

University of Groningen

Coulomb dissociation of ^{16}O into ^4He and ^{12}C

Göbel, Kathrin; Heil, Michael; Bott, Lukas; Brandenburg, Leonard; Caesar, Christoph; Deuter, Isabell; Grein, Alexander; Keliç-Heil, Aleksandra; Körper, Daniel; Löher, Bastian

Published in:
Nuclear Physics in Astrophysics IX (NPA-IX)

DOI:
[10.1088/1742-6596/1668/1/012016](https://doi.org/10.1088/1742-6596/1668/1/012016)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2020

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Göbel, K., Heil, M., Bott, L., Brandenburg, L., Caesar, C., Deuter, I., Grein, A., Keliç-Heil, A., Körper, D., Löher, B., Reifarh, R., Savran, D., Schulte, H., Simon, H., Törnqvist, H., Almusiçi, T., Alvarez-Pol, H., Atkins, L., Aumann, T., ... Schmidt, K. (2020). Coulomb dissociation of ^{16}O into ^4He and ^{12}C . In *Nuclear Physics in Astrophysics IX (NPA-IX)* (1 ed.). (Journal of Physics: Conference Series; Vol. 1668). IoP Publishing. <https://doi.org/10.1088/1742-6596/1668/1/012016>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

PAPER • OPEN ACCESS

Coulomb dissociation of ^{16}O into ^4He and ^{12}C

To cite this article: Kathrin Göbel *et al* 2020 *J. Phys.: Conf. Ser.* **1668** 012016

View the [article online](#) for updates and enhancements.

You may also like

- [Studies of the 2 and 3 channels of the \$^{12}\text{C} + ^{12}\text{C}\$ reaction in the range of \$E_{\text{c.m.}} = 8.9\$ MeV to 21 MeV using the active target Time Projection Chamber](#)
X. Y. Wang, , N. T. Zhang et al.
- [THE \$^{12}\text{C} + ^{12}\text{C}\$ REACTION AND THE IMPACT ON NUCLEOSYNTHESIS IN MASSIVE STARS](#)
M. Pignatari, R. Hirschi, M. Wiescher et al.
- [Experimental investigations of the sub-Coulomb \$^{12}\text{C} + ^{12}\text{C}\$ and \$^{12}\text{C} + ^{16}\text{O}\$ reactions](#)
S Courtin, G Fruet, D G Jenkins et al.



The Electrochemical Society
Advancing solid state & electrochemical science & technology

243rd Meeting with SOFC-XVIII

Boston, MA • May 28 – June 2, 2023

Accelerate scientific discovery!

Learn More & Register



Coulomb dissociation of ^{16}O into ^4He and ^{12}C

Kathrin Göbel¹, Michael Heil², Lukas Bott¹,
Leonard Brandenburg¹, Christoph Caesar², Isabell Deuter¹,
Alexander Grein¹, Aleksandra Kelić-Heil², Daniel Körper²,
Bastian Löher², René Reifarth¹, Deniz Savran²,
Hendrik Schulte¹, Haik Simon², Hans Törnqvist³,
Tahani Almusidi⁴, Héctor Álvarez-Pol⁵, Liam Atkins⁴,
Thomas Aumann^{3,2}, Daniel Bemmerer⁶, José Benlliure⁵,
Konstanze Boretzky², Benjamin Brückner¹,
Pablo Cabanelas Eiras⁵, Enrique Casarejos⁷,
Joakim Cederkall⁸, Leonid Chulkov⁹, Dolores Cortina-Gil⁵,
Andrey Danilov⁹, Philipp Erbacher¹,
Sonia Escribano Rodriguez⁴, Zsolt Fülöp¹⁰, Ashton Falduto³,
Stefan Fiebiger¹, Igor Gašparić¹¹, Maria José Garcia Borge¹²,
Roman Gernhäuser¹³, Jan Glorius², David Gonzales Caamaño⁵,
Anna-Lena Hartig³, Tanja Heftrich¹, Henning Heggen²,
Marcel Heine¹⁴, Andreas Heinz¹⁵, Thomas Hensel^{6,16},
Matthias Holl³, Håkan T. Johansson¹⁵, Björn Jonson¹⁵,
Nasser Kalantar-Nayestanaki¹⁷, Armel Kamenyero¹⁸,
Kafa Khasawneh¹, Oleg Kiselev³, Philipp Klenze¹³,
Marvin Kohls¹, Thorsten Kröll³, Dmytro Kresan²,
Deniz Kurtulgil¹, Nikolaus Kurz², Christoph Langer¹,
Christopher Lehr³, Yuri Litvinov², Enis Lorenz¹, Silvia Murillo
Morales⁴, Enrique Nacher¹², Thomas Nilsson¹⁵, Joochun Park⁸,
Stefanos Paschalis⁴, Angel Perea¹², Marina Petri⁴, Ralf Plag²,
Lukas Ponnath¹³, Romana Popočovski¹¹, Markus Reich¹,
Han-Bum Rhee³, Jose Luis Rodriguez Sanchez⁵,
Dominic Rossi³, Heiko Scheit³, Konrad Schmidt¹⁶,
Zuzana Slavkovská¹, Viktor Starostin⁹, Sonja Storck³,
Christian Sürder³, Junki Tanaka³, Olof Tengblad¹²,
Benedikt Thomas¹, Stefan Typel^{3,2}, László Varga², Klaus Volk¹,
Meiko Volkmandt¹, Vadim Wagner³, Felix Wamers²,
Mario Weigand¹, Lorenzo Zanetti³

¹Goethe-Universität Frankfurt, Germany

²GSI Helmholtzzentrum für Schwerionenforschung Darmstadt, Germany

³Technische Universität Darmstadt, Germany

⁴University of York, United Kingdom

⁵Universidad de Santiago de Compostela, Spain



Coulomb dissociation of ^{16}O into ^4He and ^{12}C ⁶Helmholtz-Zentrum Dresden-Rossendorf, Germany⁷Universidad de Vigo, Spain⁸Lund University, Sweden⁹NRC Kurchatov Institute Moscow, Russia¹⁰ATOMKI Debrecen, Hungary¹¹Ruđer Bošković Institute, Zagreb, Croatia¹²CSIC Madrid, Spain¹³Technische Universität München, Germany¹⁴Institut Pluridisciplinaire Hubert CURIE, France¹⁵Chalmers University of Technology, Sweden¹⁶Technische Universität Dresden, Germany¹⁷KVI-CART/University of Groningen, The Netherlands¹⁸GANIL, France

E-mail: goebel@physik.uni-frankfurt.de

Abstract.

We measured the Coulomb dissociation of ^{16}O into ^4He and ^{12}C at the R³B setup in a first campaign within FAIR Phase 0 at GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt. The goal was to improve the accuracy of the experimental data for the $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$ fusion reaction and to reach lower center-of-mass energies than measured so far.

The experiment required beam intensities of 10^9 ^{16}O ions per second at an energy of 500 MeV/nucleon. The rare case of Coulomb breakup into ^{12}C and ^4He posed another challenge: The magnetic rigidities of the particles are so close because of the same mass-to-charge-number ratio $A/Z = 2$ for ^{16}O , ^{12}C and ^4He . Hence, radical changes of the R³B setup were necessary. All detectors had slits to allow the passage of the unreacted ^{16}O ions, while ^4He and ^{12}C would hit the detectors' active areas depending on the scattering angle and their relative energies. We developed and built detectors based on organic scintillators to track and identify the reaction products with sufficient precision.

1. The fusion reaction $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$

The fusion reaction of carbon and helium to oxygen is key to understanding the evolution of stars and the relative abundances of both elements. The reaction rate of $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$ has to be known with an uncertainty lower than 10% at a center-of-mass energy of 300 keV during Helium burning conditions. A direct measurement of the cross section $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$ reaction in the astrophysically important energy region around 300 keV is very challenging because of the extremely low value of about 10^{-17} b [1].

Huge efforts have been undertaken to determine the $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$ cross section over the last decades. Starting at higher energies, lower and lower center-of-mass energies were investigated. So far, experiments have studied the reaction down to about 1 MeV, e.g. [2]. Hence, only extrapolations of experimental data from higher center-of-mass energies to the astrophysical relevant energy region are available.

Coulomb dissociation of ^{16}O into ^4He and ^{12}C **2. Coulomb dissociation of ^{16}O**

Indirect methods may bridge the gap towards the stellar energy regime. The Coulomb dissociation of ^{16}O is very promising and had first been suggested by Baur, Bertulani and Rebel [3, 4].

We measured the Coulomb dissociation of ^{16}O into ^4He and ^{12}C at the R³B setup in a first campaign within FAIR Phase-0 at GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt. The ^{16}O beam impinged on a lead target, where the ions could be excited in the Coulomb field of the lead nuclei such that ^{16}O would break up into ^{12}C and ^4He . A count rate of about 140 counts per hour was estimated at $E_{\text{CM}} = 1$ MeV using a 50 mg/cm² lead target and a rate of $5 \cdot 10^9$ ^{16}O ions per second. This would allow to extract the $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$ cross section with considerably reduced statistical errors, and even to extend the measured region down to about $E_{\text{CM}} = 0.8$ MeV.

Nuclear breakup reactions from direct collisions have to be disentangled from the Coulomb dissociation. A beryllium target was used, which has a low Z compared to lead, since the target-charge dependence of the corresponding cross sections is very different. To understand this separation procedure and to investigate possible interference effects between the nuclear and Coulomb breakup we also used a third, intermediate- Z tin target [5].

3. The setup

The Coulomb dissociation experiment of ^{16}O required radical changes compared to the standard R³B setup [6]: (1) The magnetic rigidities of the particles are so close because of the same mass-to-charge-number ratio $A/Z = 2$ for ^{16}O , ^{12}C and ^4He . (2) The high beam intensities of 10^9 ions per second could not be measured by our scintillation tracking detectors. Hence, all detectors had slits to allow the passage of the unreacted ^{16}O ions, while ^4He and ^{12}C would hit the detectors' active areas due to the scattering angle and their relative energies from the Coulomb dissociation reaction.

Figure 1 shows a sketch of our setup. The ions passed through two active collimators (ROLU) in front of the target to center and focus the beam during the beam setup phase. The CALIFA prototype around the target measured prompt γ -rays from excited ^{12}C fragments. The unreacted ^{16}O ions as well as the reaction products ^4He and ^{12}C were deflected in the superconducting magnet GLAD.

We used three pairs of scintillation fiber detectors to track the ions' trajectories. The detectors were mounted on linear drives to adjust the slits to the beam dimensions during the setup phase. The two fiber detectors between the target and GLAD are made of 200 μm square fibers and have an active area of 10x10 cm². They were designed and built at Goethe University Frankfurt. The four fiber detectors in the vacuum chamber connected to GLAD are significantly larger, they are made of 500 μm square fibers and cover an active area of about 50x50 cm². They were built at the detector laboratory at GSI Helmholtzzentrum. Figure 2 shows the fiber detector setups.

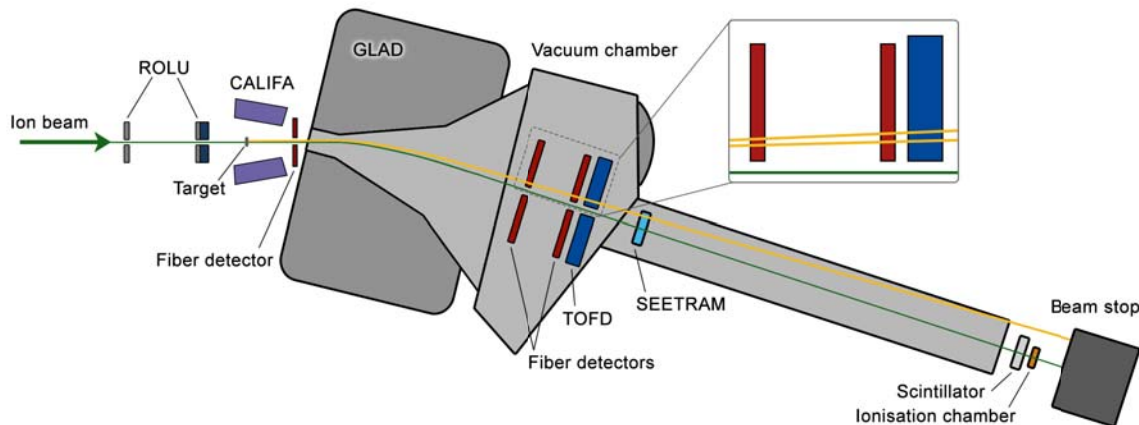
Coulomb dissociation of ^{16}O into ^4He and ^{12}C 

Figure 1. Experimental setup for the Coulomb dissociation of ^{16}O . The ions passed through two active collimators (ROLU) in front of the target to center and focus the beam during the beam setup phase. The CALIFA prototype measured prompt γ -rays from excited ^{12}C fragments. The tracking detectors - a pair of fiber detectors before the magnet GLAD and two pairs of fiber detectors and the time-of-flight wall ToFD behind GLAD - had slits to allow the unreacted beam to pass through while the breakup products would be detected. A SEETRAM [7] detector behind ToFD as well as a scintillator and an ionisation chamber at the end of the beam line measured the beam intensities. A beam stop was installed in the cave due to the expected high dose rate.

The ToFD detector measured the flight time and the energy loss of the ions, from which the charge Z can be determined. The detector consisted of two layers of scintillation bars, each 2.7 cm wide, 0.5 cm thick and about 1 m long. The first layer had 41 bars and an inner gap of about 8 cm, the second layer had 42 bars and an inner gap of about 5.5 cm. The layers are shifted by half a paddle, so that the paddles of the second layer cover the small gaps of the first layer and vice versa.

A SEETRAM detector behind ToFD as well as a scintillator and an ionisation chamber at the end of the beam line measured the beam intensities. The different intensity ranges of these detectors were used for a step-by-step calibration with 10^5 to 10^9 particles per second during the beam setup phase.

4. The first experimental campaign

4.1. A first look at the data

Figure 3 shows the calibrated charge number measured by plane 1 of ToFD as a function of the paddle number for a subset of the recorded data. All charges from eight to two are visible in the plot. The inner paddles receive a high beam rate, which smears out the charges. Paddle numbers 1 to 20 show higher count rates than numbers 24 to 44. Fragments from nuclear reactions have a lower energy than the primary beam and will therefore be deflected in the magnetic field to the side of ToFD with low paddle numbers.

Coulomb dissociation of ^{16}O into ^4He and ^{12}C 

Figure 2. Scintillation fiber detectors to track the reaction products. Left: Two fiber detectors with 200 μm square fibers and an active area of 10x10 cm^2 . Right: Four fiber detectors with 500 μm square fibers and an active area of 50x50 cm^2 in the vacuum chamber connected to GLAD. All fiber detectors are mounted on linear drives to adjust the slits inbetween.

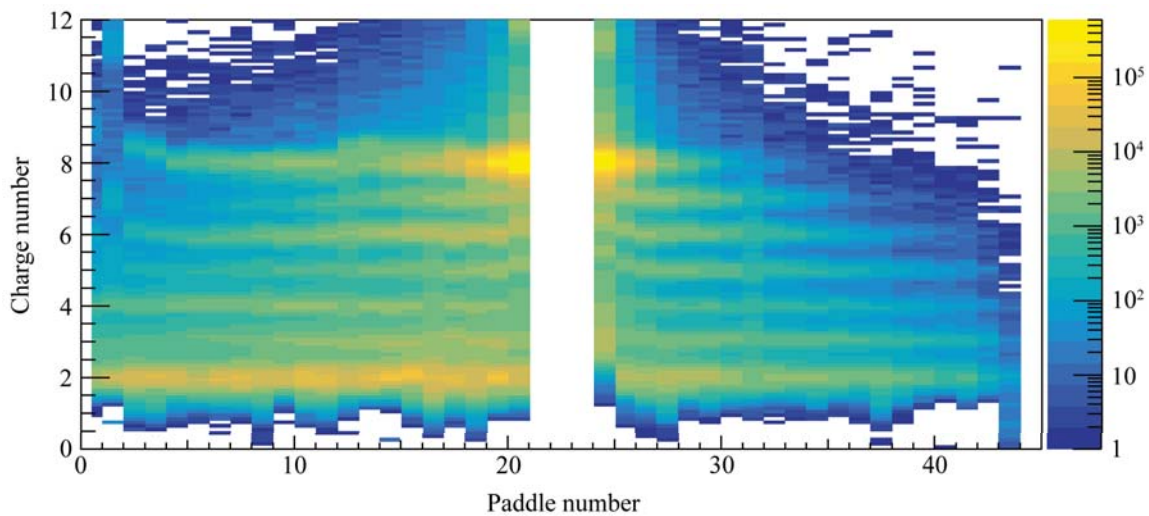


Figure 3. Charge number measured by plane 1 of ToFD as a function of the paddle number for a subset of the recorded data.

4.2. The beamtime

The first experimental campaign was carried out for six days in April 2019. Unfortunately, the accelerator could not reach the conditions desired by the experiment. The used extraction method of the synchrotron accelerator caused a micro-structure of the spills that resulted in high dead times of the data acquisition system. Overall, the statistics on tape is about a factor 20 lower than expected, which is especially problematic for reactions with very small cross sections at low center-of-mass energies.

Nevertheless, many events at higher energies were recorded, which will allow the

Coulomb dissociation of ^{16}O into ^4He and ^{12}C

validation of the Coulomb dissociation method and the comparison against results of previous direct reaction measurements. Future experimental campaigns will attempt to gather the necessary statistics to reach low center-of-mass energies of $E_{\text{CM}} = 0.8$ MeV or lower.

Acknowledgements

This project was carried out within FAIR Phase 0 at GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt. We thank the organizers and operators very much for their support.

This project was supported by the Bundesministerium für Bildung und Forschung (BMBF) (05P19RFFN1, 05P15RFFN1, 05P15RDFN1), HGS-HIRE, HIC for FAIR and the GSI-TU Darmstadt cooperation agreement.

I. Gašparić and R. Popočovski have been supported by the Croatian Science Foundation under projects no. 1257 and 7194.

References

- [1] deBoer R J, Görres J, Wiescher M, Azuma R E, Best A, Brune C R, Fields C E, Jones S, Pignatari M, Sayre D, Smith K, Timmes F X and Uberseder E 2017 *Review of Modern Physics* **89**(3) 035007
- [2] Plag R, Reifarh R, Heil M, Käppeler F, Rupp G, Voss F and Wisshak K 2012 *Physical Review C* **86**(1) 015805
- [3] Baur G, Bertulani C A and Rebel H 1986 *Nuclear Physics A* **458** 188–204
- [4] Baur G and Rebel H 1996 *Annual Review of Nuclear and Particle Science* **46** 321–350
- [5] Fleurot F, van den Berg A, Davids B, Harakeh M, Kravchuk V, Wilschut H, Guillot J, Laurent H, Willis A, Assunção M, Kiener J, Lefebvre A, de Séréville N and Tatischeff V 2005 *Physics Letters B* **615** 167 – 174
- [6] Reifarh R, Altstadt S, Göbel K, Heftrich T, Heil M, Koloczek A, Langer C, Plag R, Pohl M, Sonnabend K, Weigand M, Adachi T, Aksouh F, Al-Khalili J, AlGarawi M, AlGhamdi S, Alkhozov G, Alkhomashi N, Alvarez-Pol H, Alvarez-Rodriguez R, Andreev V, Andrei B, Atar L, Aumann T, Avdeichikov V, Bacri C, Bagchi S, Barbieri C, Beceiro S, Beck C, Beinrucker C, Belier G, Bemmerer D, Bendel M, Benlliure J, Benzoni G, Berjillos R, Bertini D, Bertulani C, Bishop S, Blasi N, Bloch T, Blumenfeld Y, Bonaccorso A, Boretzky K, Botvina A, Boudard A, Boutachkov P, Boztosun I, Bracco A, Brambilla S, Monago J B, Caamano M, Caesar C, Camera F, Casarejos E, Catford W, Cederkall J, Cederwall B, Chartier M, Chatillon A, Cherciu M, Chulkov L, Coleman-Smith P, Cortina-Gil D, Crespi F, Crespo R, Cresswell J, Csatlós M, D’Áchery F, Davids B, Davinson T, Derya V, Detistov P, Fernandez P D, DiJulio D, Dmitry S, DorÁl D, DueÁs J, Dupont E, Egelhof P, Egorova I, Elekes Z, Enders J, Endres J, Ershov S, Ershova O, Fernandez-Dominguez B, Fetisov A, Fiori E, Fomichev A, Fonseca M, Fraile L, Freer M, Friese J, Borge M G, Redondo D G, Gannon S, Garg U, Gasparic I, Gasques L, Gastineau B, Geissel H, Gernhäuser R, Ghosh T, Gilbert M, Glorius J, Golubev P, Gorshkov A, Gourishetty A, Grigorenko L, Gulyas J, Haiduc M, Hammache F, Harakeh M, Hass M, Heine M, Hennig A, Henriques A, Herzberg R, Holl M, Ignatov A, Ignatyuk A, Ilieva S, Ivanov M, Iwasa N, Jakobsson B, Johansson H, Jonson B, Joshi P, Junghans A, Jurado B, Körner G, Kalantar N, Kanungo R,

Coulomb dissociation of ^{16}O into ^4He and ^{12}C

Kelic-Heil A, Kezzar K, Khan E, Khanzadeev A, Kiselev O, Kogimtzis M, Körper D, Kräckmann S, Kröll T, Krücken R, Krasznahorkay A, Kratz J, Kresan D, Krings T, Krumbholz A, Krupko S, Kulesa R, Kumar S, Kurz N, Kuzmin E, Labiche M, Langanke K, Lazarus I, Bleis T L, Lederer C, Lemasson A, Lemmon R, Liberati V, Litvinov Y, Löher B, Herraiz J L, Münzenberg G, Machado J, Maev E, Mahata K, Mancusi D, Marganiec J, Perez M M, Marusov V, Mengoni D, Million B, Morcelle V, Moreno O, Movsesyan A, Nacher E, Najafi M, Nakamura T, Naqvi F, Nikolski E, Nilsson T, Nociforo C, Nolan P, Novatsky B, Nyman G, Ornelas A, Palit R, Pandit S, Panin V, Paradela C, Parkar V, Paschalis S, Pawlowski P, Perea A, Pereira J, Petrache C, Petri M, Pickstone S, Pietralla N, Pietri S, Pivovarov Y, Potlog P, Prokofiev A, Rastrepina G, Rauscher T, Ribeiro G, Ricciardi M, Richter A, Rigollet C, Riisager K, Rios A, Ritter C, Frutos T R, Vignote J R, Röder M, Romig C, Rossi D, Roussel-Chomaz P, Rout P, Roy S, Söderström P, Sarkar M S, Sakuta S, Salsac M, Sampson J, Sanchez J, del Rio Saez, Rosado J S, Sanjari S, Sarriguren P, Sauerwein A, Savran D, Scheidenberger C, Scheit H, Schmidt S, Schmitt C, Schnorrenberger L, Schrock P, Schwengner R, Seddon D, Sherrill B, Shrivastava A, Sidorchuk S, Silva J, Simon H, Simpson E, Singh P, Slobodan D, Sohler D, Spieker M, Stach D, Stan E, Stanoiu M, Stepantsov S, Stevenson P, Strieder F, Stuhl L, Suda T, Sümmerer K, Streicher B, Taieb J, Takechi M, Tanihata I, Taylor J, Tengblad O, Ter-Akopian G, Terashima S, Teubig P, Thies R, Thoennessen M, Thomas T, Thornhill J, Thungstrom G, Timar J, Togano Y, Tomohiro U, Tornyi T, Tostevin J, Townsley C, Trautmann W, Trivedi T, Typel S, Uberseder E, Udias J, Uesaka T, Uvarov L, Vajta Z, Velho P, Vikhrov V, Volkmandt M, Volkov V, von Neumann-Cosel P, von Schmid M, Wagner A, Wamers F, Weick H, Wells D, Westerberg L, Wieland O, Wiescher M, Wimmer C, Wimmer K, Winfield J S, Winkel M, Woods P, Wyss R, Yakorev D, Yavor M, Cardona J Z, Zartova I, Zerguerras T, Zgura M, Zhdanov A, Zhukov M, Zieblinski M, Zilges A and Zuber K 2016 *Journal of Physics: Conference Series* **665** 012044

- [7] Junghans A, Clerc H G, Grewe A, de Jong M, Müller J and Schmidt K H 1996 *Nuclear Instruments and Methods in Physics Research A* **370** 312–314