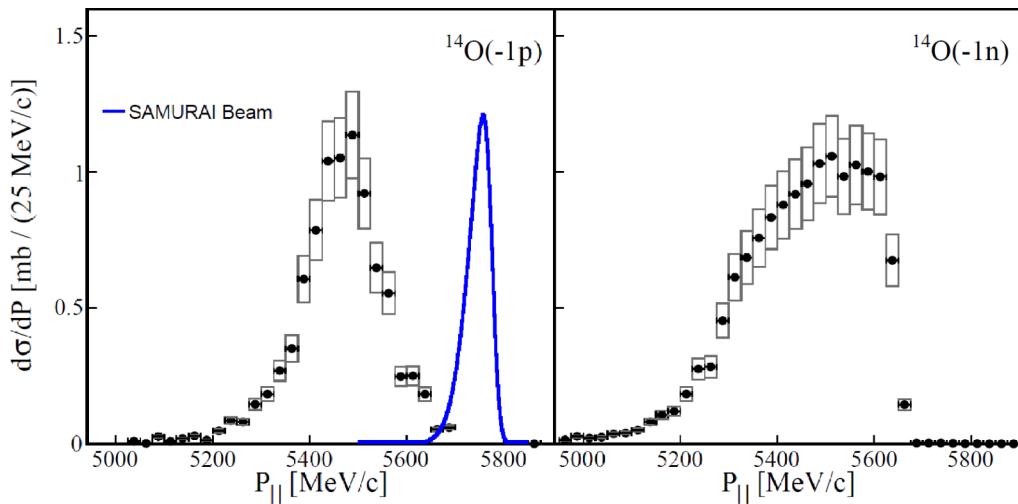
Solution:

- Water energy loss simulation
- Simulation benchmarked with momentum of unreacted beam
- Background subtraction with empty target runs

Experimental Results



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Preliminary Results (working on final corrections)

- Squares are the systematic errors (mainly from target thickness)
- Blue line is experimental beam response (shifted by -200 MeV/c)
- Cross section $^{14}\text{O}(-1p)$ 8(2) mb $^{14}\text{O}(-1n)$ 14(3) mb

Theoretical calculations



DWIA (Ogata *et al.*, Phys. Rev. C. 92, (2015)):

- **Folding potential** with Melbourne G-matrix interaction
- **Transition** process calculated with **Franey-Love interaction**
- **Perey correction** applied for the non-localities
- **Energy dependence** of the optical potential considered with the scattering energy of the emitted nucleons

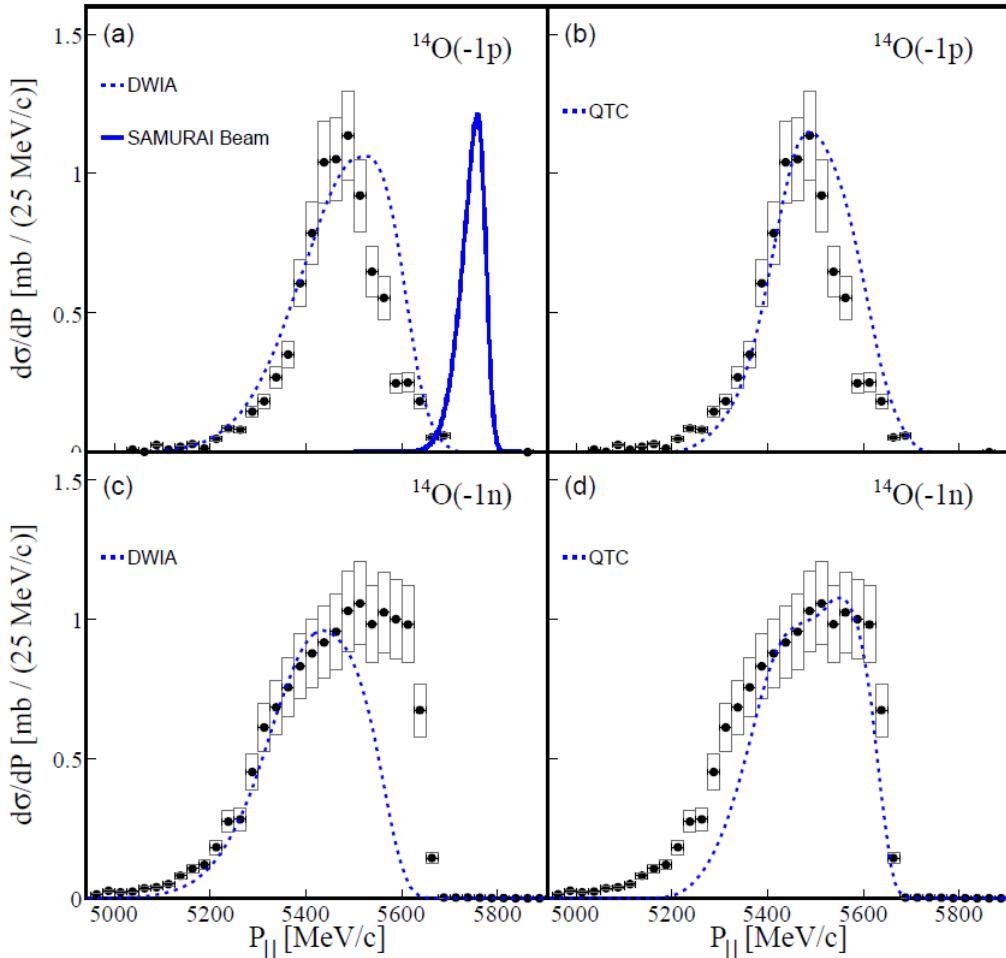
^{14}O structure:

- Single particle wave function from a **Woods-Saxon potential**
- Shell model calculation with **YSOX/WPB/WBT interactions** in psd model space

Experimental data with theoretical calculations



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Preliminary Results (working on final corrections)

$^{14}\text{O}(-1\text{p})$:

- DWIA peak position has offset
- QTC not fully able to reproduce tail

$^{14}\text{O}(-1\text{n})$:

- DWIA does not reproduce cut-off
- QTC close to match cut-off better, but underestimates the low momentum tail

Transfer and inelastic excitation

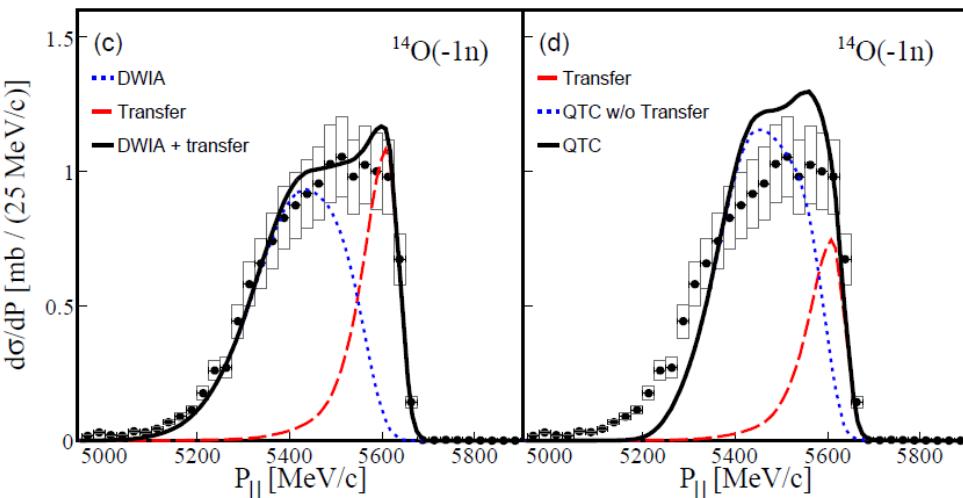
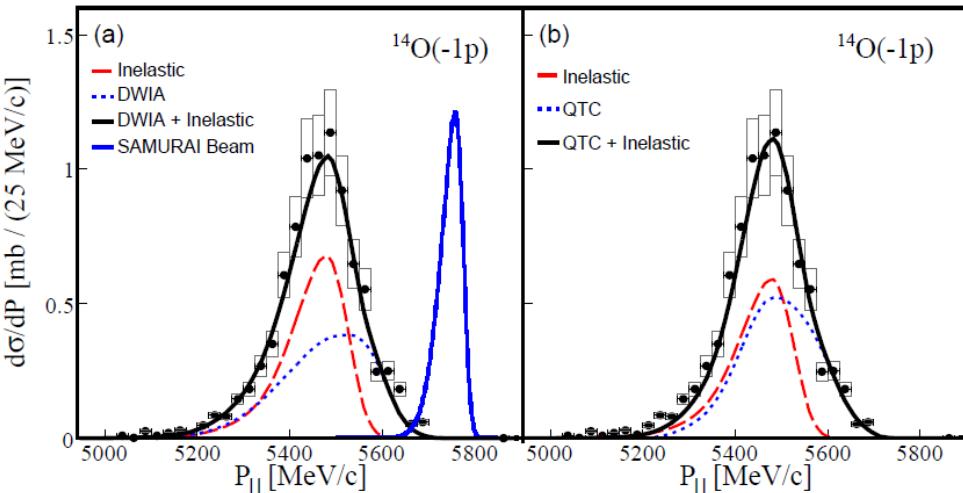
Inelastic excitation (p,p') (R. Schaeffer and J. Raynal, DWBA70 program (unpublished),(1970)):

- Microscopic DWIA reaction model
- Structure input is the OBTD from shell model calculations
- Franey-Love interaction for the transition
- Koning-Delaroche optical potential for the distorted waves

Transfer (p,d):

- Distorted-Wave Born Approximation
- $d-^{13}\text{O}$ potential calculated with the Johnson-Soper prescription
- The $p-^{13}\text{O}$ and $n-^{13}\text{O}$ folding potential is adopted at half of the deuteron energy

Results - PMD



Preliminary Results (working on final corrections)

^{13}N Residue:

- Both models reproduce the experimental data well
- (a) 57 % Inelastic, 43 % DWIA
- (b) 44 % Inelastic, 56 % TC

^{13}O Residue:

- DWIA + transfer reproduce the data well
- QTC not able to reproduce low momentum tail

Summary



Residue	J^π	σ_{exp} [mb]	SF	Theory	σ_{sp} [mb]	σ_{th} [mb]	R_s
$^{13}\text{N}_{\text{g.s.}}$	1/2 ⁻	8(1)	1.6	DWIA	5.2	9	
				Inelastic	-	9(1)	
				Sum		18(1)	0.4(1)
	3/2 ⁻	14(2)	3.4	QTC	7.0	12	
				Inelastic	-	9(1)	
				Sum		21(1)	0.4(1)
$^{13}\text{O}_{\text{g.s.}}$	3/2 ⁻	14(2)	3.4	DWIA	6.3	23	
				Transfer	3(1)	11(3)	
				Sum		34(3)	0.4(1)
				QTC	13.5	49	0.3(1)

Preliminary Results (working on final corrections)

- Nucleon removal reaction $^{14}\text{O}(\text{p},\text{X})^{13}\text{O}/^{13}\text{N}$ at ~ 94 MeV/nucleon
- PMD's asymmetric for deeply-bound nucleon removal
- Sizeable contribution from inelastic scattering for -1p ($\sim 50\%$) and transfer for -1n ($\sim 30\%$) proven from the parallel momentum distributions
- Inclusive cross sections give a R_s of $0.3(1) - 0.4(1)$



Thank you for your attention !

Spokesperson SAMURAI31: Y. L. Sun, J. Lee

Collaborators:

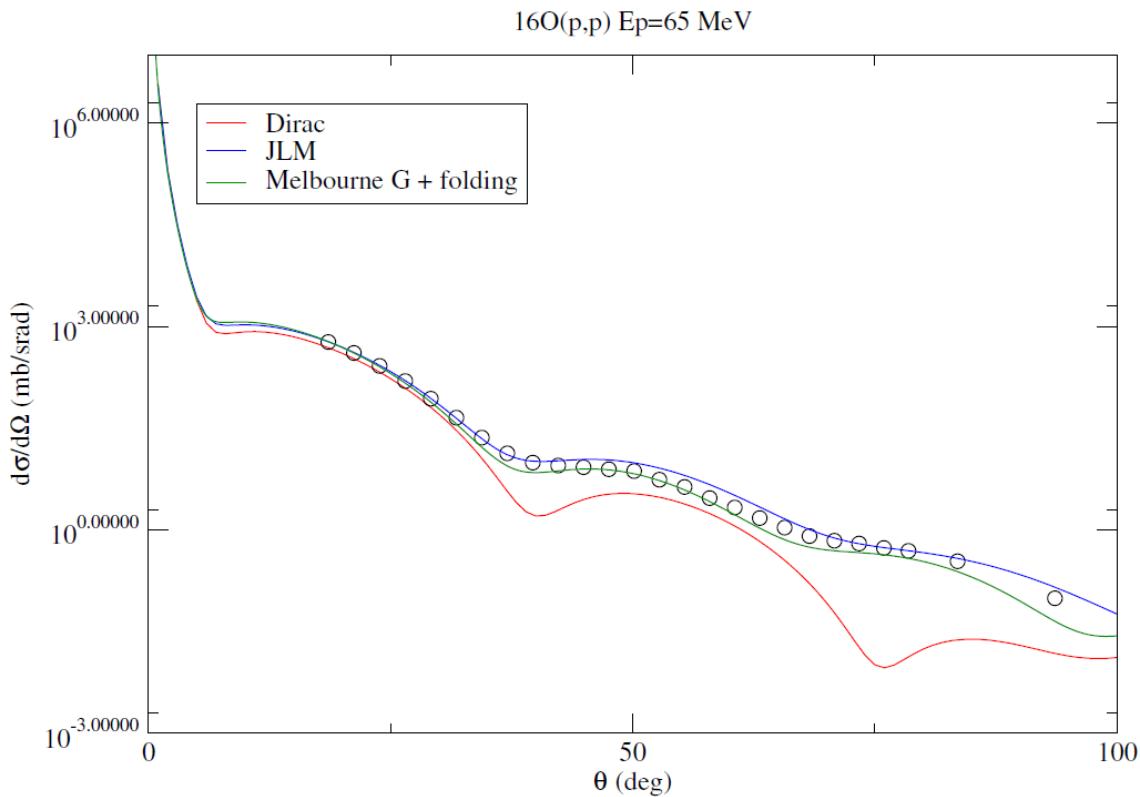
A. Obertelli, M. Gómez-Ramos, K. Ogata, K .Yoshida, B. S. Cai, C. X. Yuan, B. A. Brown, H. Baba, D. Beaumel, A. Corsi, J. Gao, J. Gibelin, A. Gillibert, K. I. Hahn, T. Isobe, D. Kim, Y. Kondo, T. Kobayashi, Y. Kubotoa, P. Li, P. Liang, H. N. Liu, J. Liu, T. Lokoto, F. M. Marqués, Y. Matsuda, T. Motobayashi, T. Nakamura, N. A. Orr, H. Otsu, V. Panin, S. Y. Park, S. Sakaguchi, M. Sasano, H. Sato, H. Sakurai, Y. Shimizu, L. Stuhl, D. Suzuki, Y. Togano, T. Uesaka, H. Wang, X. Xu, Z. H. Yang, K. Yoneda, and J. Zenihiro



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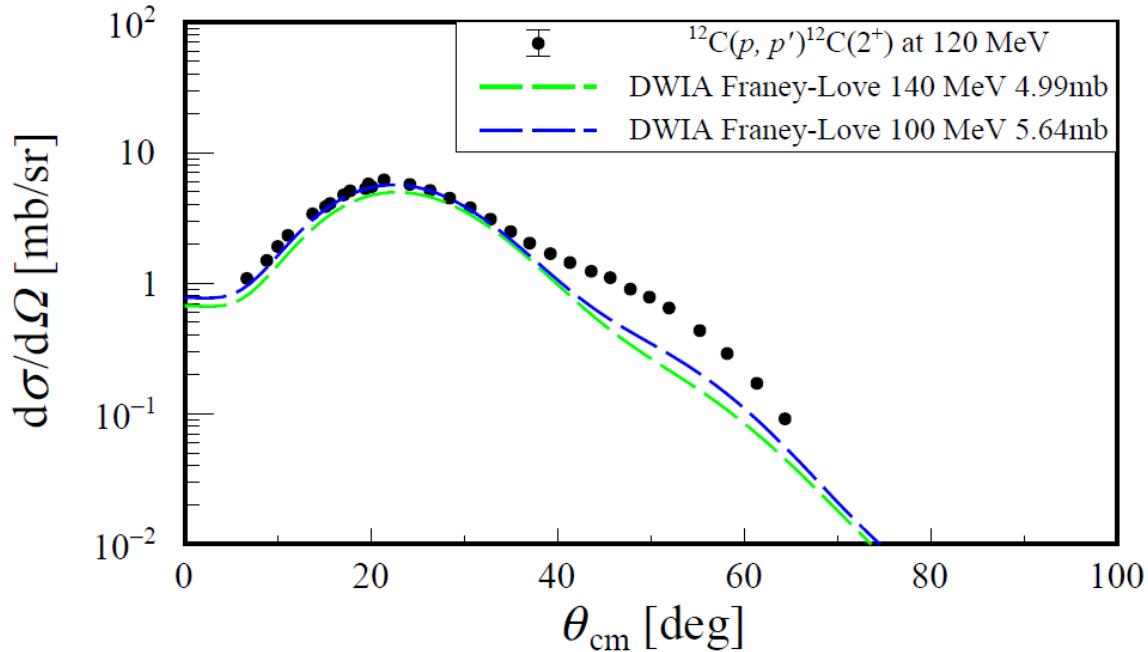
Additional slides

Benchmark knockout potentials



Courtesy M. Goméz and K. Yoshida

Benchmark inelastic calculation

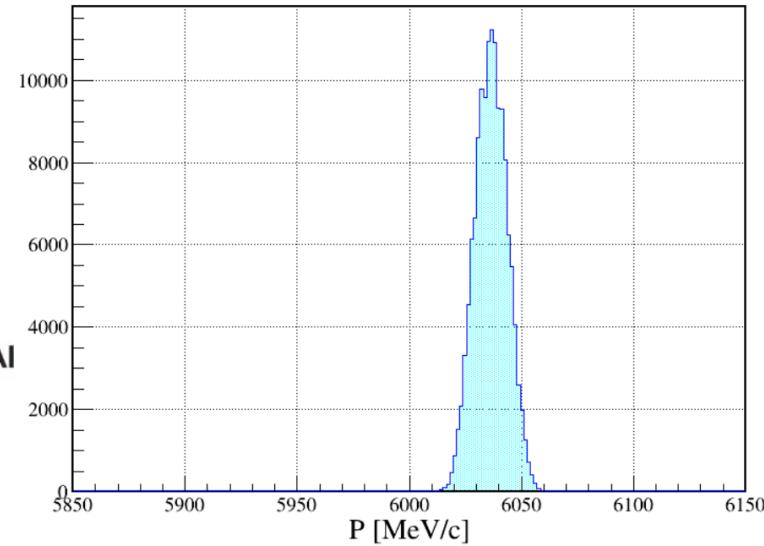
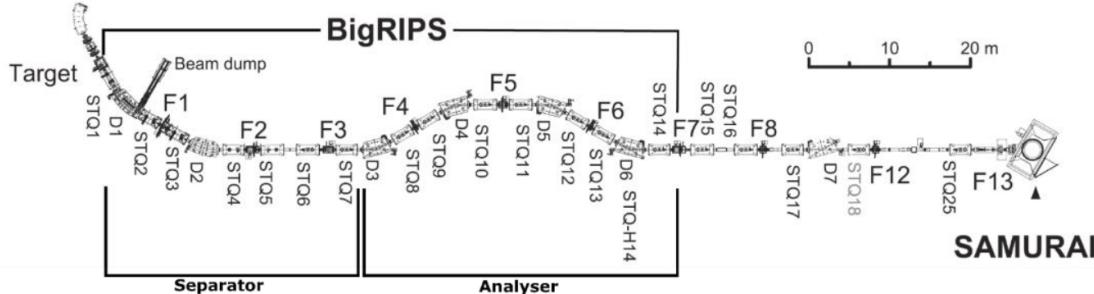


Courtesy Y. Sun

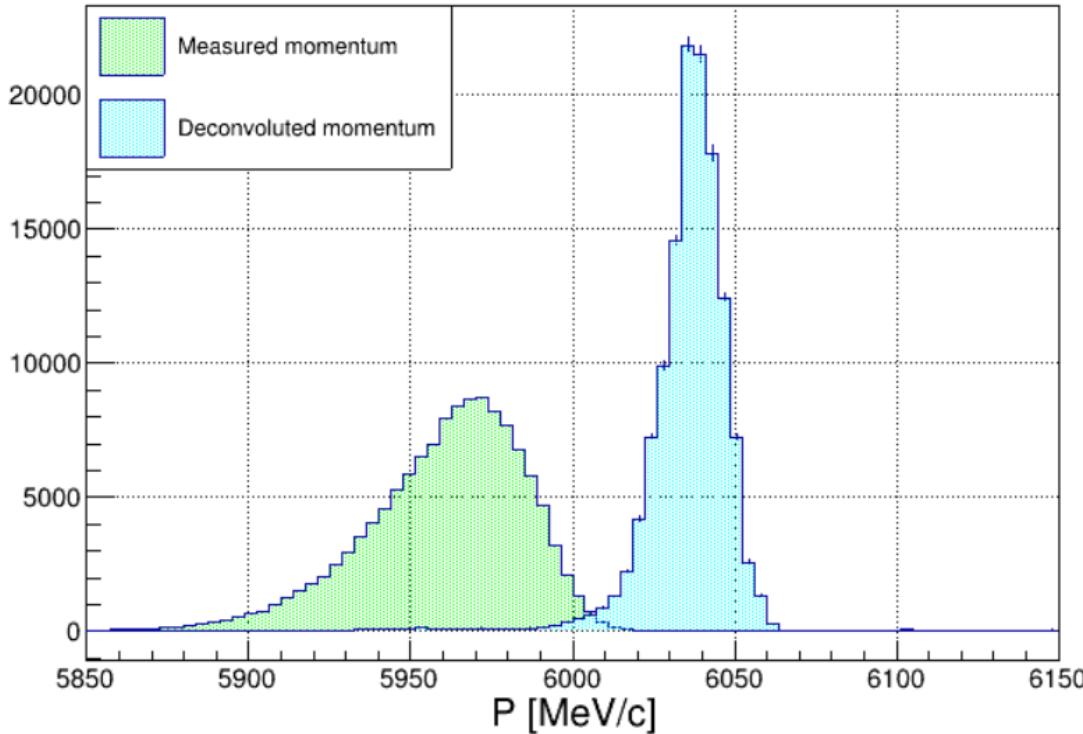
Experimental Setup - BigRIPS



- Production of unstable ^{14}O beam at 100 AMeV with a ^{18}O beam
- Using plastic scintillator F3, F5 and F13 for the identification of the secondary beam
- 2 mm slit at F1, which gives a dp/p of 0.19 %
- Use a pure proton target to perform one nucleon knockout from ^{14}O



Deconvolution



- Deconvolution with the algorithm of D'Agostini [1] implemented in RooUnfold [2].
- Deconvoluted results consistent with our BigRIPS momentum distribution

[1] G. D'Agostini, „Improved iterative Bayesian unfolding“, arXiv:1010.0632 (2010)

[2] T. Ayde, „RooUnfold: unfolding framework and algorithms“, presentations to the Oxford and RAL ATLAS Groups (2008)