Precise Measurement of the ^{7}Be and ^{163}Ho Electron Capture Q-value for Neutrino Studies

Ramesh Bhandari[1], M.V.W Horana Gamage[1], Dakota Keblbeck[1],N.D Gamge[1], M. Redshaw[1]

Department of Physics, Central Michigan University, Mt. Pleasant, MI

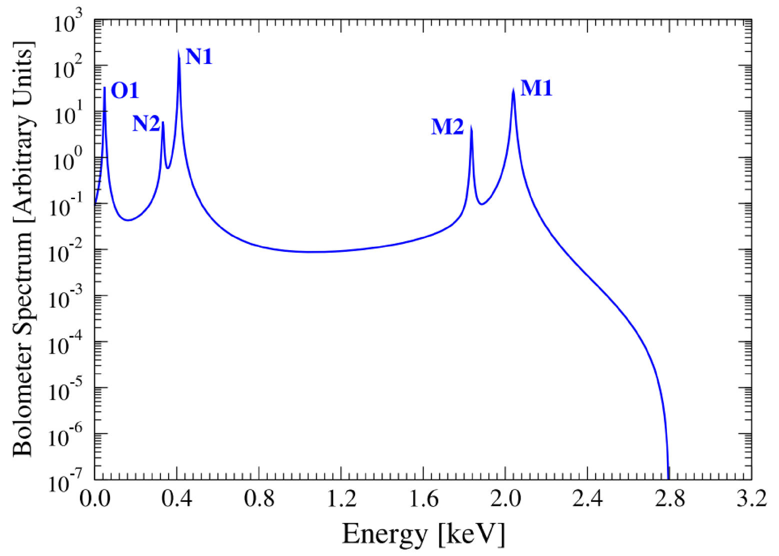
Big Picture Question

What are absolute masses of neutrinos?
Do sterile neutrinos exist?

Background

Neutrinos

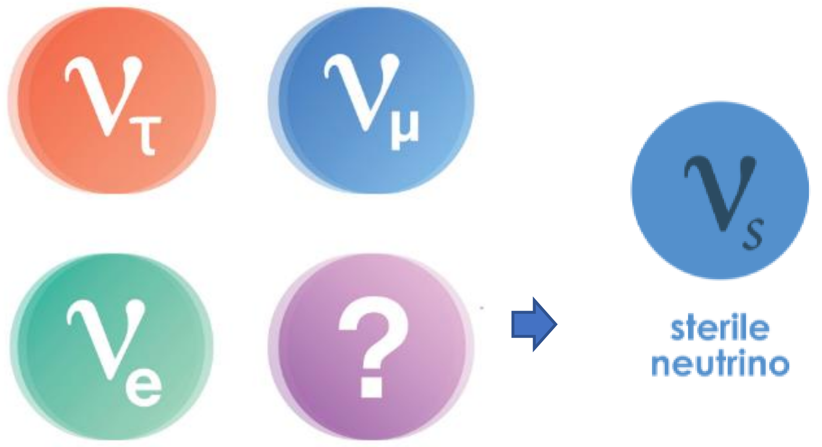
Neutrino mass and sterile neutrino

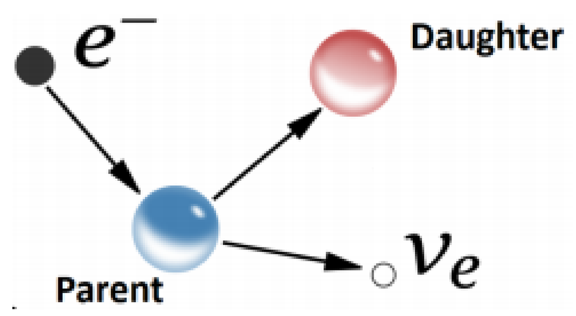


^{163}Ho + e$^-$ → 163Dy* + ν_e

- m_ν is determined from a fit near the end point of the energy spectrum

Fig: Calorimeter spectrum of ^{163}Dy de-excitation after electron capture decay of ^{163}Ho. The peaks correspond to capture from different ^{163}Ho electron shells.





$$T_d = \frac{Q_{EC}^2 - m_\nu^2 c^4}{2\left(Q_{EC} + m_d c^2\right)}$$

$$T_\nu = \frac{\left(m_\nu c^2 - Q_{EC}\right)\left(c^2(m_\nu - 2m_d) - Q_{EC}\right)}{2\left(m_d c^2 + Q_{EC}\right)}$$

Fig: Momentum reconstruction in Electron Capture Decay

Motivation

Need parent/daughter mass ratios <10^{-11} for very high precision Q values

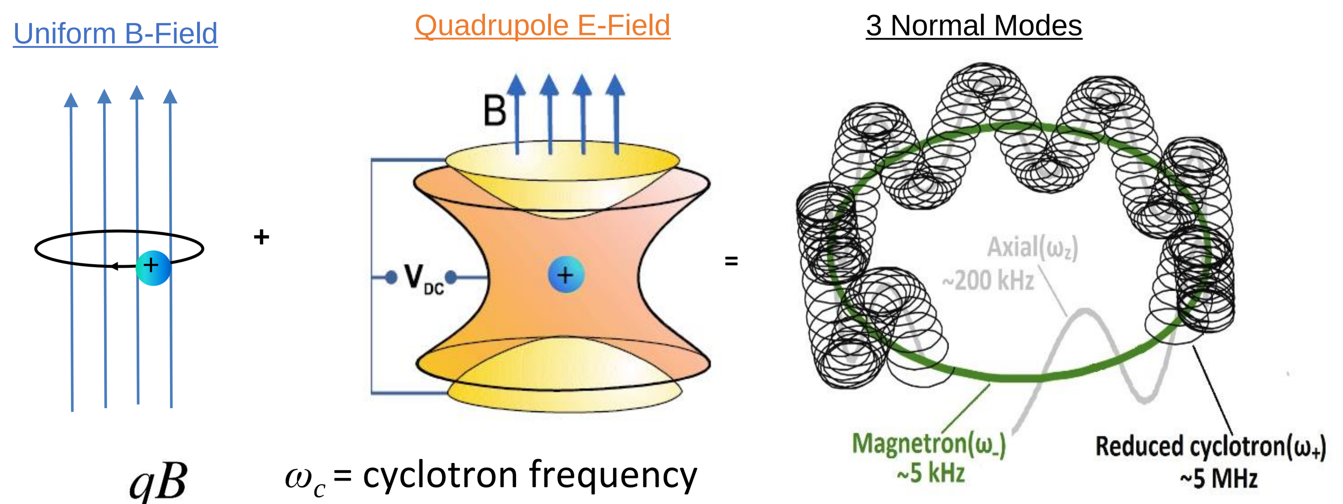
Approach

Penning Trap Mass Spectrometry

Apparatus: the Penning trap

The cyclotron frequency ω_c of an ion of charge q and mass m in a magnetic field of strength *B* is given by

$$\omega_c = \frac{qB}{m}$$



$$\omega_c = \frac{qB}{m}$$

ω_c = cyclotron frequency
m = mass
q = charge
B = magnetic field strength

$$\omega_c^2 = \omega_+^2 + \omega_-^2 + \omega_z^2$$

Measure cyclotron frequency to determine mass

$$R = \frac{m(^{163}\mathrm{Dy}^+)}{m(^{163}\mathrm{Ho}^+)} = \frac{\omega_c(^{163}\mathrm{Ho}^+)}{\omega_c(^{163}\mathrm{Dy}^+)}$$

$$Q = m(^{163}\mathrm{Ho}) - m(^{163}\mathrm{Dy})$$
$$= [m(^{163}\mathrm{Ho}) - m_e](1 - R)$$

Method

The Central Michigan High Precision Penning Trap (CHIP-TRAP)

CHIP-TRAP

The Central Michigan University High Precision Penning trap (CHIP-TRAP) will be used for mass measurements of stable and long lived radioactive isotopes. We aim to measure the ^{163}Ho and ^{7}Be electron capture Q values via the ^{163}Ho - ^{163}Dy and ^{7}Be – ^{7}Li mass differences, which are important for experiments investigating neutrinos.

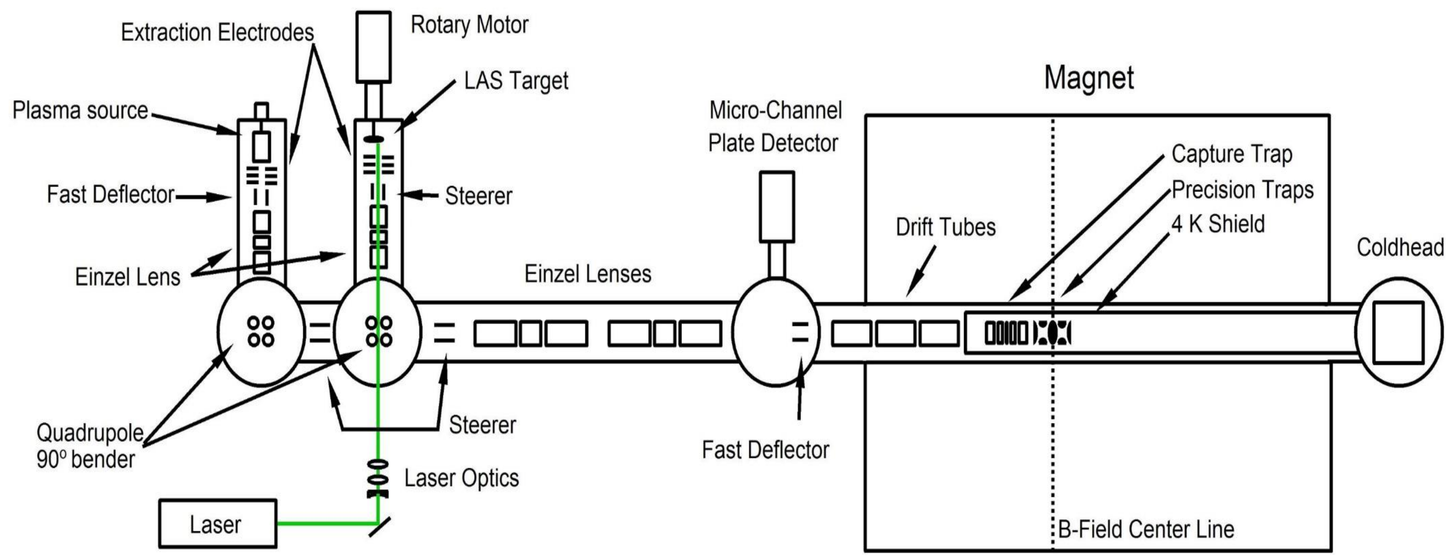
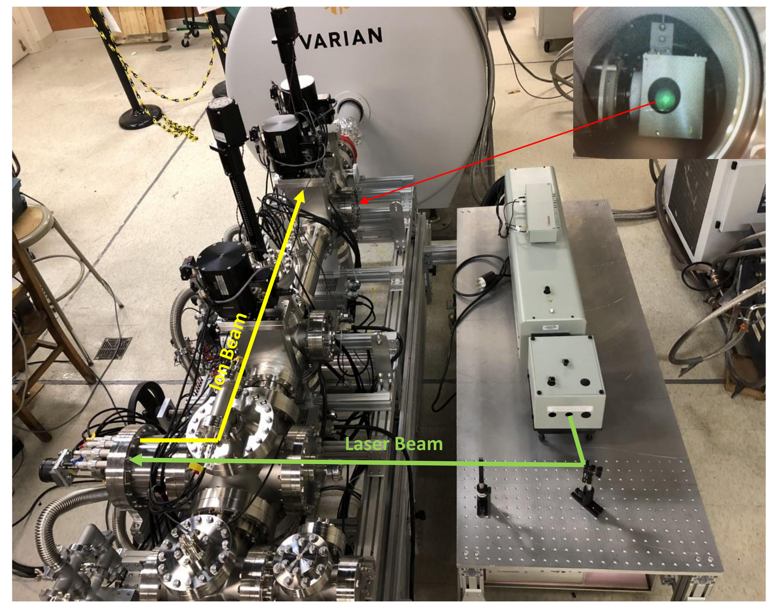


Fig: Schematic of CHIP-TRAP experiment layout

Question

How are ions produced using LAS?

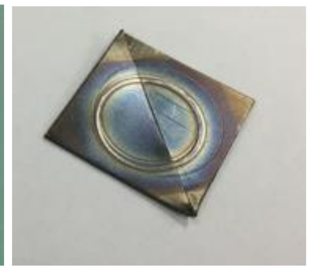
Laser Ablation Source(LAS)



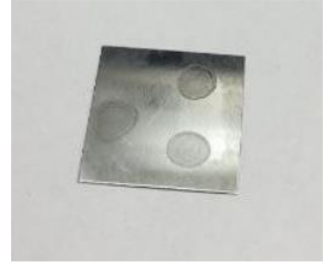
Laser ablation source

Metal traget in target holder

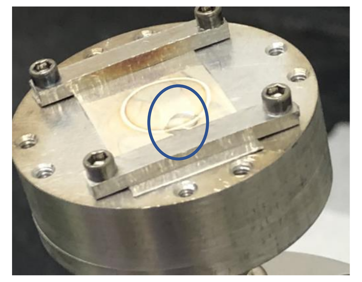
Sigradar



Holmium target



HoN solution



MgHCl solution

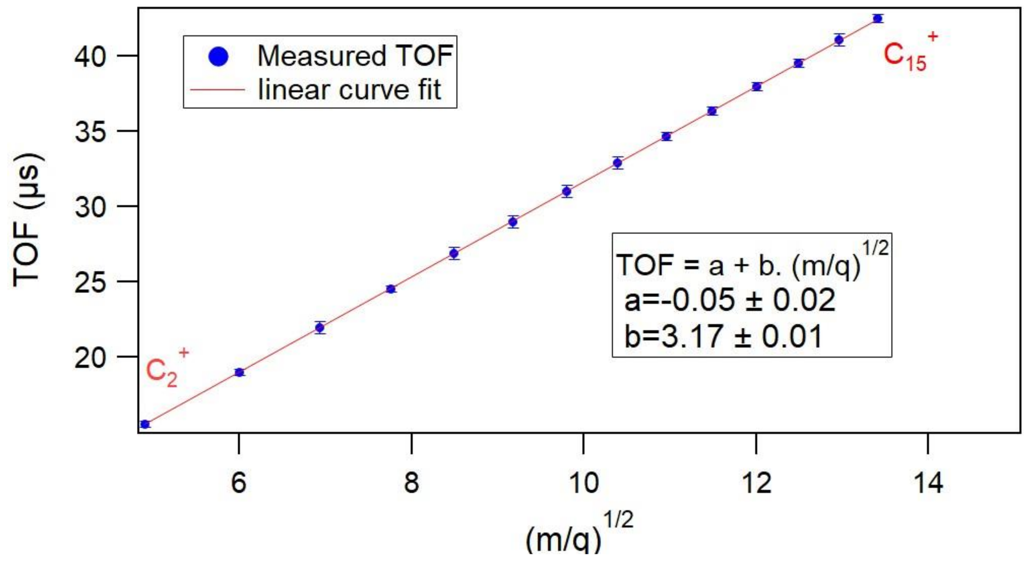
Results

Did LAS produce specific ions?

$$t_{TOF} = \frac{x}{\sqrt{2V}}\sqrt{\frac{m}{q}} \qquad t_1 = \sqrt{\frac{m_1}{m_2}}\, t_2$$

X= path length
V =ions accl. potential

m_2 and t_2 are reference ion's mass and time



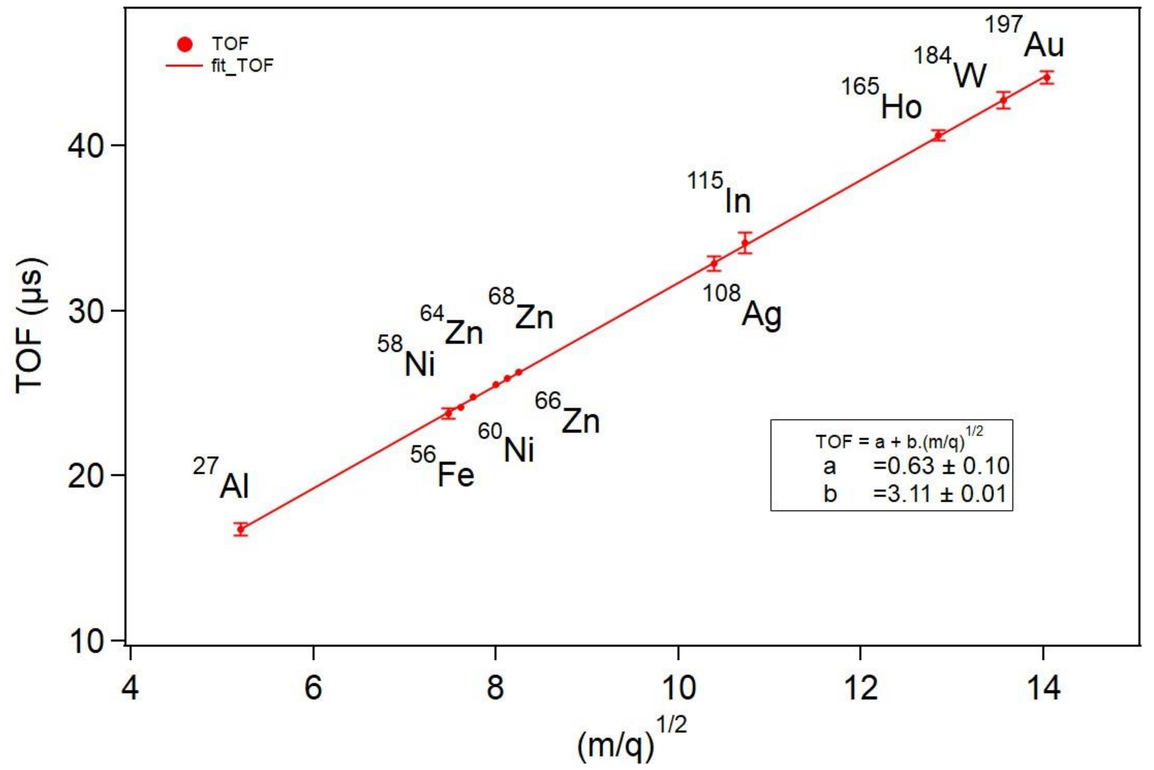


Fig: TOFs of different metals

Results

Did you produce Ho+ and Be+ ions?

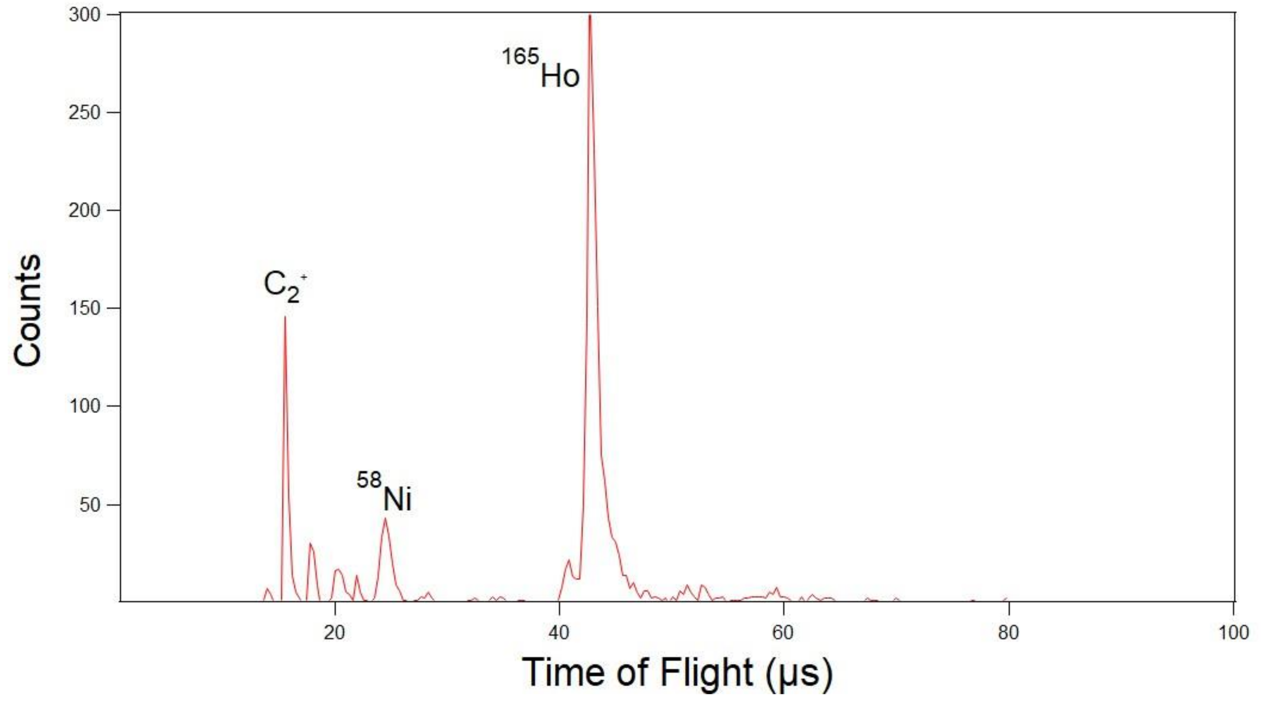
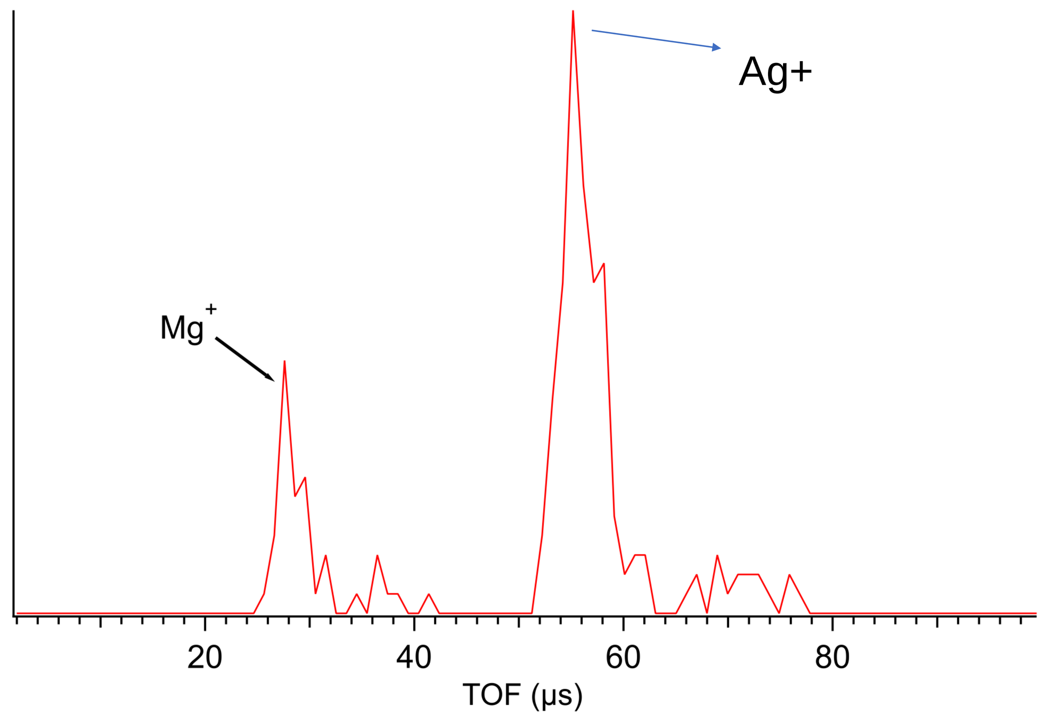


Fig: Production of Ho+ ions from HoN Powder solution

We are investigating production of ^{9}Be ions before ^{7}Be because 7Be is radioactive and would require additional safety precautions. Beryllium also requires special safety precautions, so we performed initial tests with MgHCl solution.



Conclusions and further works.

- **We successfully investigated production of 165Ho using HoN Powder solution.**
- **We can use nickel as a backing material for the experiment of 163Ho**
- **We have found that we need as few as ~10^{17} no. of atoms to perform expt.**
- **Investigate ways to improve efficiency and resolution of the peak.**
- **Insert MR-TOF-MS into the beamline of the CHIP-TRAP.**
- **Perform preliminary test measurements.**
- **Start the investigation for ion production of ^{7}Be$^+$ ions using ^{9}Be.**

Reference

[1] M. Eibach, T. Beyer, K. Blaum, M. Block, Ch.E. Düllmann, K. Eberhardt, J. Grund, S. Nagy, H. Nitsche, W. Nörtershäuser *et al.*, Phys. Rev. C 89, 064318 (2014).

[2] F. Schneider, T. Beyer, K. Blaum, M. Block, S. Chenmarev, H. Dorrer, Ch. E. Düllmann, K. Eberhardt, M. Eibach, S. Eliseev, J. Grund, U. Köster, Sz. Nagy, Yu. N. Novikov, D. Renisch, A. Türler, and K. Wendt, Eur. Phys. J. A 51 89 (2015)

[3] M. Redshaw et al./Nuclear Instruments and Methods in Physics Research B 376 (2016) 302–30