Peeling off Neutrons:

Using Fragmentation Reactions to Measure the Neutron Skin

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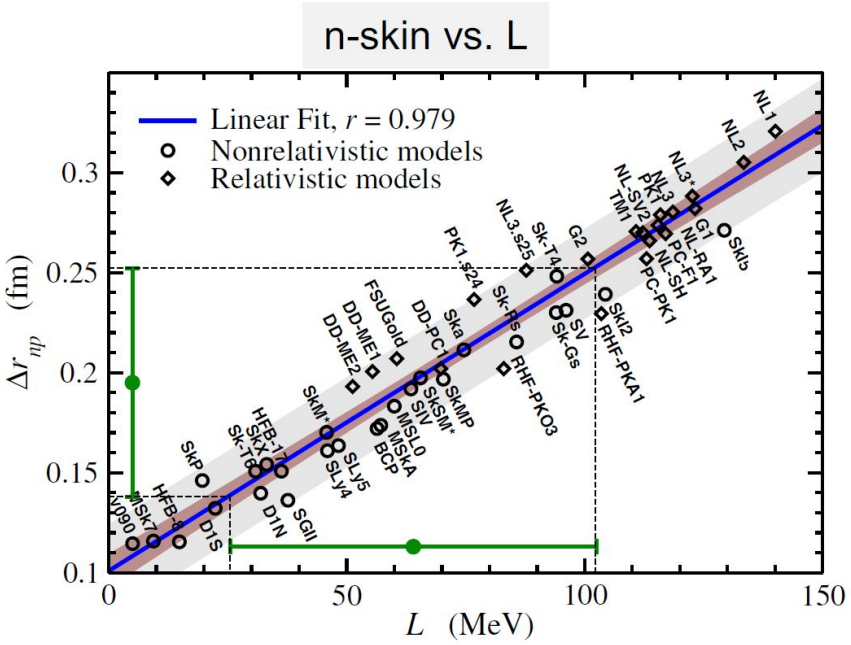
Neutron-skin thickness

- Neutron-skin thickness (Δr_{np}) in neutron-rich nuclei shows good potential to constrain L
- $\Delta r_{np} = \langle r_n^2 \rangle^{1/2} - \langle r_p^2 \rangle^{1/2}$
- Neutron excess causes $P_n > P_p$
  - Related to E/A, therefore density and asymmetry
- $\epsilon_A(\rho, \delta) = \epsilon_A(\rho, 0) + S_A(\rho)\delta^2 + ...$
- $S(\rho) = J + \frac{L}{3}\frac{\rho - \rho_0}{\rho_0} + ...$
- Relationship between J, L instrumental to n-skin thickness
- Correlate r_n, r_p using RMF or HF theories

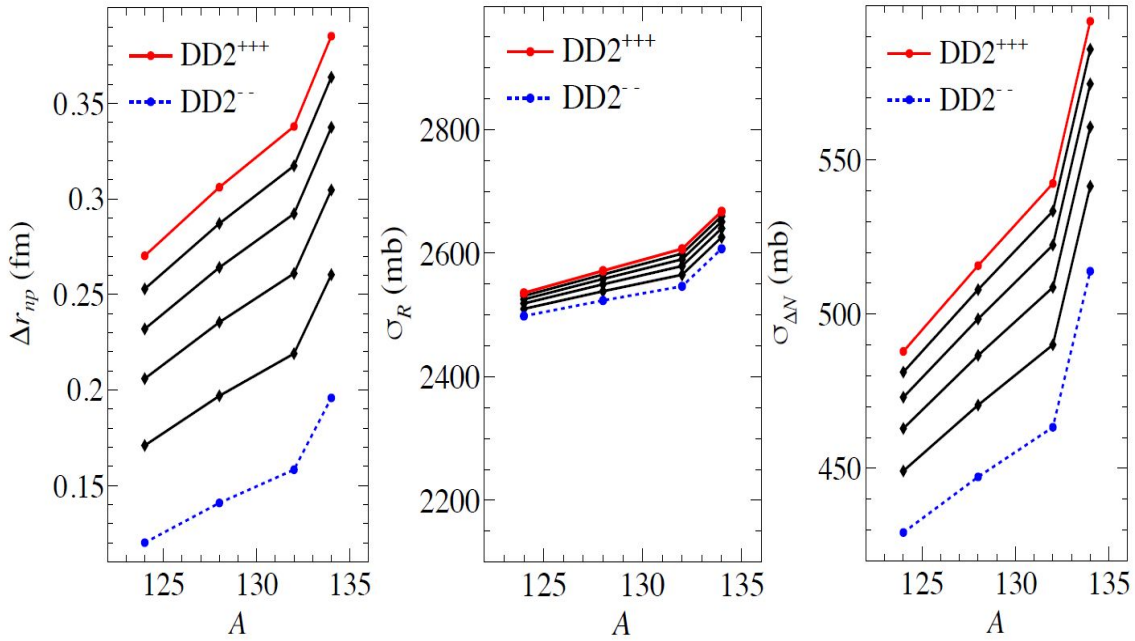


X. Roca-Maza, *et al.*, Phys. Rev. Lett. **106**, 252501 (2011)

Motivation for Fragmentation Reactions

- Two methods to measure n-skin thickness:
  - Electron scattering (PREX)
  - Hadronic probes
- Fragmentation reactions allow precise measurement of probes across an **isotopic chain**
  - Provides additional, more rigorous test of the models
- Propose a new method to extract the neutron-skin thickness

Relevance of Neutron-Removal Cross Section

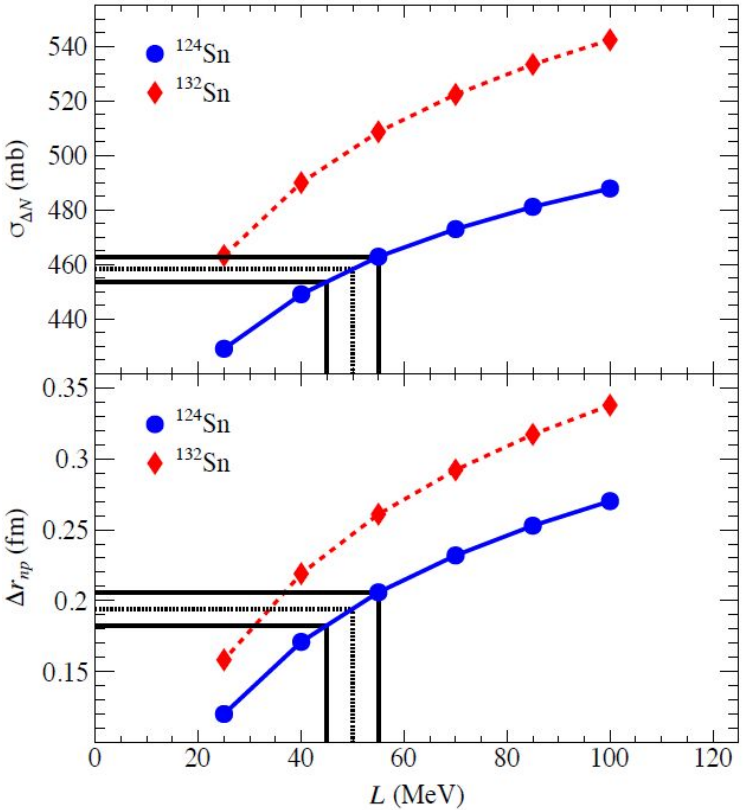


- Use RMF DD interactions to simulate Δr_{np}, σ_R, $\sigma_{\Delta N}$
  - Sn isotopic chain
  - Systematically varying L (25-100 MeV)
- Large difference in Δr_{np} as function of L
  - $\delta(\Delta r_{np})$=0.19 fm for ^{132}Sn
- Change in total reaction cross section very small
  - 2.5% effect
- Neutron-removal cross section more sensitive
  - 20% effect

T. Aumann, C.A. Bertulani, F. Schindler, S. Typel, Phys. Rev. Lett. **119**, 211101 (2017)
Relativistic Mean Field Theory (DD2): S. Typel, Phys. Rev. C **89**, 064321 (2014)

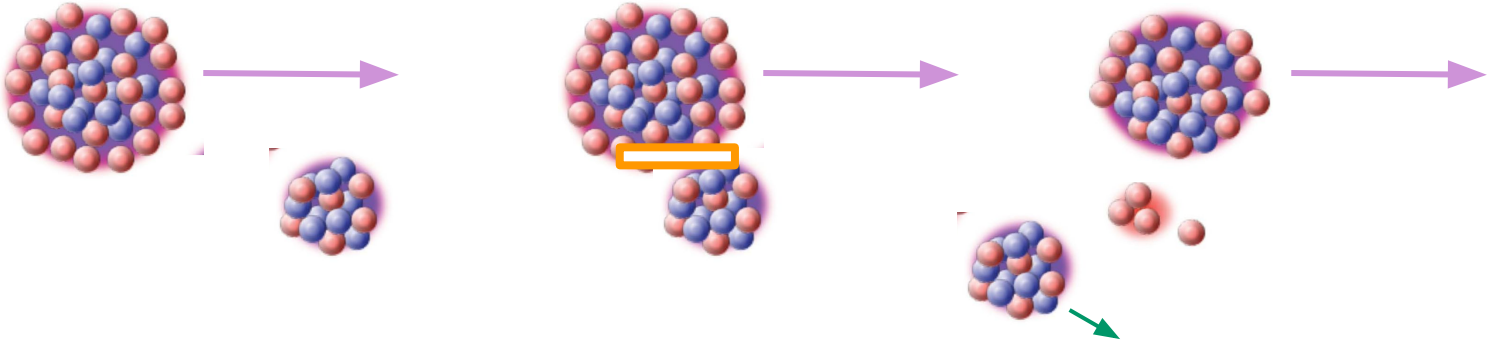
How well could one constrain the slope?

- Variation of L = ± 5 MeV corresponds to:
  - $\delta\Delta r_{np} \approx 0.01$ fm
  - $\delta\sigma_{\Delta N} \approx 1\%$
- A very precise measurement of $\sigma_{\Delta N}$ across an isotopic chain can give much insight into the slope of the density dependence of the symmetry term!



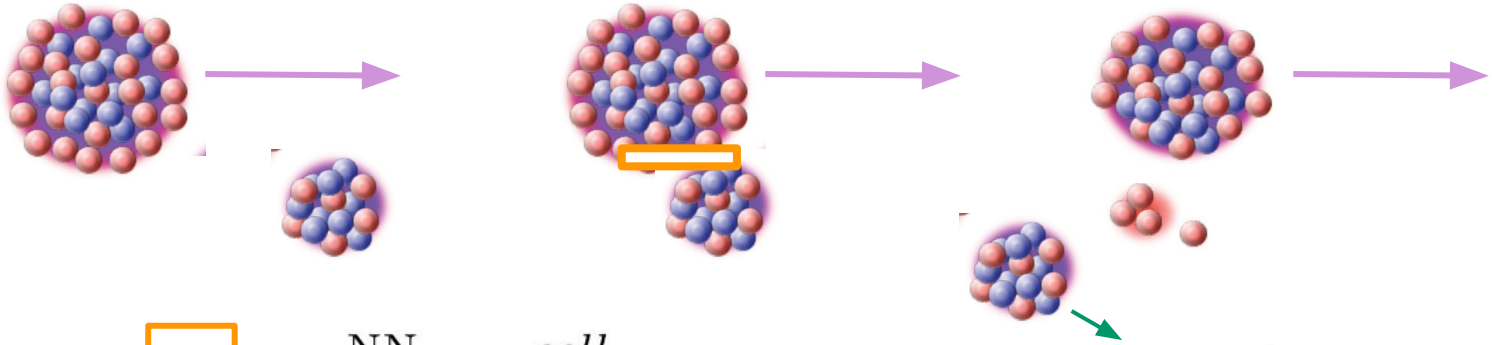
T. Aumann, C.A. Bertulani, F. Schindler, S. Typel, Phys. Rev. Lett. **119**, 211101 (2017)

Link to Experimental Quantities



$$\sigma_R = \sigma_R^{\mathrm{NN}} + \sigma_R^{coll}$$

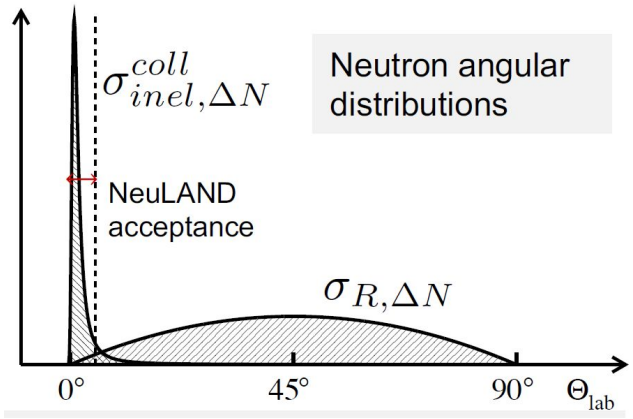
Link to Experimental Quantities



$$\sigma_R = \sigma_R^{\mathrm{NN}} + \sigma_R^{coll}$$

$$\sigma_{R,\Delta Z}^{\mathrm{NN}} + \sigma_{R,\Delta Z}^{coll} + \sigma_{R,\Delta N}^{\mathrm{NN}} + \sigma_{R,\Delta N}^{coll}$$

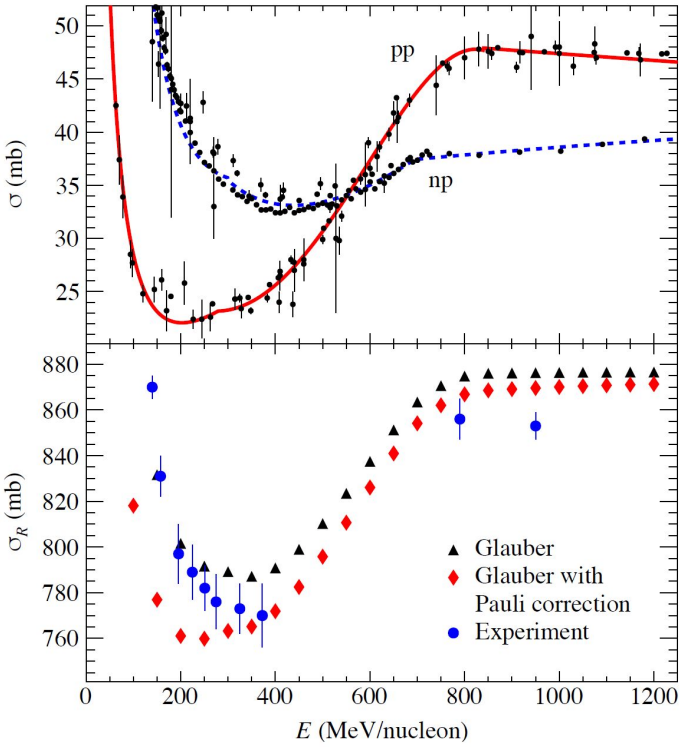
Glauber/Eikonal Theory



Neutron angular distributions

Eikonal Theory

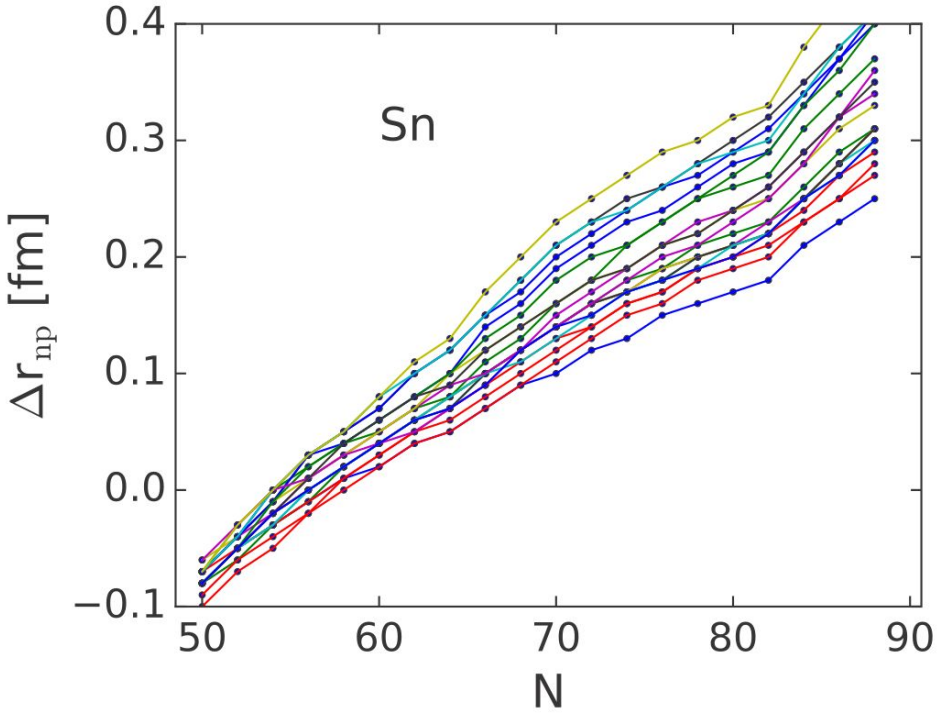
- The σ_{pp} and σ_{pn} can be utilized to test Eikonal Theory
- σ_{pp} and σ_{pn} fits used as inputs
- Glauber model results without corrections
- Fairly good agreement of Glauber model with the experimental data
  - More exploration at E>400 MeV/nuc. needed



T. Aumann, C.A. Bertulani, F. Schindler, S. Typel, Phys. Rev. Lett. **119**, 211101 (2017)

Examination of the ϱ^{P}_{p} and ϱ^{P}_{n} on the neutron thickness

- 23 Skyrme interaction inputs
- Δr_{np} increases as neutron content increases
- Interactions diverge as the neutron content increases
  - Systematic examination of neutron-rich nuclei essential



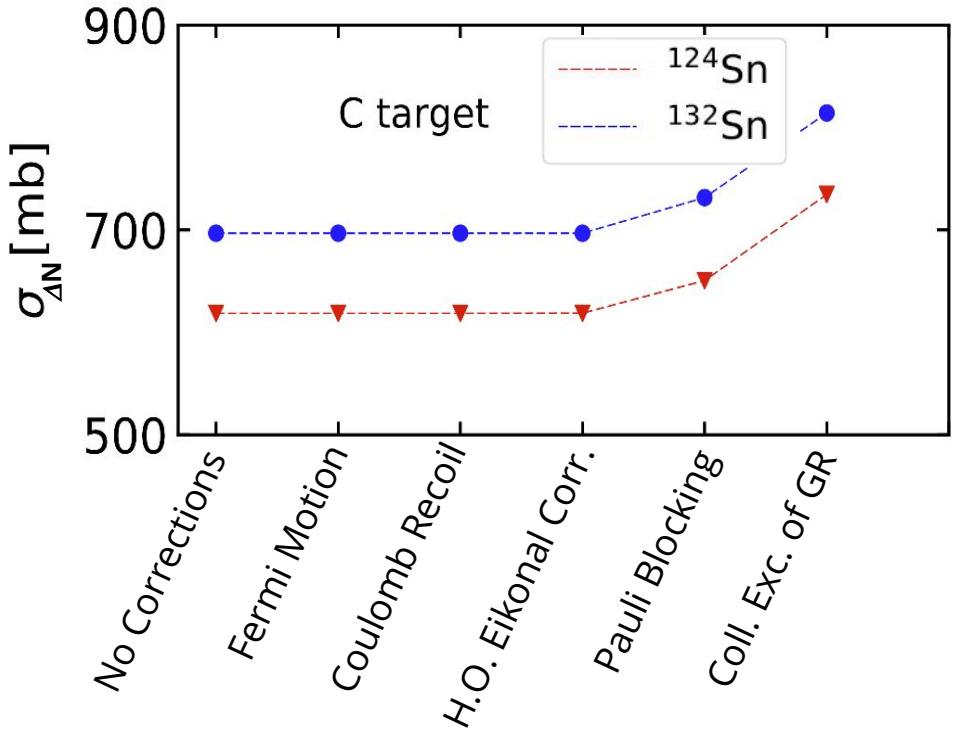
C. A. Bertulani and J. Valencia, Phys. Rev. C **100**, 015802

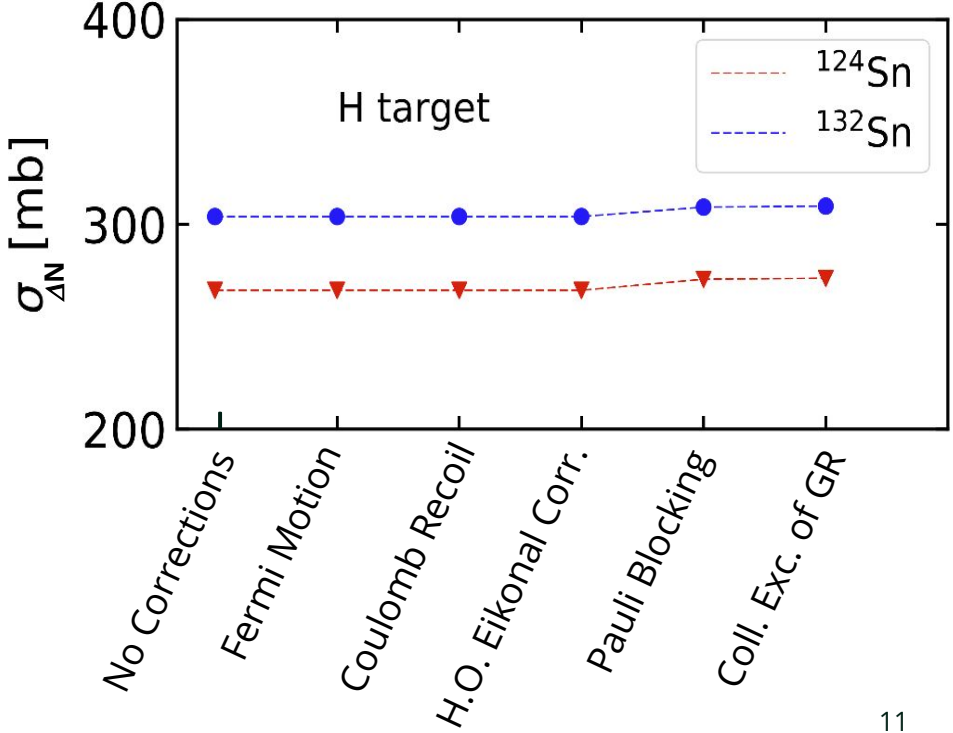
Glauber Model Corrections

Following corrections need to be quantified:

1. Fermi Motion
2. Coulomb Recoil
3. Higher Order Eikonal Corrections
4. Pauli Blocking
5. Collective Excitation of GR

Quantifying Corrections

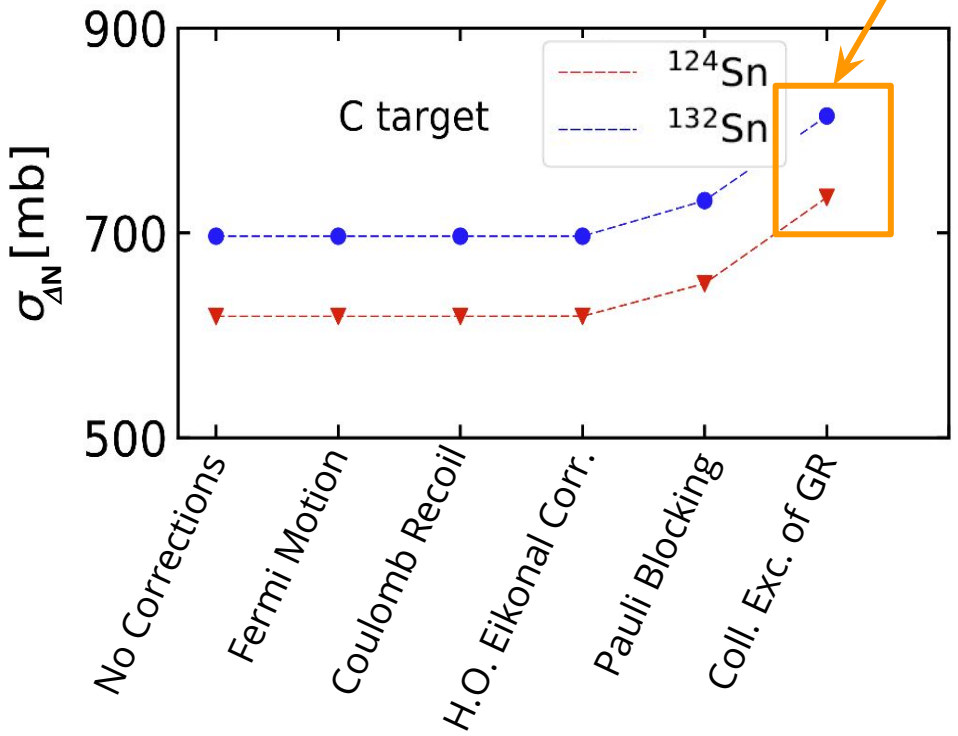


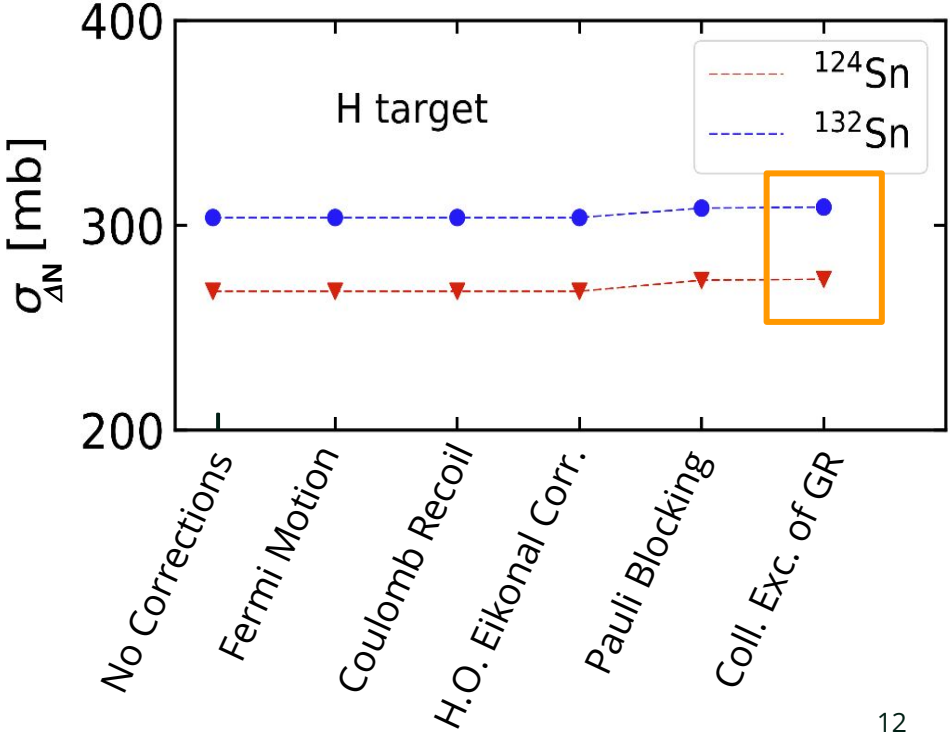


A. Horvat, PhD Thesis, TU Darmstadt (2019)
C. Bertulani, 2021

Quantifying Corrections

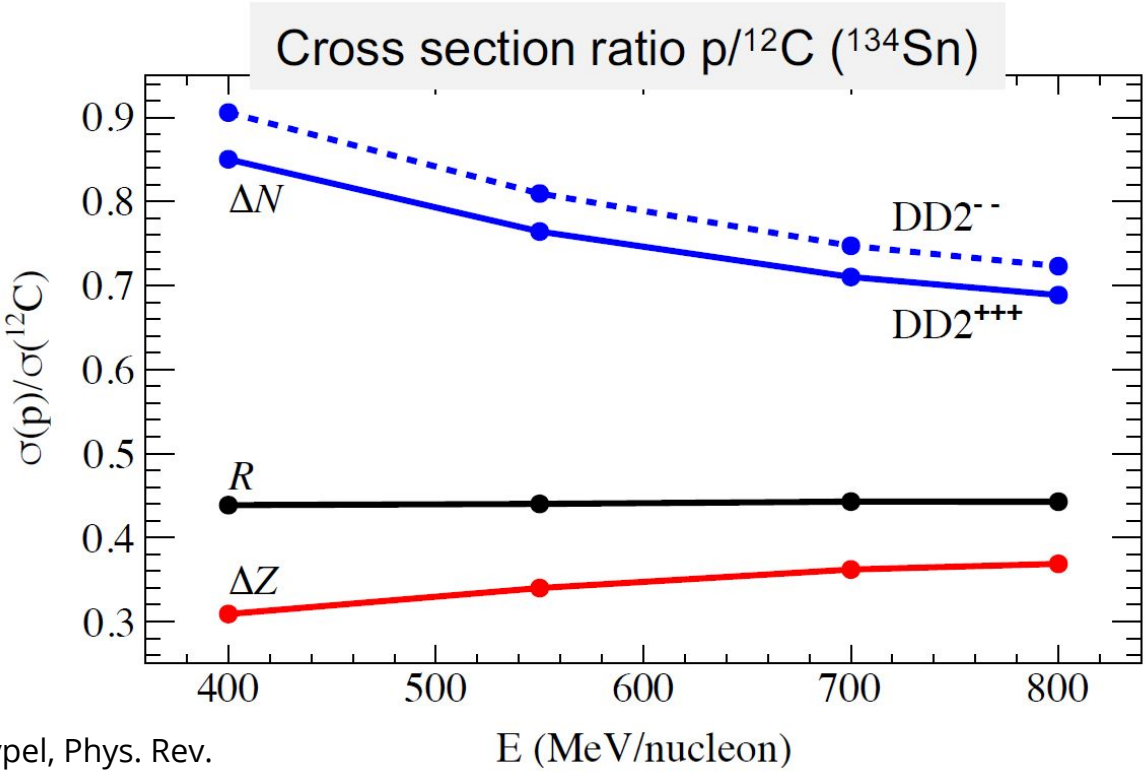
Experimentally verifiable
77.7 ± 5.5 mb for $^{132}Sn+^{12}C$





More insight from comparing targets

- Medium effects studied by comparing p, ^{12}C targets
- Neutron-removal cross section ratio sensitive to the slope

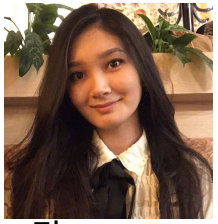


T. Aumann, C.A. Bertulani, F. Schindler, S. Typel, Phys. Rev. Lett. **119**, 211101 (2017)

Experiments at R3B

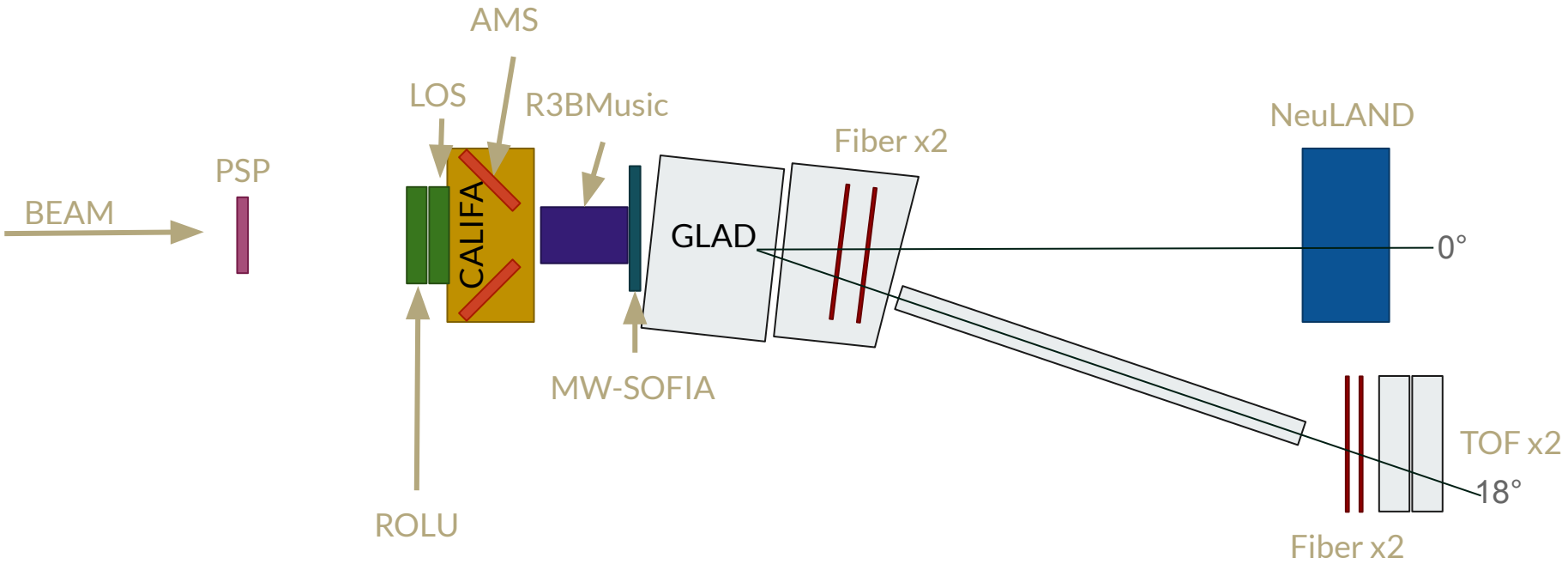
- Two experimental campaigns in the R3B collaboration at GSI:
  - First campaign: February 2019
    - Stable beams
    - ^{120}Sn projectile @ 400, 550, 800, 1000 MeV/nuc
    - Targets: C, CH_2 and Pb
  - Second campaign: April 2021
    - Radioactive beams
    - ^{124,128,132,134}Sn projectile @ 900 MeV/nuc
    - ^{132,134}Sn projectile @ 600 MeV/nuc
    - ^{124}Sn projectile @ 400 MeV/nuc
    - Targets: C, CH_2 and Pb

Ashton Falduto

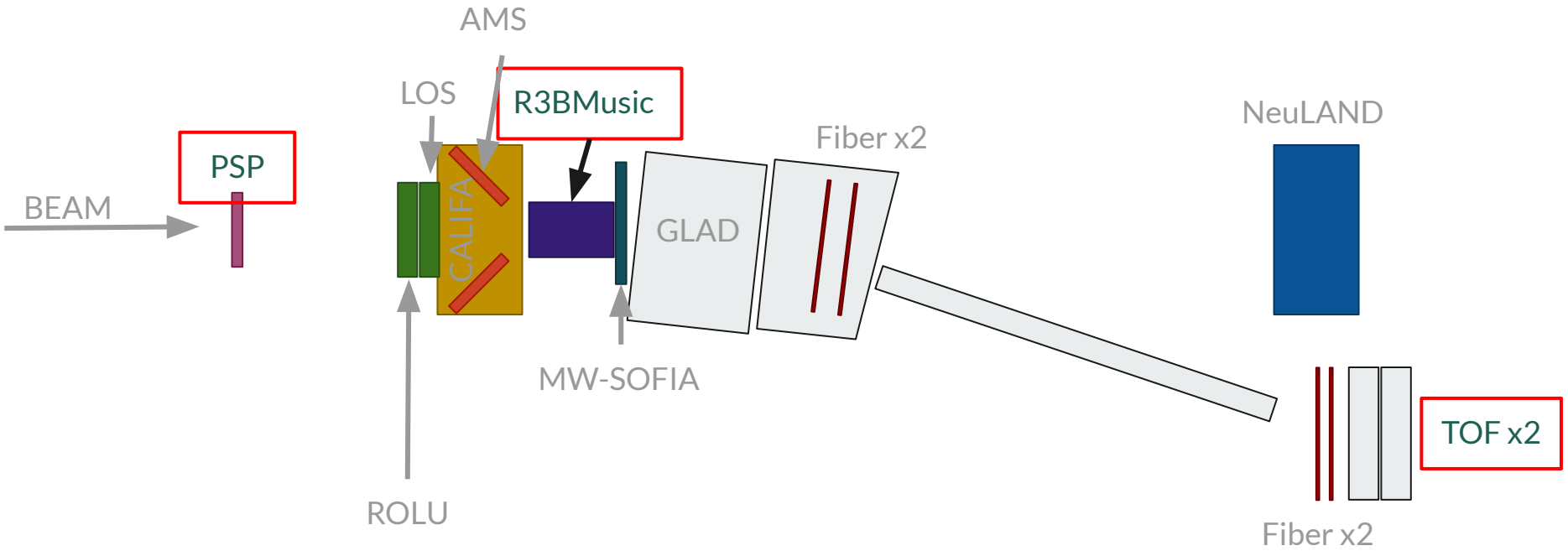


Eleonora Kudaibergenova

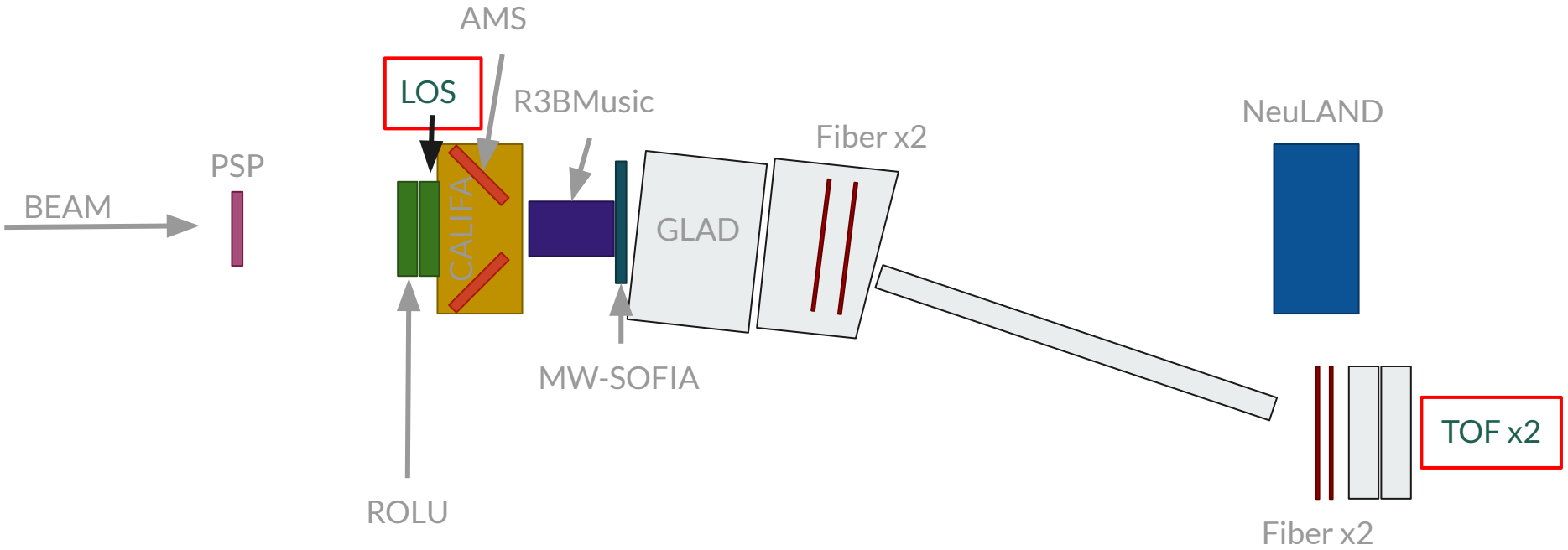
Experimental Setup



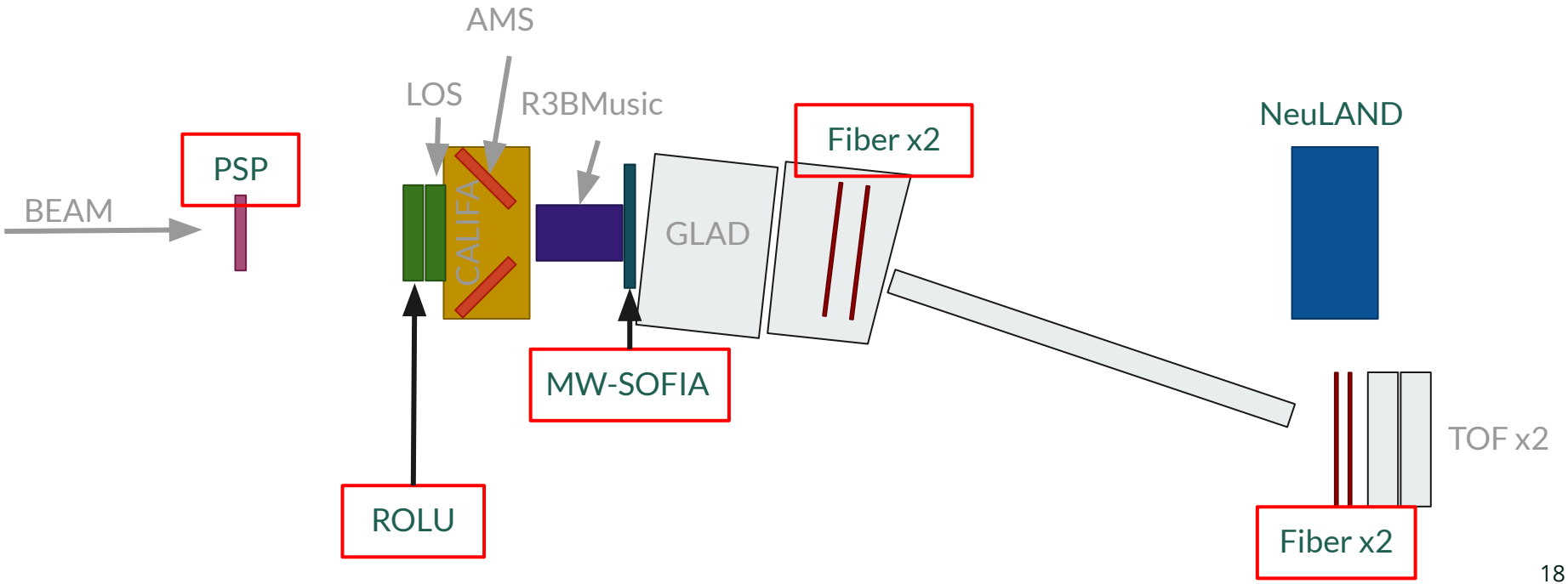
Charge Identification



Mass Identification



Position Tracking



Summary

- Propose using neutron-removal cross sections to constrain L
  - Along Sn isotopic chain
- Precise measurement of the $\sigma_{\Delta N}$ can constrain L within ± 5 MeV
- Performed experiments at GSI

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Thank you and stay tuned!

Questions?