Measurement of the Total Neutron-Removal Cross Section of ^{120}Sn at R^3B to Determine Constraints on the Equation of State

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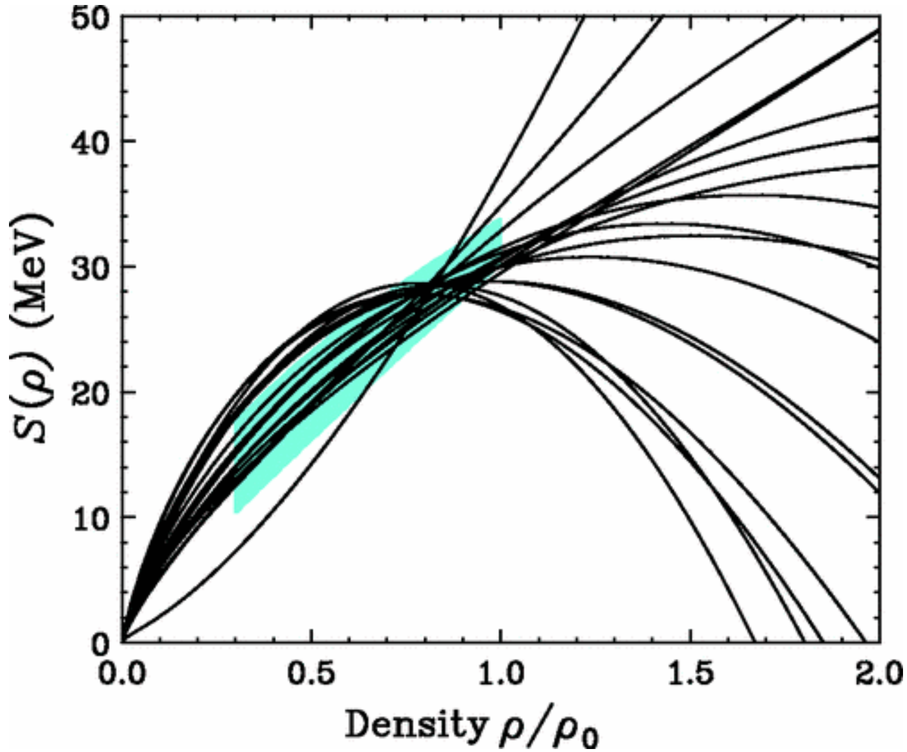
Motivation

- Why do we need an Equation of State (EoS) for neutron rich matter?
  - Understand properties of neutron stars, core-collapse supernova, and neutron-star mergers
- The atomic nucleus is the only environment we can study in a laboratory
- Exotic nuclei- atomic nuclei with shorter lifetimes and have an imbalanced ratio between proton and neutron number
- Constraints on the EoS can be obtained from measurements of bulk properties of neutron-rich matter

The L Parameter

- Around saturation density, the EoS for asymmetric nuclear matter is usually characterized by the symmetry energy at saturation J and its slope L
  - Experimentally, L is very poorly constrained
- Two observables that can potentially put better constraints on L are the neutron skin thickness of neutron-rich nuclei and the ground-state dipole polarizabilty



M. B. Tsang et al., Phys. Rev. C 86, 015803 (2012)

Neutron Skin Thickness

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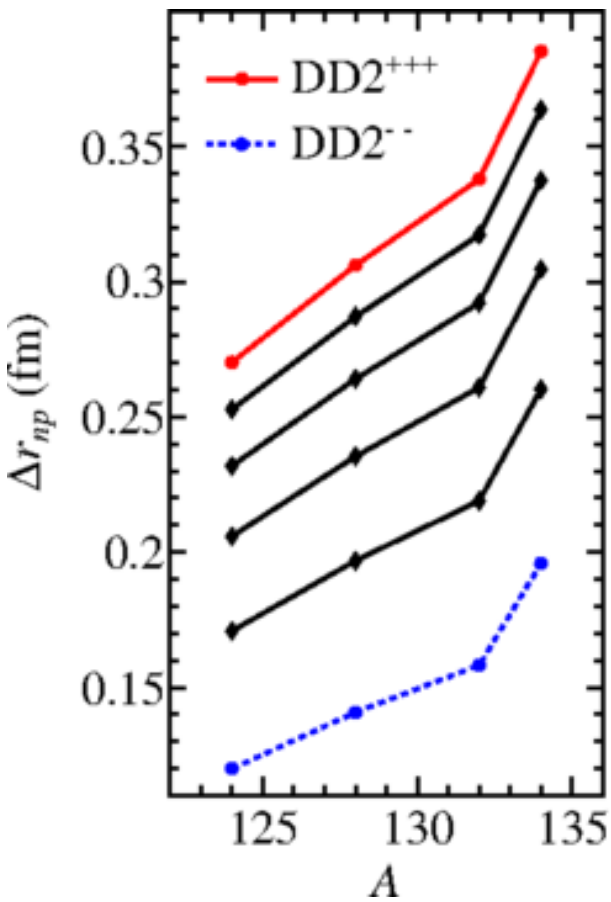
- If a nuclei is neutron-rich, it is expected to form a neutron rich surface layer called the neutron skin
- The difference of the root mean square (rms) radii of neutron and proton distributions

$$\Delta r_{np} = \langle r_n^2 \rangle^{\frac{1}{2}} - \langle r_p^2 \rangle^{\frac{1}{2}}$$

- Affects the neutron-removal cross section



T. Aumann et al., Phys. Rev. Letters 119.26, 262501 (2017)

R3B

Glauber Multiple Scattering Method

- Scattering model of nucleon-nucleon interactions
  - Cross section for the production of a fragment (Z,N) from a projectile (Z_p,N_p):

$$\sigma = \binom{Z_P}{Z}\binom{N_P}{N}\int d^2b\left[1-P_p(b)\right]^{Z_P-Z}P_p^Z(b)\times\left[1-P_n(b)\right]^{N_P-N}P_n^N(b)$$

  - The probability a proton survives:

$$P_p(b) = \int dz d^2 s \rho_p^P(\boldsymbol{s},z) exp\left[-\sigma_{pp}Z_T\int d^2 s\rho_p^T(\boldsymbol{b}-\boldsymbol{s},z) - \sigma_{pn}N_T\int d^2 s\rho_n^T(\boldsymbol{b}-\boldsymbol{s},z)\right]$$

  - σ_{pp}, σ_{pn} → proton-proton and proton-neutron cross sections
  - $\rho_{n(p)}^{P(T)}$→ projectile (target), proton (neutron) densities
- $\sigma_{\Delta Z}, \sigma_{\Delta N}, \& \ \sigma_R$ are obtained from the summation of all corresponding fragments

Cross-Sections

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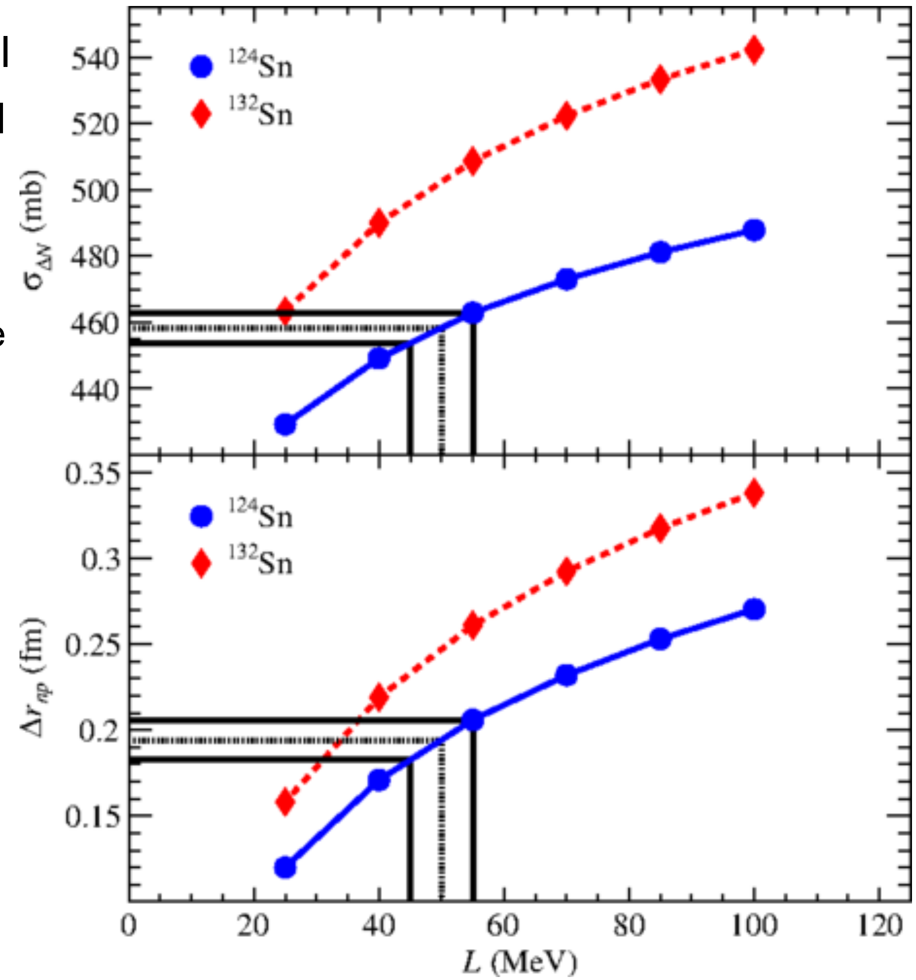
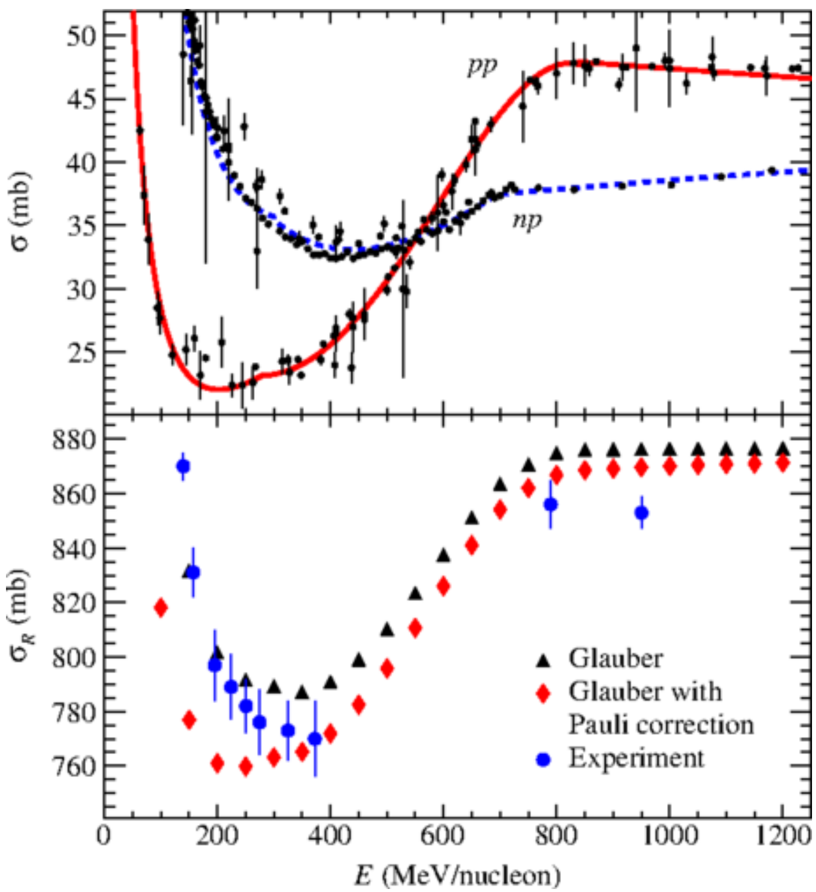
- Cross Sections are calculated using theoretical density distributions from relativistic mean-field calculations
- $\sigma_{\Delta Z}$ → total charge-changing cross section
  - at least one proton is removed from the projectile
- $\sigma_{\Delta N}$ → neutron-removal cross section
  - at least one neutron is removed from the projectile
  - charge number does not change
- $\sigma_R = \sigma_{\Delta Z} + \sigma_{\Delta N}$ → total reaction cross section
- Goal: measure within 1% accuracy
  - experimentally and theoretically
  - ±10 MeV constraint on L

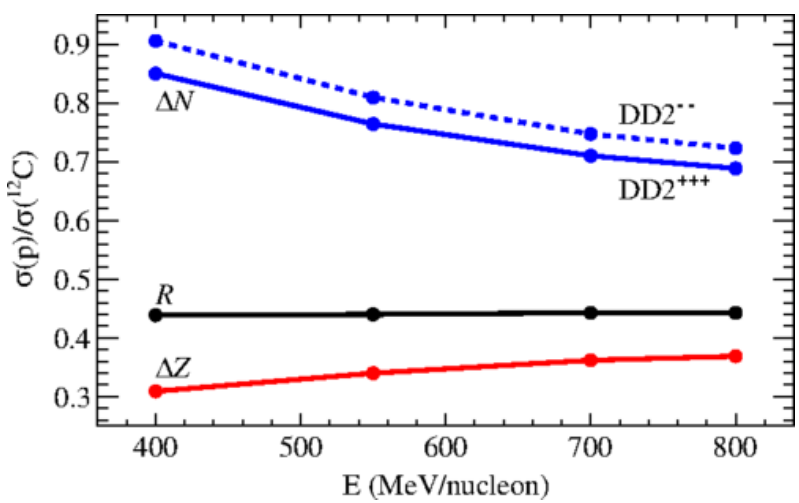


R3B

Reaction Theory Challenges



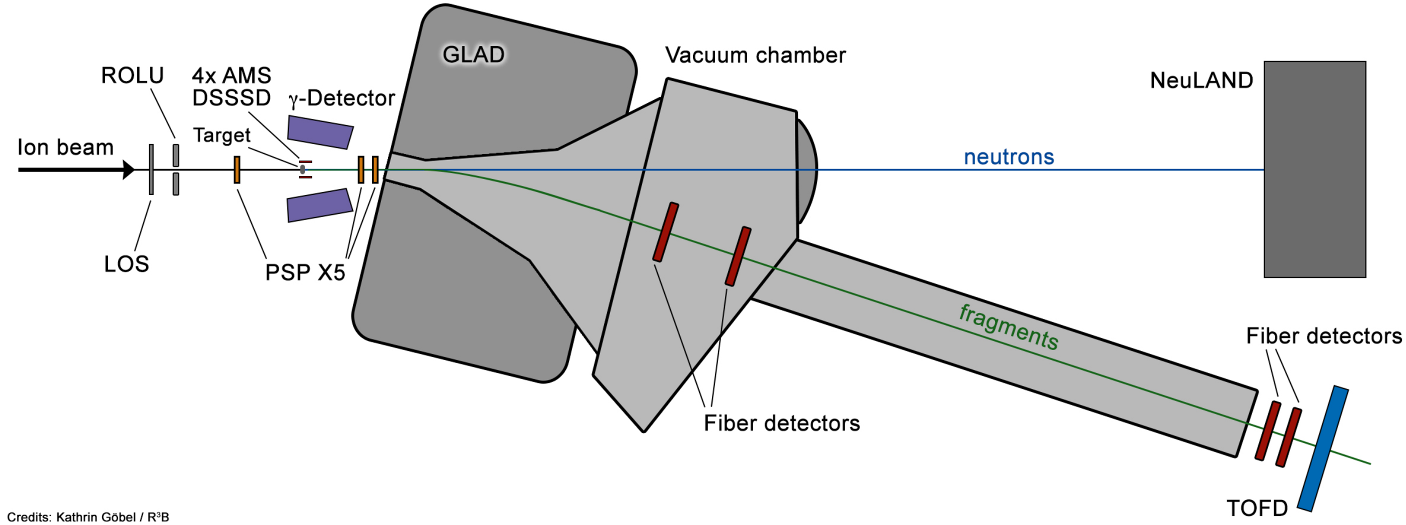
- Energy point at 950 is overestimated by 2%
- Experimental data is missing between 400 and 800
- Target and energy dependence



Experimental Challenges

- Precise knowledge of response functions- risk of nongaussian distribution
- Large resolution is helpful
- Detectors with high efficiency and acceptance
- Determine the collective cross section with ≤5% uncertainty
  - More precise neutron detection and reconstruction (3n channel)
- Previous experiment with ^{124}Sn projectile on ^{12}C target:
  - $\sigma_{\Delta N} \approx$ 550 mb (F. Schindler, Ph.D. Thesis)
  - $\sigma_{\Delta N(coll)} \approx$ 100 mb

Experimental Setup

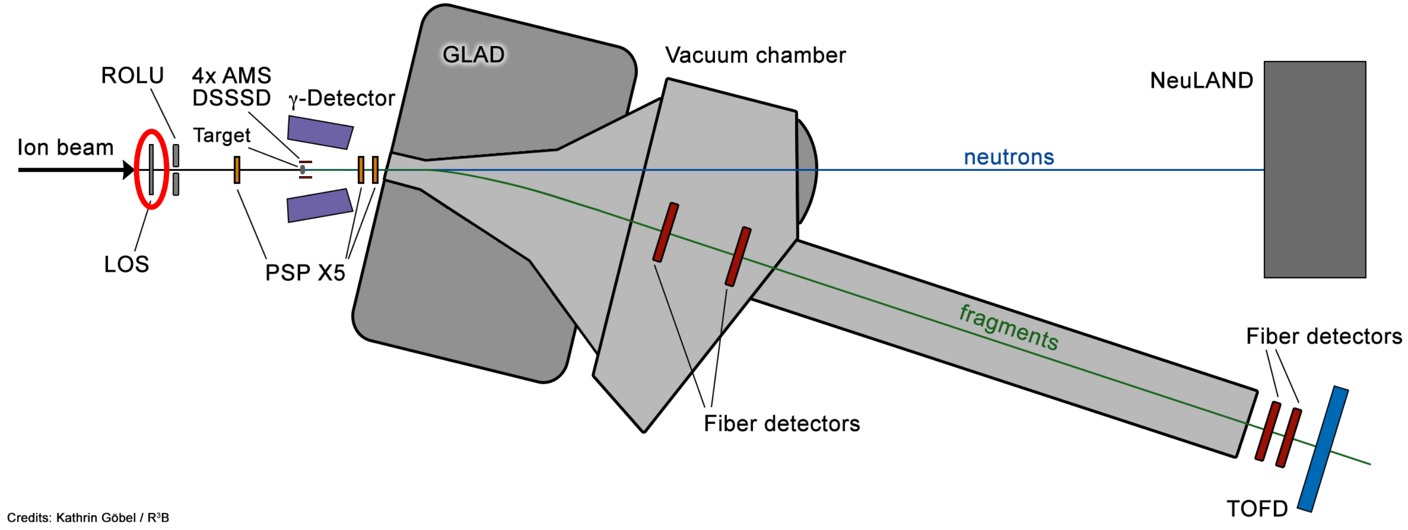


FAIR Phase 0 R³B setup, February 2019

Experiment	Beam	Energies (AMeV)	Targets
s444	^{12}C	400, 550, 650, 800, 1000	C, CH_2, Pb, empty
s473	^{120}Sn	400, 550, 650, 800, 900	C, CH_2, Pb, empty

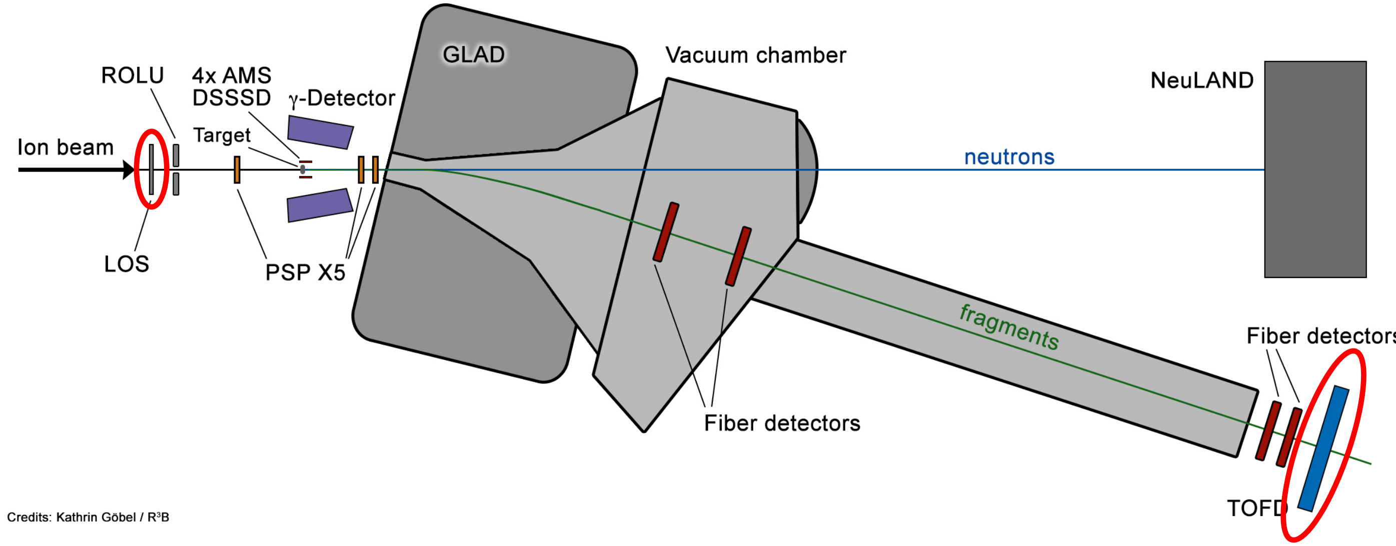
*Different thicknesses for C and CH_2 were used

Experimental Setup- Detectors



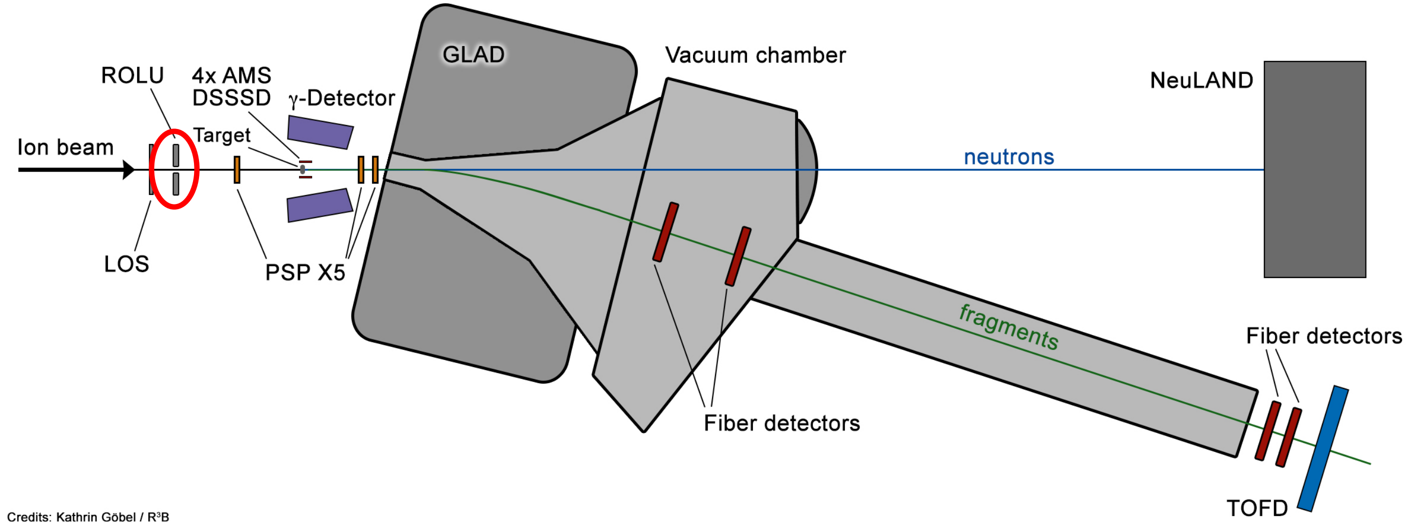
- LOS- incoming beam velocity, start time for TOFD

Experimental Setup- Detectors



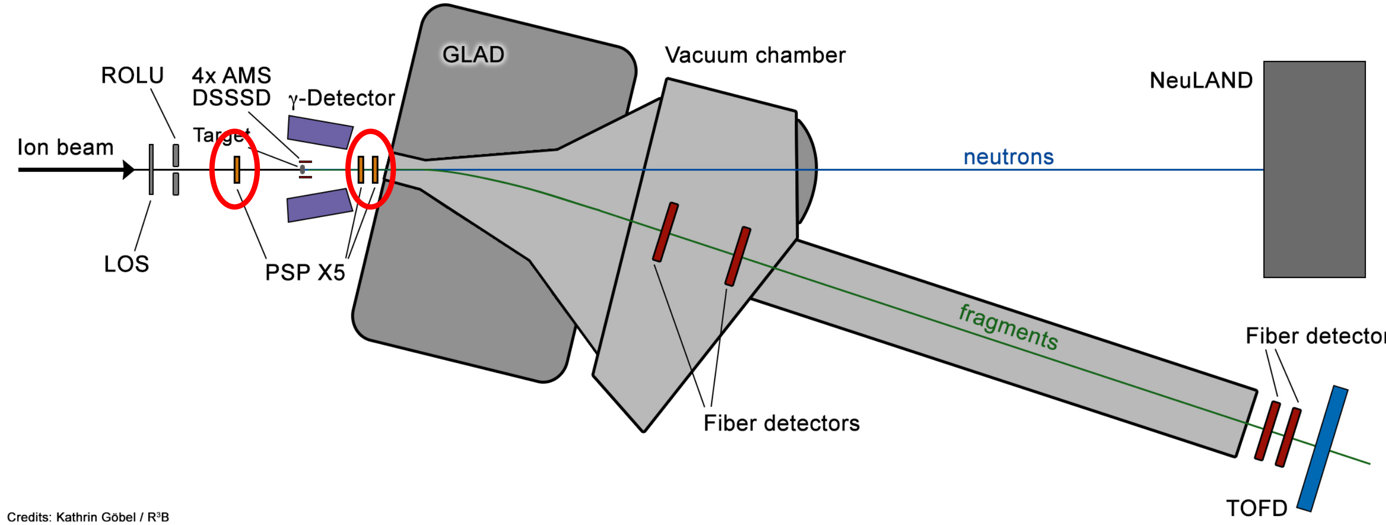
- LOS- incoming beam velocity, start time for TOFD
- TOFD- Time of Flight, beam trajectory

Experimental Setup- Detectors



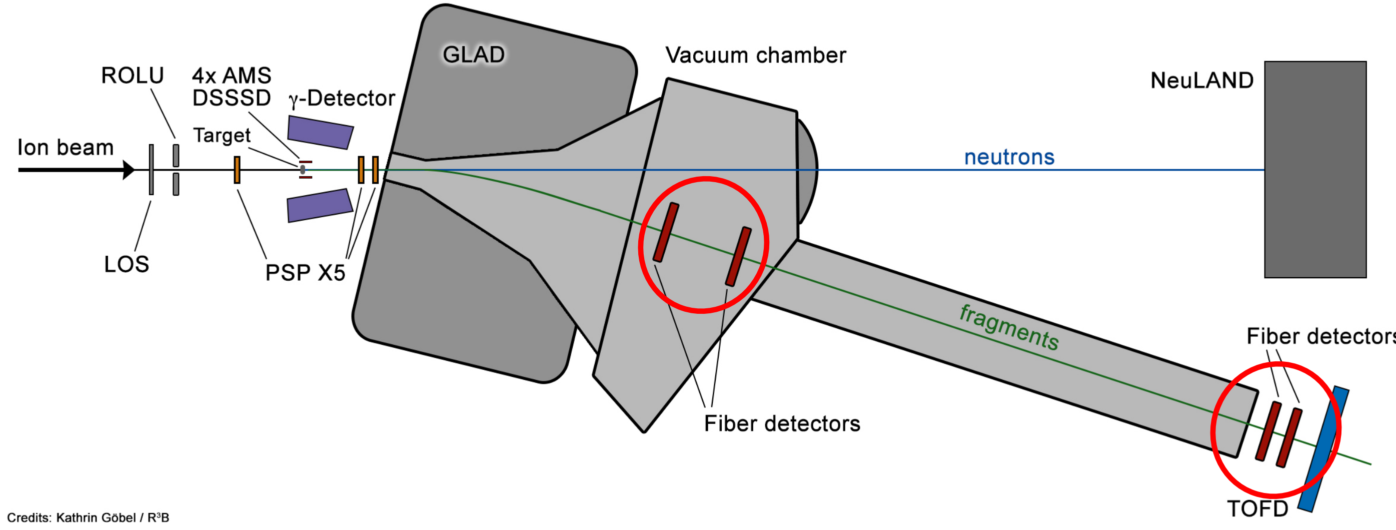
- LOS- incoming beam velocity, start time for TOFD
- TOFD- Time of Flight, beam trajectory
- ROLU- collimator for incoming beam

Tracking Detectors



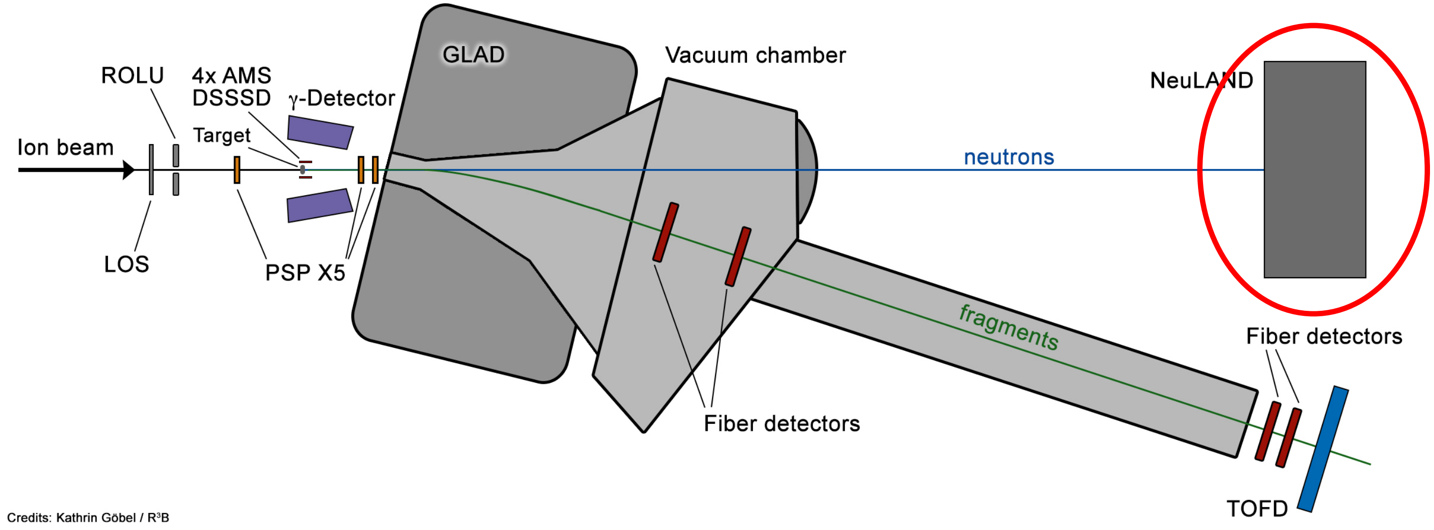
- PSP X5- Position Sensitive Pin diode

Tracking Detectors



- PSP X5- Position Sensitive Pin diode
- Fiber Detectors- 1,024 500 µm fibers

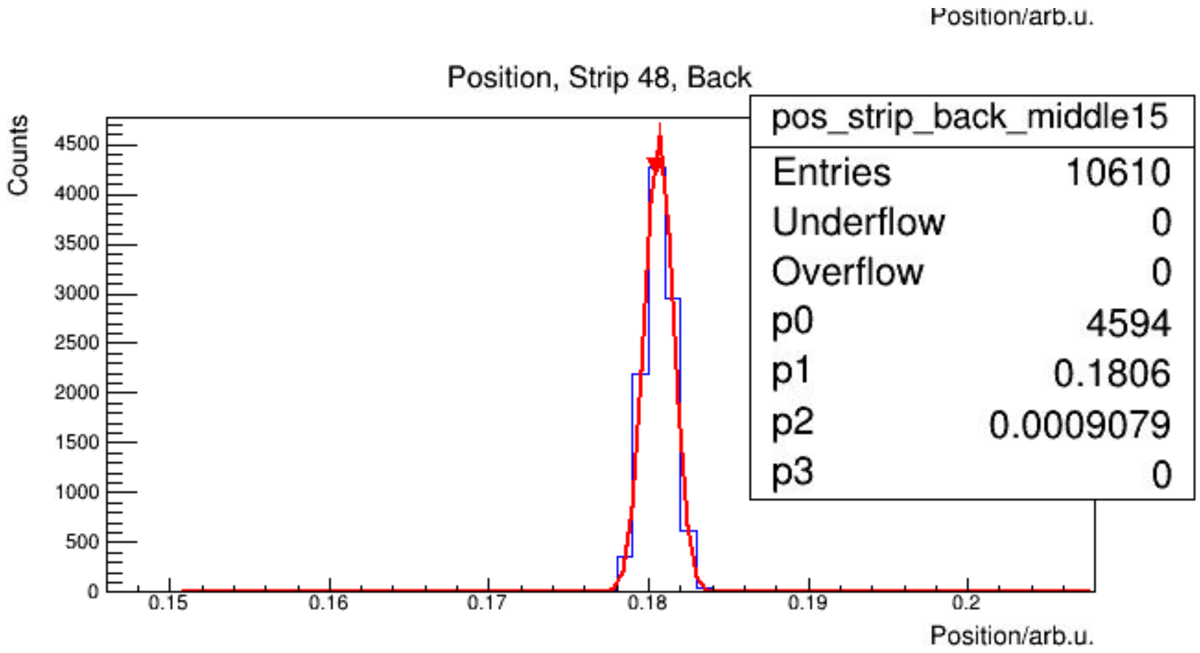
Neutron Detector



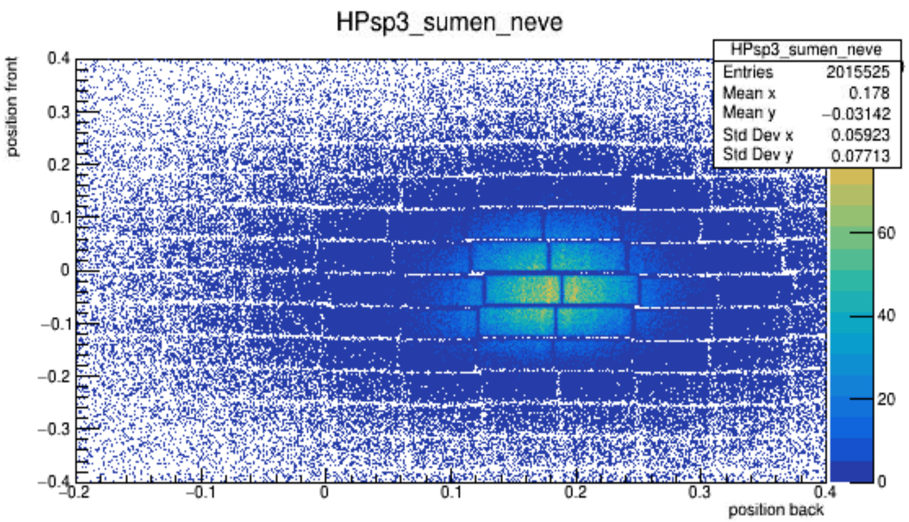
- NeuLAND- New Large Area Neutron Detector
- Fully active plastic scintillator, time resolution of 150 pico seconds, 1 neutron detection efficiency of >95% from 100 to 1000 MeV, multi-hit capabilities (more than 2 neutrons, up to 5),

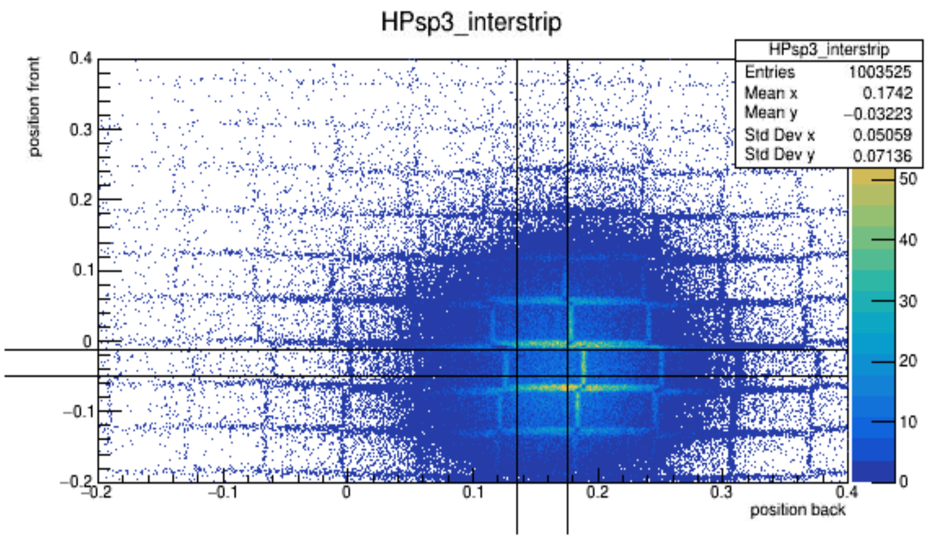
Analysis

Calibration is in 3 steps- position, energy, and conversion

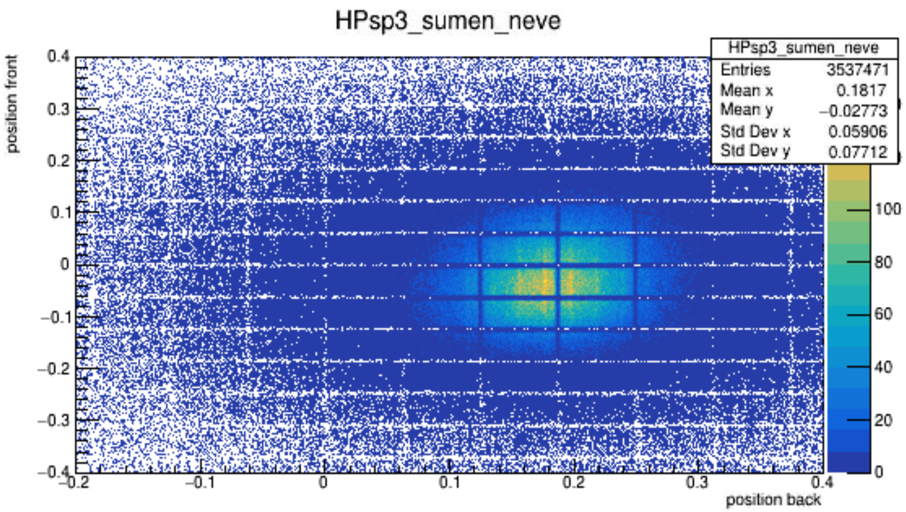


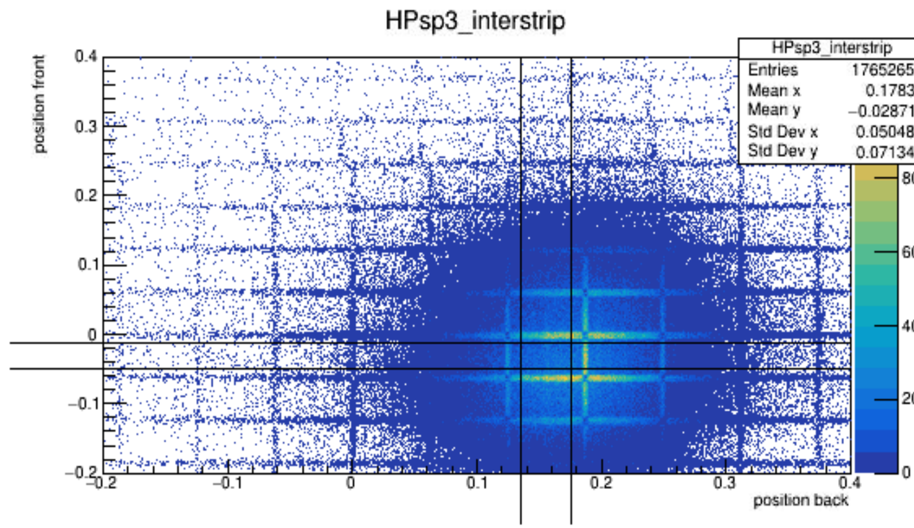
Position Calibration



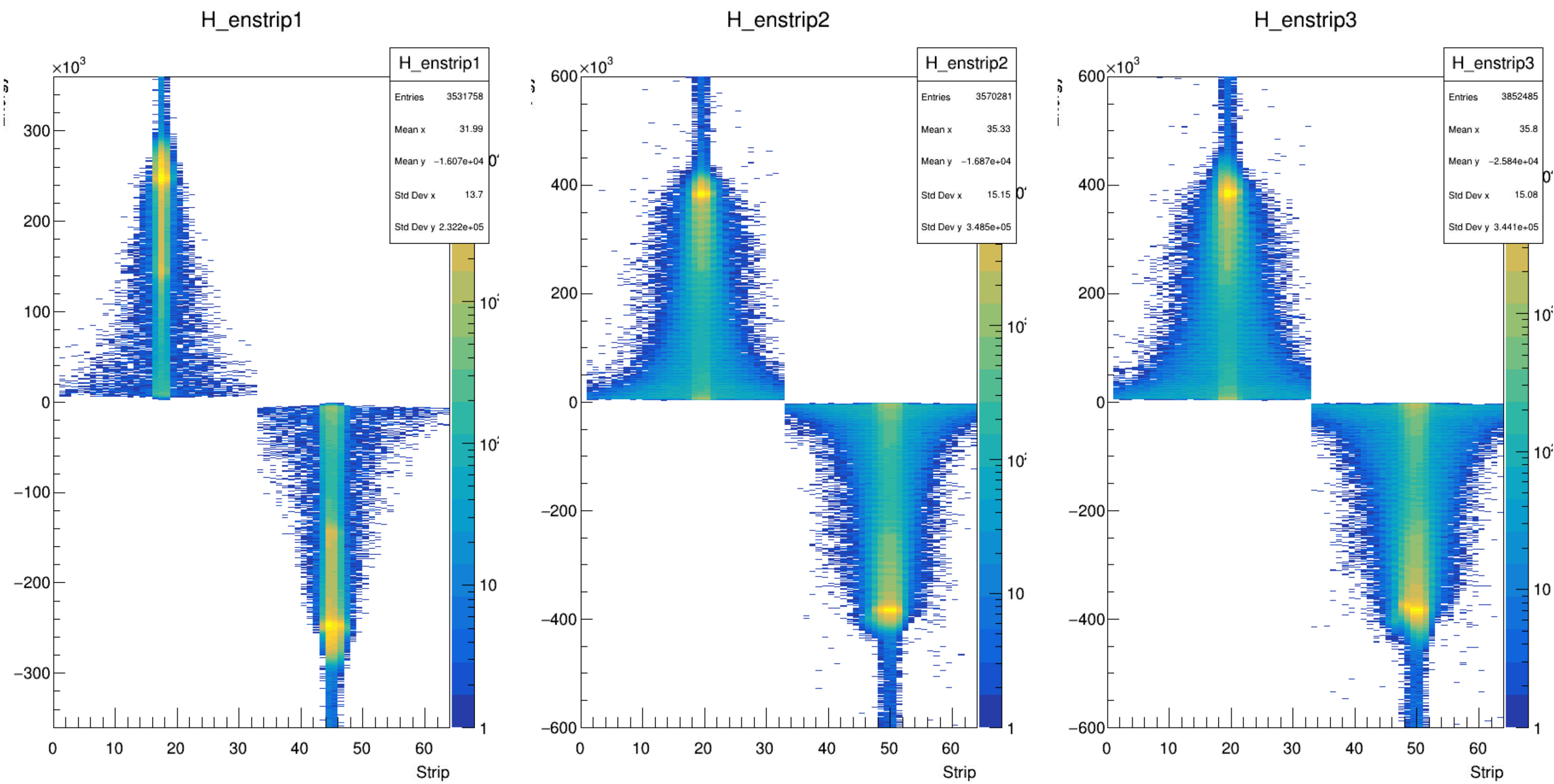


Position Calibration

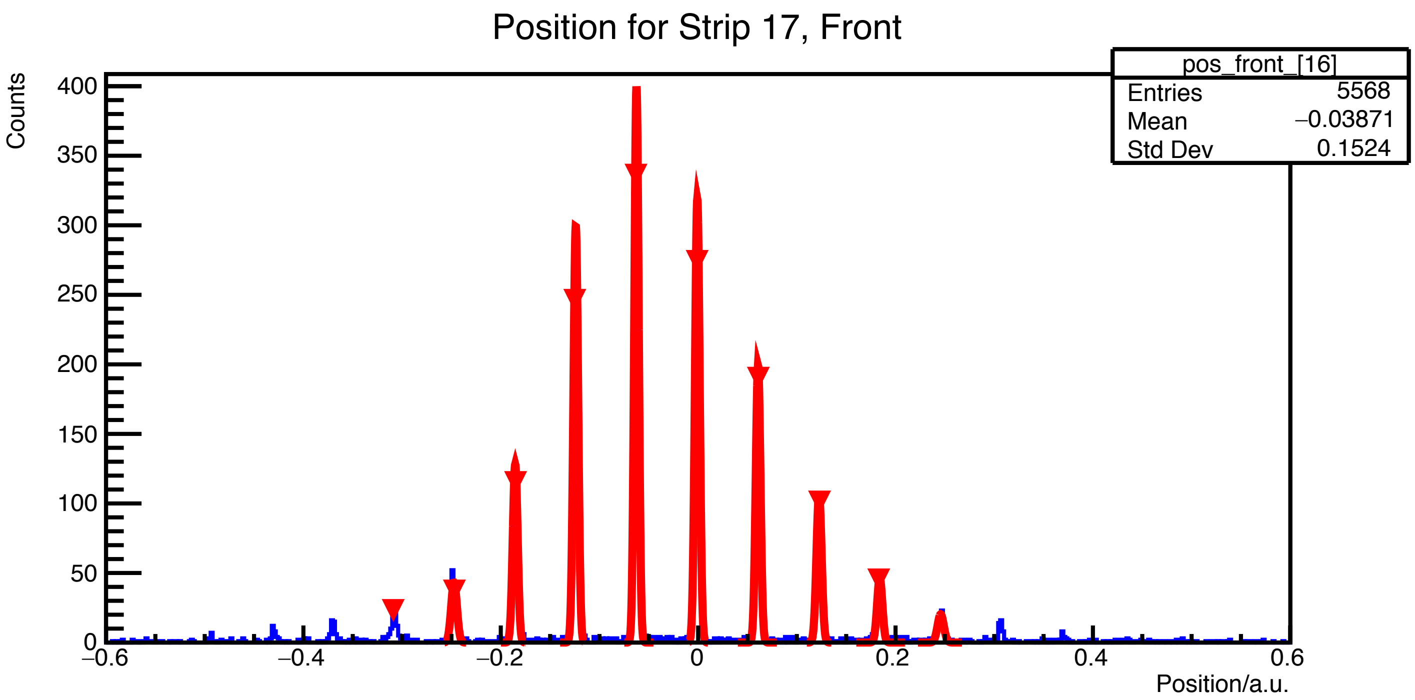




Energy Calibration

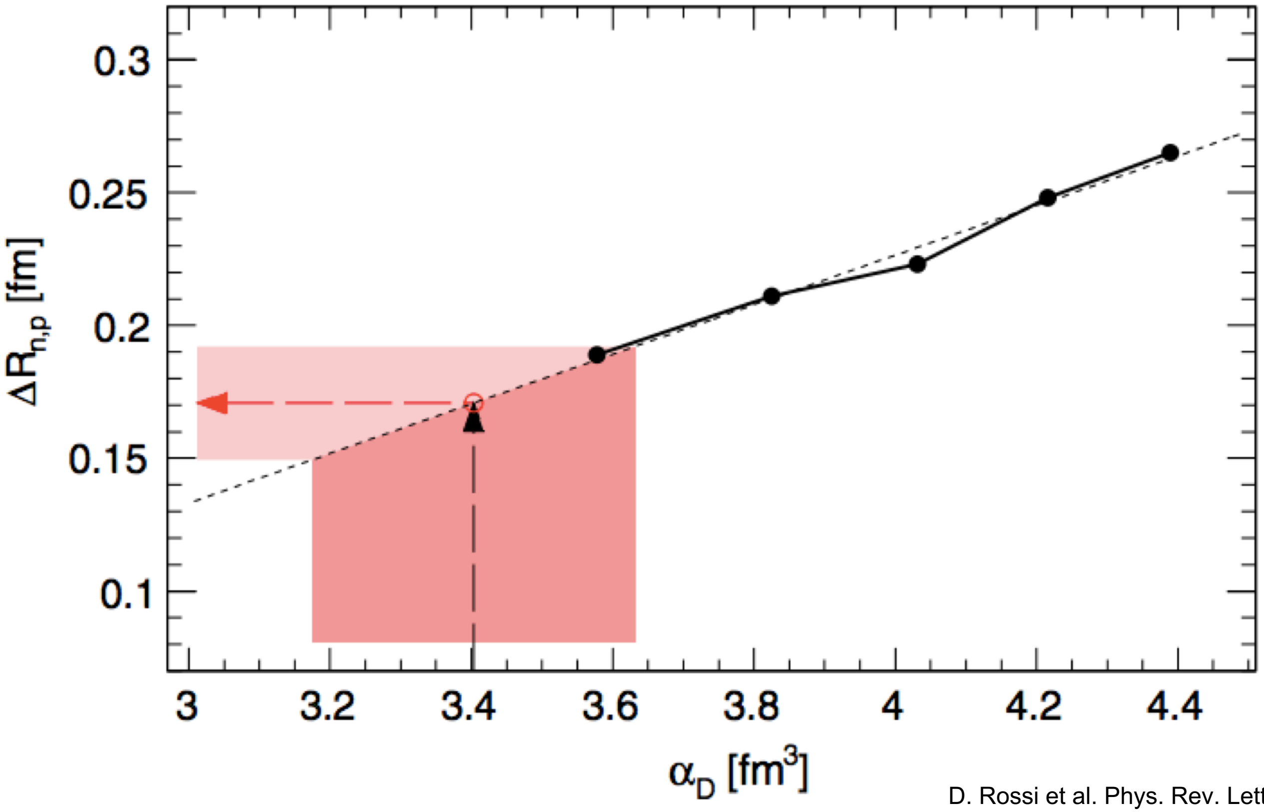


Final "Conversion" Calibration



Previous R³B Constraints

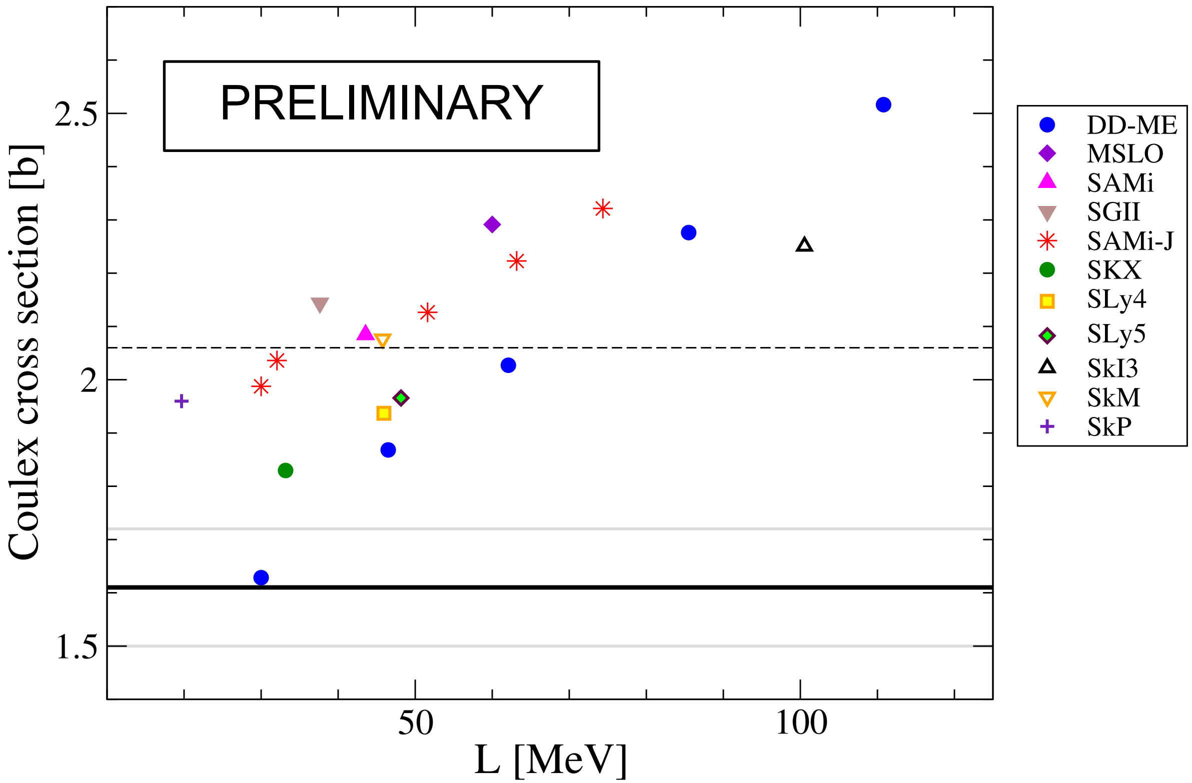
^{68}Ni



D. Rossi et al. Phys. Rev. Letters 111.42503 (2013)

Coulomb Excitation Cross Section

^{132}Sn on Pb target at 514 MeV



A. Horvat, Private Communication

Conclusion

- What we’ve done so far
  - Experiments ran with ^{12}C and ^{120}Sn Beams
  - Nearly calibrated the PSPs from ^{120}Sn data
- Next Steps:
  - Charge Changing Cross section
  - Calibration of the remaining detectors
  - Calculate Neutron-Removal and Total Reaction cross sections
  - Determine ratios from different targets

Questions?

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Thank you for your attention!!!

R3B

GSI

Bundesministerium für Bildung und Forschung

FAIR Phase 0 Research Program

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