



Quasi-Free Scattering from Carbon and Oxygen Isotopes

Matthias Holl for the R³B Collaboration



- spectroscopic factor S_j

$$\langle \Psi_{A-1}(\vec{r}) | \Psi_A(\vec{r}) \rangle = \sum_{j=l_A-l_{A-1}}^{l_A+l_{A-1}} c_j \psi_j(\vec{r})$$

$$S_j = |c_j|^2$$

- cross section

$$\sigma_{th} = \sum_j S_j \cdot \sigma_{sp}(nlj)$$

Spectroscopic Factors

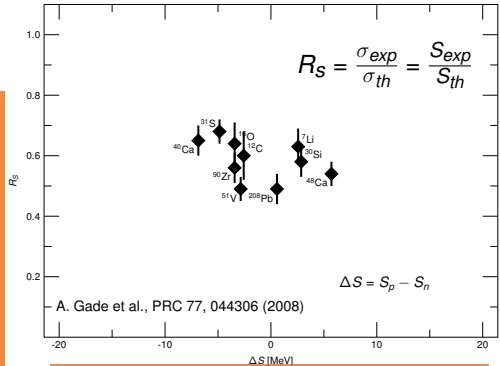
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- stable nuclei (e,e'p)
- $R_S \approx 0.6$, "Quenching"

Spectroscopic Factors



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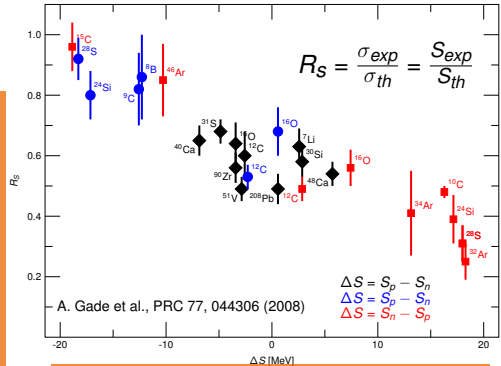
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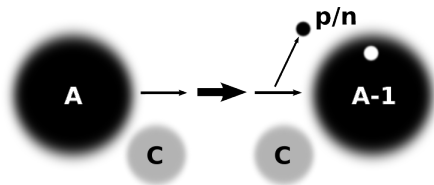


- stable nuclei (e,e'p)
- $R_S \approx 0.6$, "Quenching"
- unstable nuclei
- dependence on ΔS

Knockout and Quasi-Free Scattering



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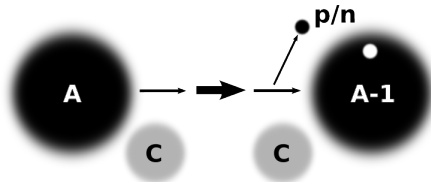
Knockout

- ▶ carbon or beryllium target
- ▶ nucleon from projectile scattered
- ▶ residual nucleus and target unaffected
- ▶ reaction concentrated on surface

Knockout and Quasi-Free Scattering

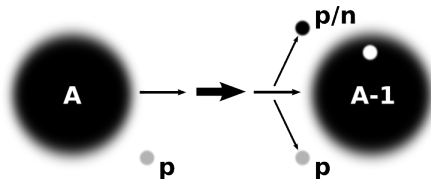


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Knockout

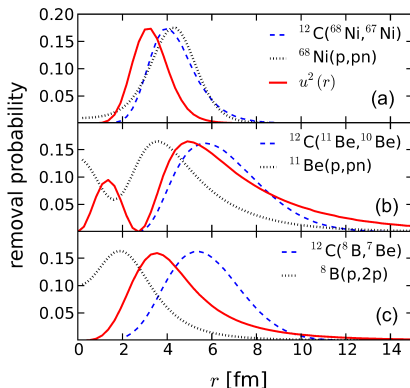
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Quasi-Free Scattering

- ▶ ideally hydrogen target
- ▶ both projectile and target nucleon scattered
- ▶ investigation of nuclear interior

Knockout and Quasi-Free Scattering



Aumann, Bertulani, Ryckebusch,
PRC 88, 064610 (2013)

Knockout

- carbon or beryllium target
- nucleon from projectile scattered
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- reaction concentrated on surface

Quasi-Free Scattering

- ideally hydrogen target
- both projectile and target nucleon scattered
- investigation of nuclear interior



- ▶ simple reaction mechanism
- ⇒ distorted wave impulse approximation (DWIA)
- ▶ inverse kinematics
- ⇒ large acceptance
- ⇒ redundant information from scattered nucleons and fragments

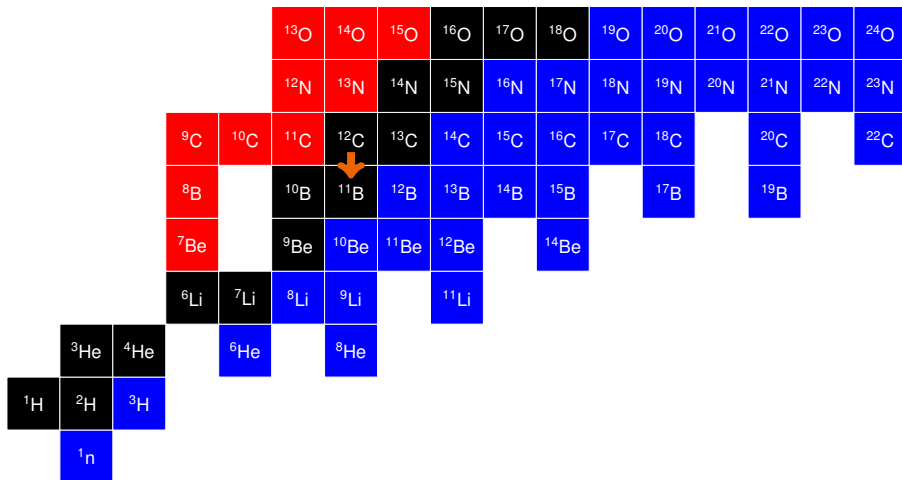


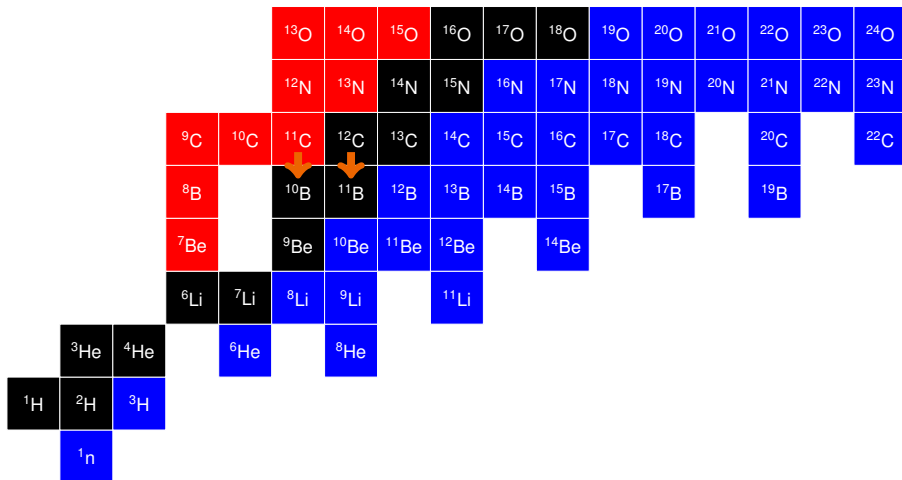
The diagram illustrates the periodic table of nuclides, showing isotopes from ^1H to ^{24}O . The nuclides are color-coded based on their stability:

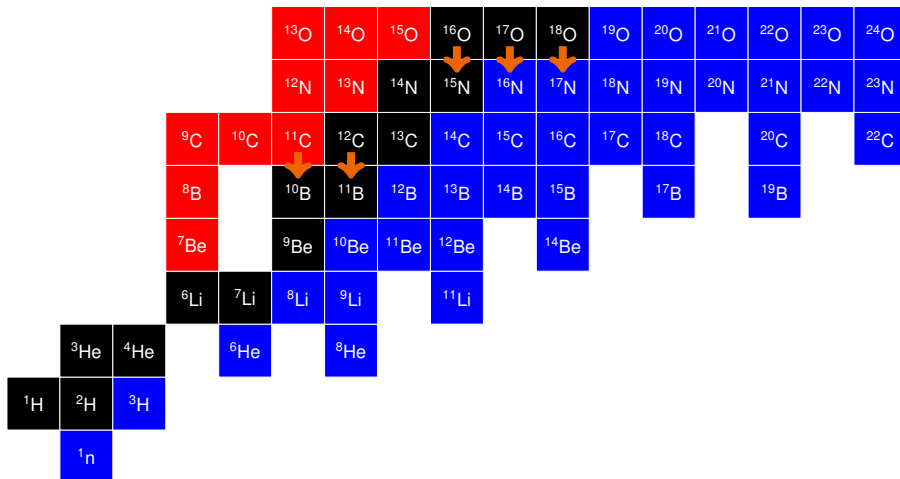
- Red:** Stable nuclides.
- Black:** Unstable nuclides with half-lives $> 10^8$ years.
- Blue:** Unstable nuclides with half-lives $< 10^8$ years.

The table shows the following nuclides:

- Hydrogen (H):** ^1H (black), ^2H (black), ^3H (blue), ^1n (blue).
- Helium (He):** ^3He (black), ^4He (black), ^6He (blue), ^8He (blue).
- Lithium (Li):** ^6Li (black), ^7Li (black), ^8Li (blue), ^9Li (blue), ^{11}Li (blue).
- Beryllium (Be):** ^7Be (red), ^9Be (black), ^{10}Be (blue), ^{11}Be (blue), ^{12}Be (blue), ^{14}Be (blue).
- Boron (B):** ^8B (red), ^{10}B (black), ^{11}B (black), ^{12}B (blue), ^{13}B (blue), ^{14}B (blue), ^{15}B (blue), ^{17}B (blue), ^{19}B (blue).
- Carbon (C):** ^9C (red), ^{10}C (red), ^{11}C (red), ^{12}C (black), ^{13}C (black), ^{14}C (blue), ^{15}C (blue), ^{16}C (blue), ^{17}C (blue), ^{18}C (blue), ^{20}C (blue), ^{22}C (blue).
- Nitrogen (N):** ^{12}N (red), ^{13}N (red), ^{14}N (black), ^{15}N (black), ^{16}N (blue), ^{17}N (blue), ^{18}N (blue), ^{19}N (blue), ^{20}N (blue), ^{21}N (blue), ^{22}N (blue), ^{23}N (blue).
- Oxygen (O):** ^{13}O (red), ^{14}O (red), ^{15}O (red), ^{16}O (black), ^{17}O (black), ^{18}O (black), ^{19}O (blue), ^{20}O (blue), ^{21}O (blue), ^{22}O (blue), ^{23}O (blue), ^{24}O (blue).



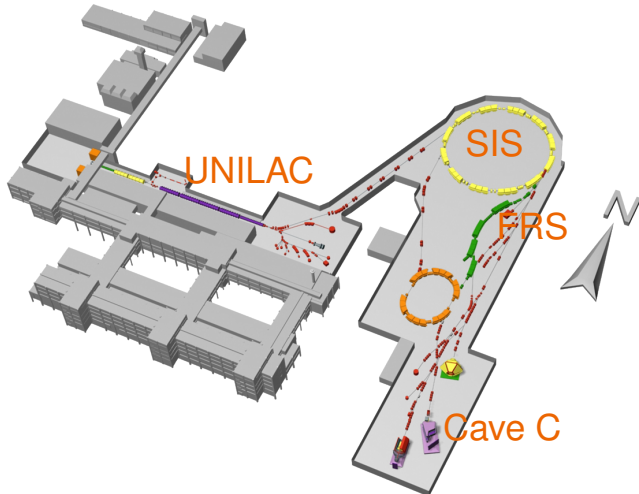




Beam Production at GSI

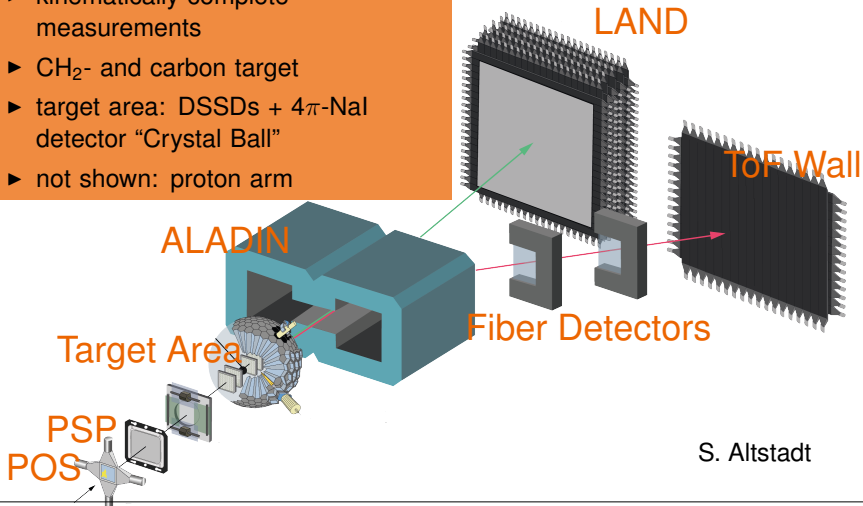


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R³B-LAND Setup

- ▶ kinematically complete measurements
- ▶ CH₂- and carbon target
- ▶ target area: DSSDs + 4 π -NaI detector "Crystal Ball"
- ▶ not shown: proton arm



S. Altstadt

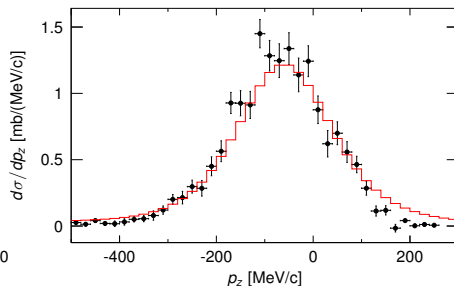
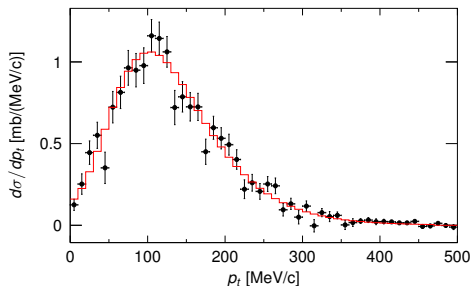
Prototype Experiment: $^{12}\text{C}(\text{p},2\text{p})$



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- ▶ spectroscopic factors in agreement with previous measurements
- ▶ 65 % of expected spectroscopic strength observed in $^{12}\text{C}(\text{p},2\text{p})^{11}\text{B}$
- ▶ >80 % observed in ground state
- ▶ excitation spectrum shows sensitivity to knockout from s-shell

V. Panin, publication in preparation



- comparison to DWIA calculations by C. Bertulani
- assumption: knockout from $p_{3/2}$ -shell



- ▶ cross sections for $^{16,17,18}\text{O}(p,2p)^{15,16,17}\text{N}$ obtained
- ▶ analysis of $^{19-21}\text{O}(p,2p)$ ongoing



L. Atar, priv. comm.



- ▶ (p,2p) in inverse kinematics is a tool to obtain spectroscopic information
- ▶ successful prototype experiment using ^{12}C
 - ▶ very good agreement with (e,e'p) and (p,2p) in direct kinematics
 - ▶ indication of knockout from s-shell
- ▶ examples of further carbon and oxygen isotopes
 - ▶ $^{11}\text{C}(p,2p)$: application to unstable nucleus
 - ▶ $^{16-18}\text{O}$: beginning of systematic study

The R³B Collaboration



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Thank you for your attention!

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