Tracking saddle-to-scission dynamics using N/Z in projectile breakup reactions

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CHEMISTRY @ Indiana University

U.S. DEPARTMENT OF ENERGY
Office of Science

INDIANA UNIVERSITY
CENTER FOR EXPLORATION OF ENERGY AND MATTER
Bloomington

Nuclear Equation of State

$$E(\rho,\delta) = E(\rho,\delta=0) + E_{sym}(\rho)\delta^2 \qquad \delta = \frac{\rho_n - \rho_p}{\rho_{Total}}$$

➜ Migration of neutron to low-density region

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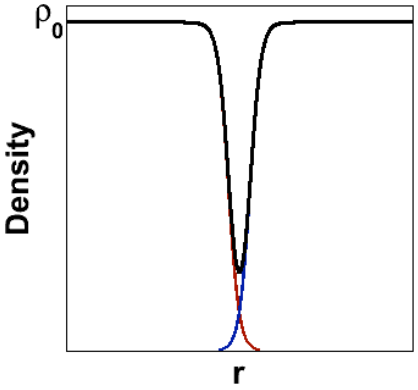

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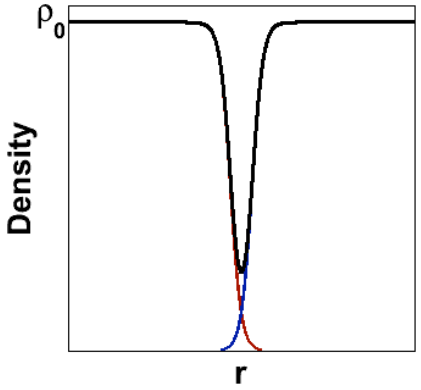

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➜ Observation of n-rich material in overlap region for a **symmetric** system

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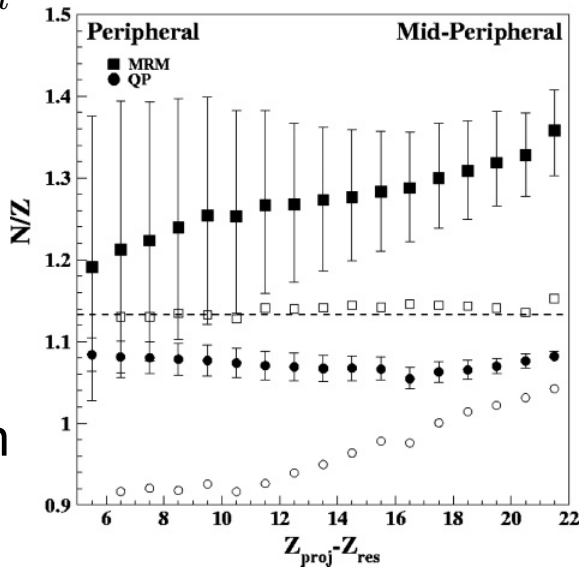

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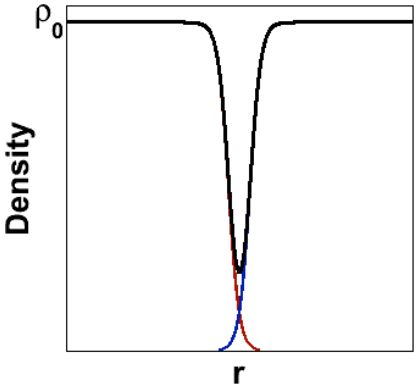

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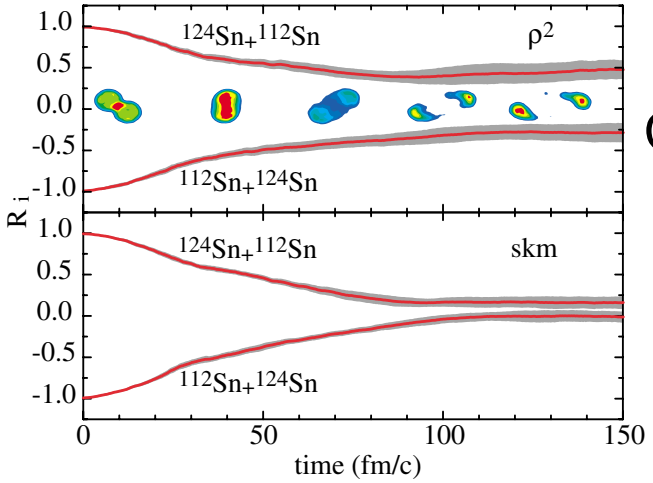

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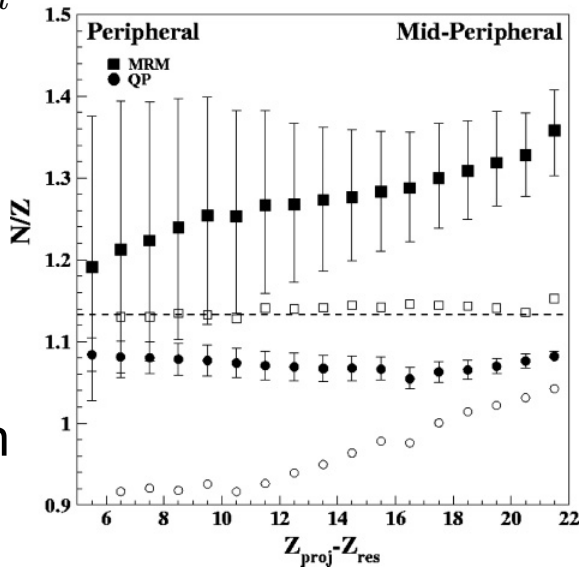

Collisions of N/Z asymmetric nuclei

➜ Short times

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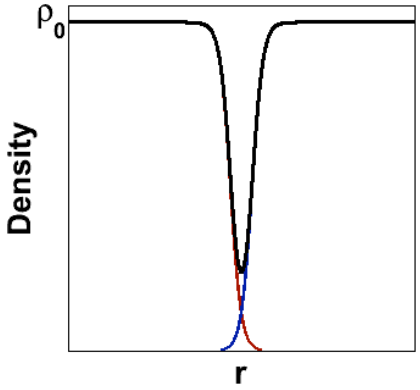

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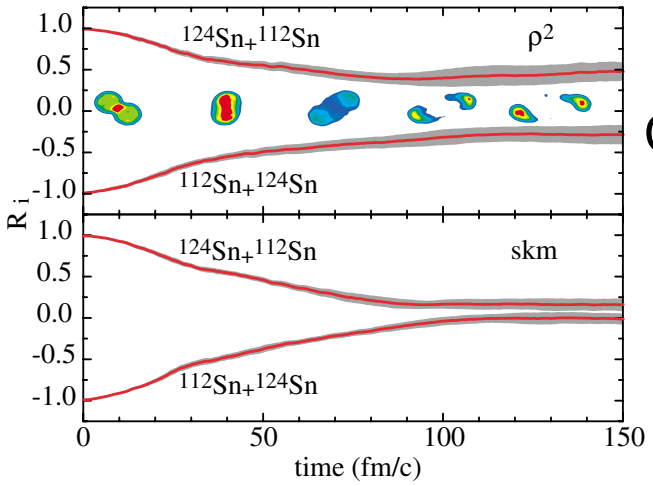

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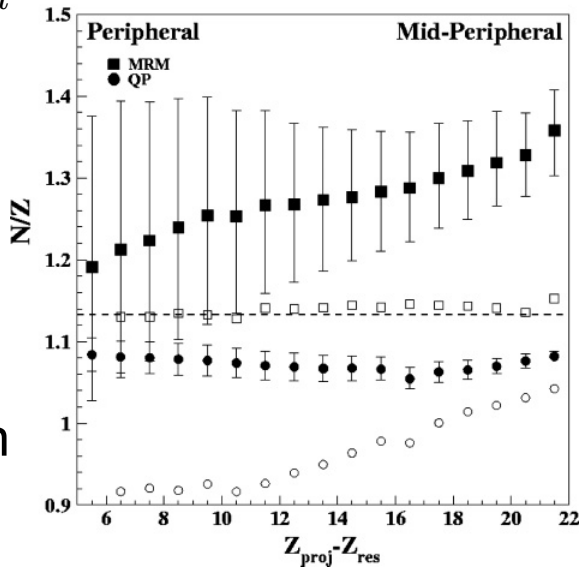

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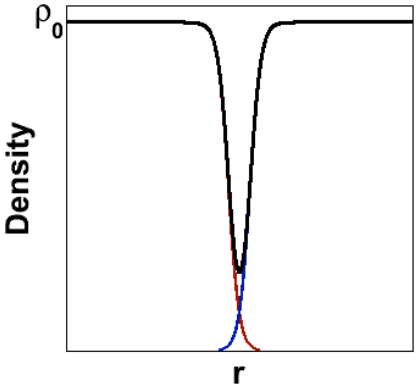

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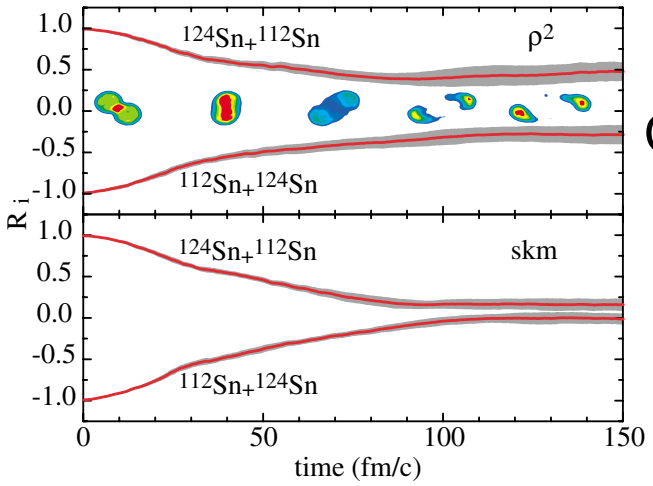

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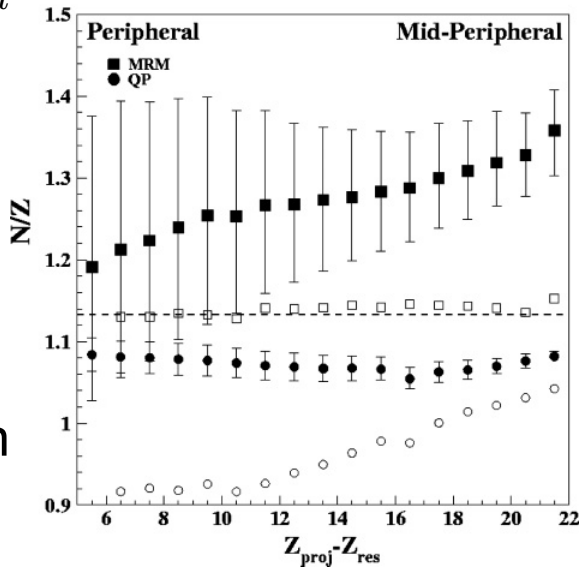

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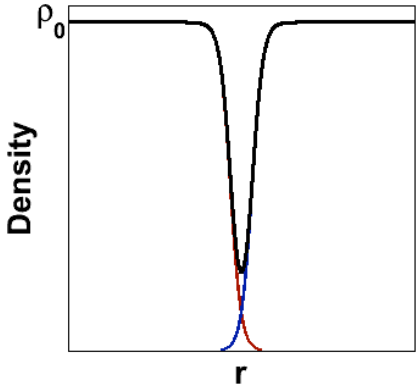

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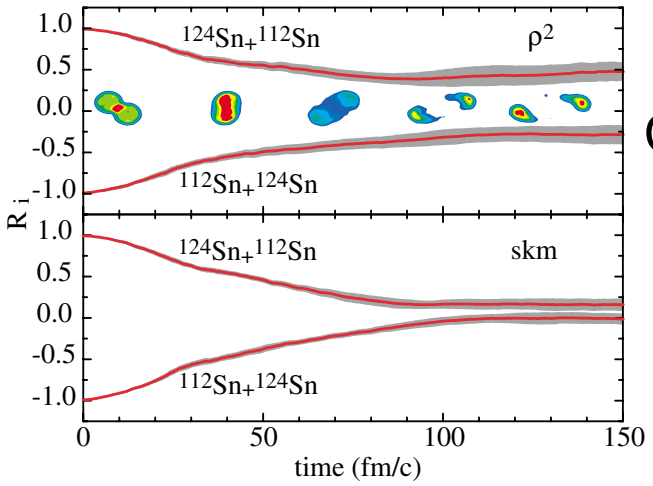

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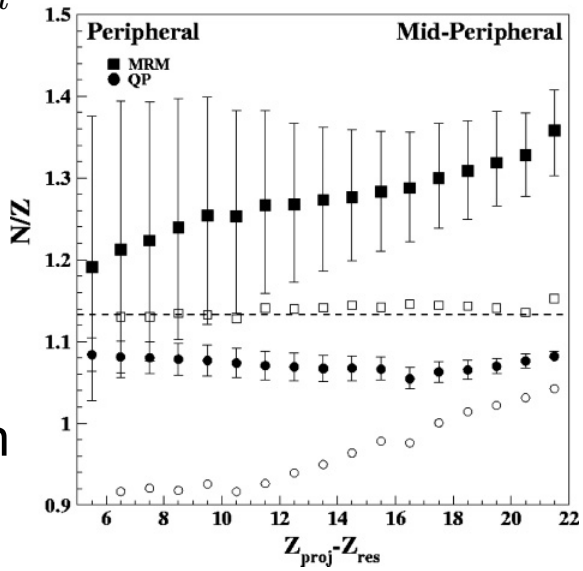

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➜ **Binary decay of PLF***

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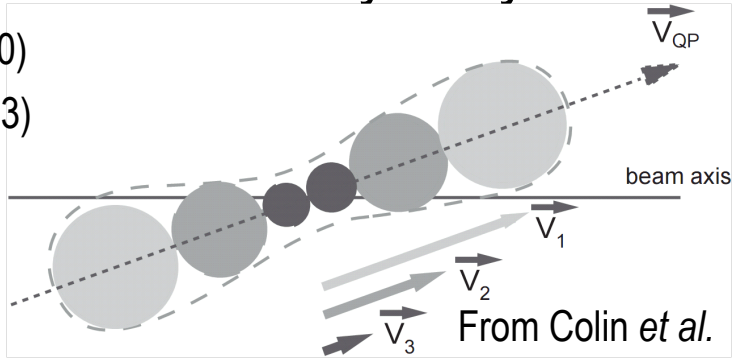

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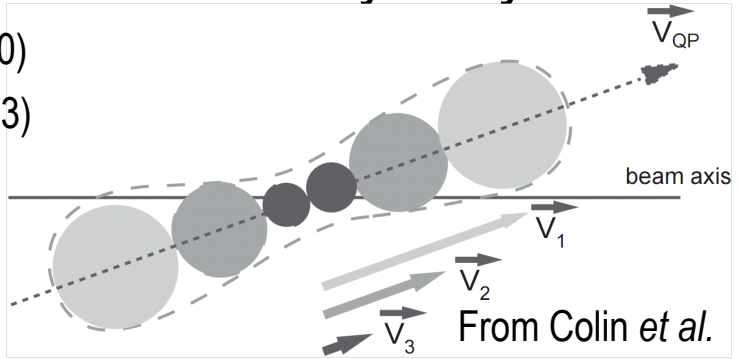

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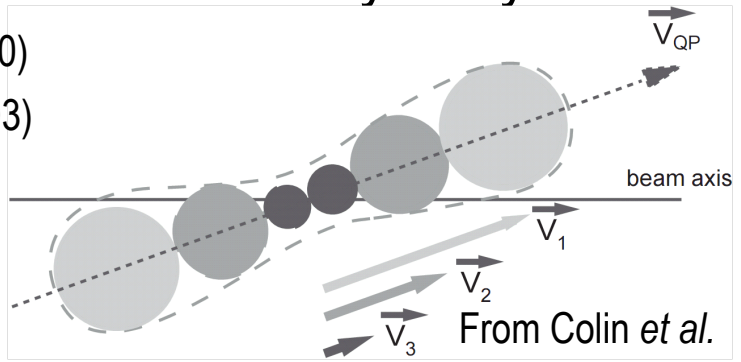

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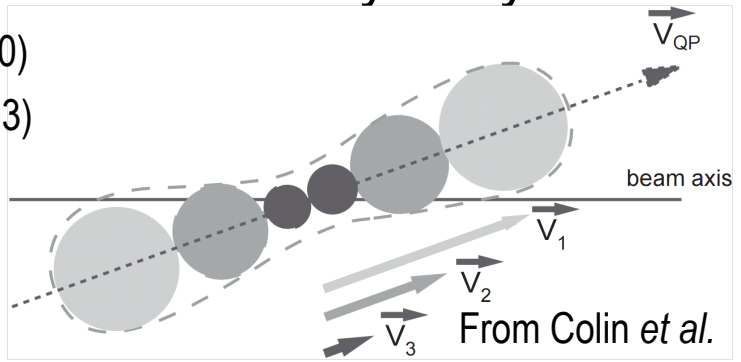

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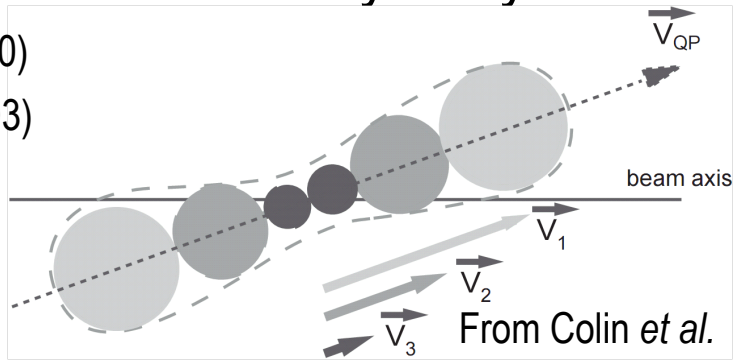

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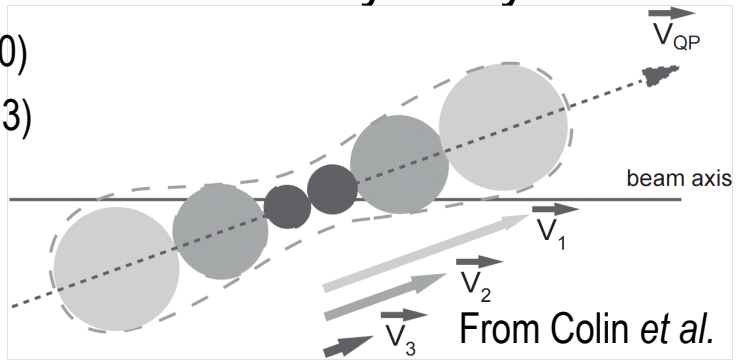

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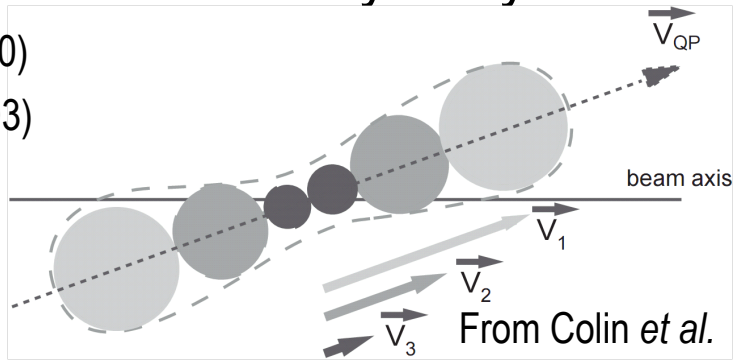

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- The system is not in close proximity with the target but could be influenced by the target Coulomb field

Experimental Setup

$^{124(,136)}Xe + {}^{112,124}Sn$ @ 49.2 MeV/A

Experiment performed at GANIL (France)

N/Z

^{124}Xe	^{124}Sn	^{112}Sn
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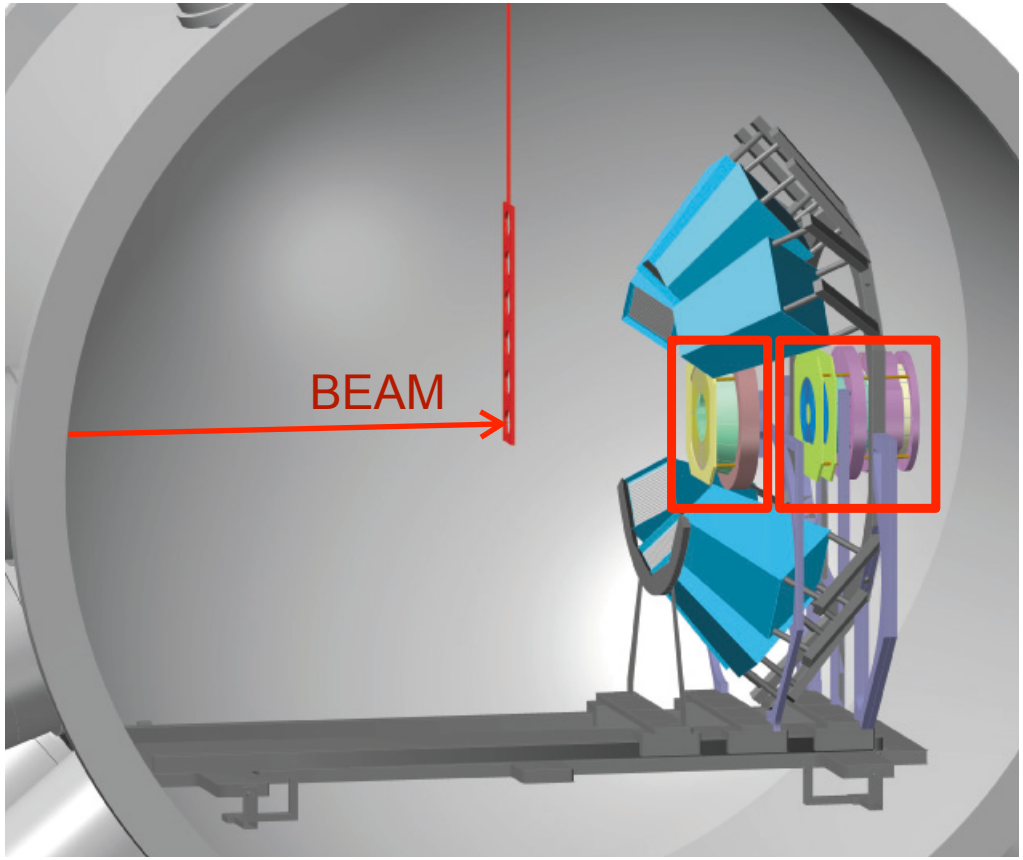

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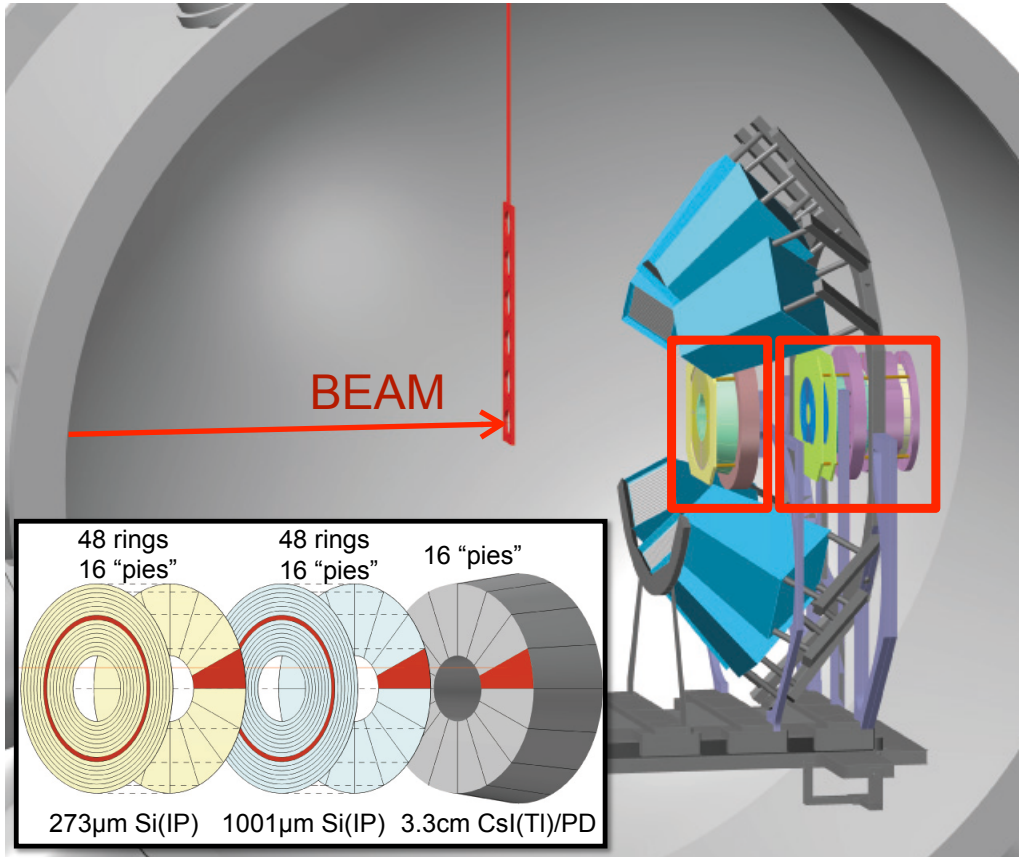

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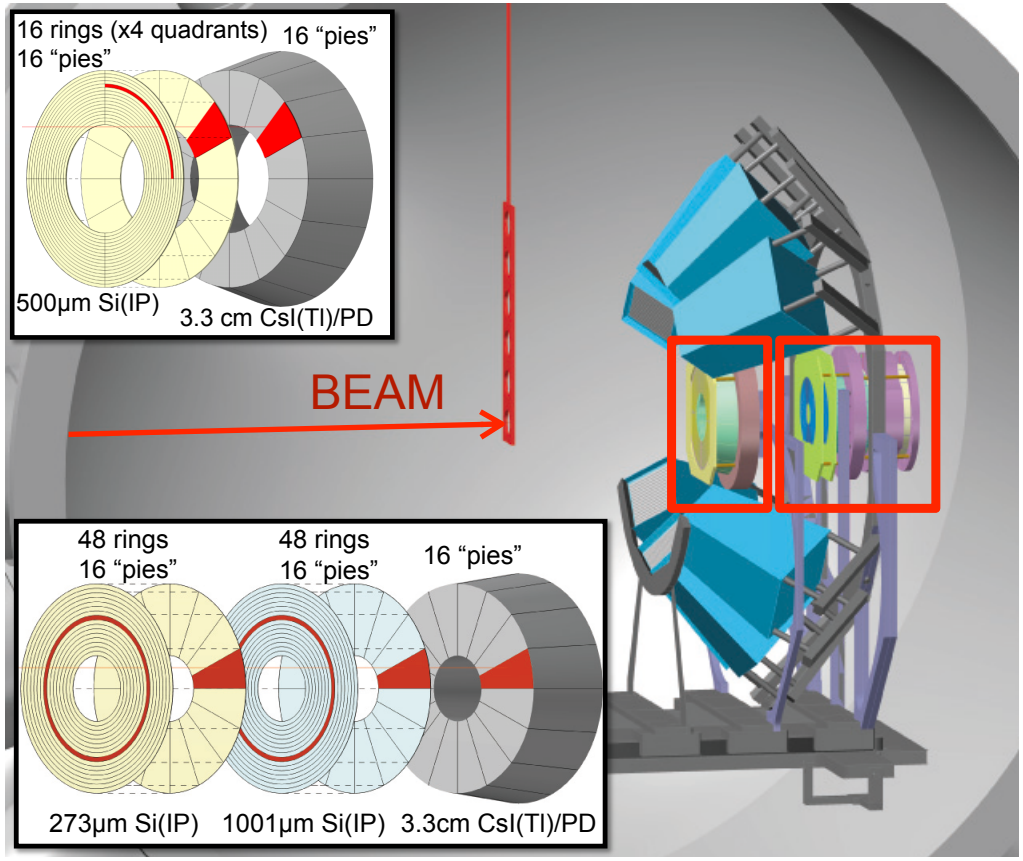

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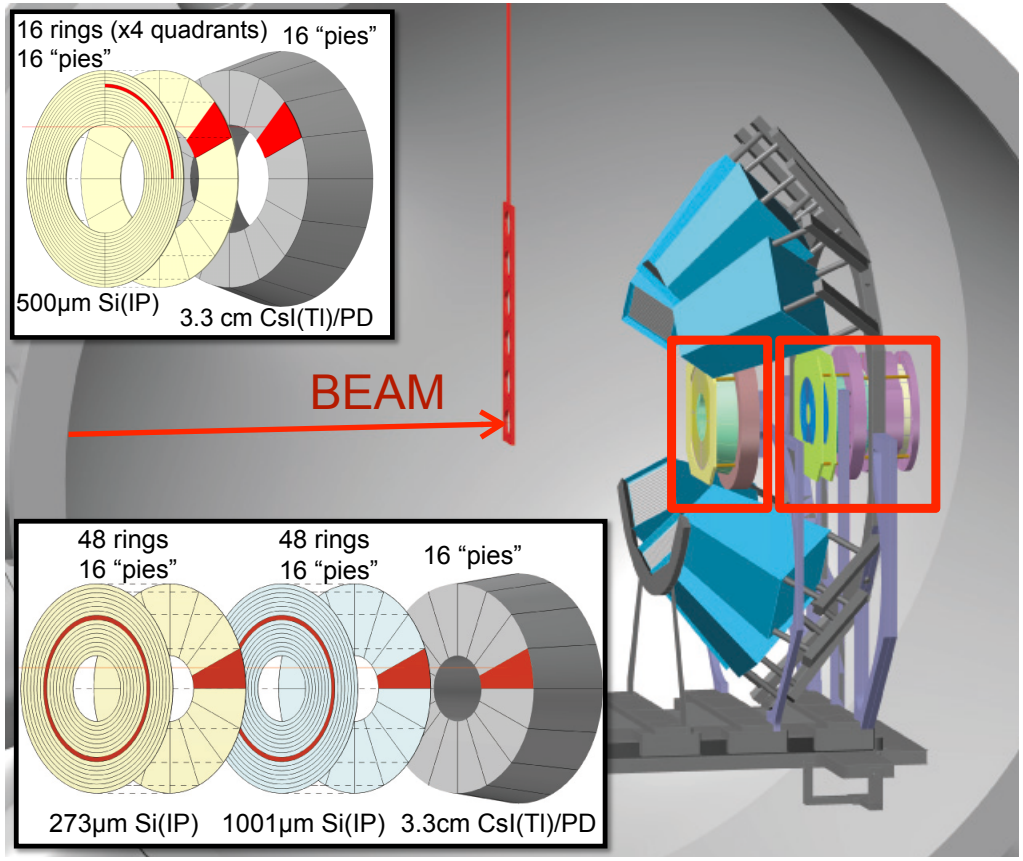
- DEMON: n TOF



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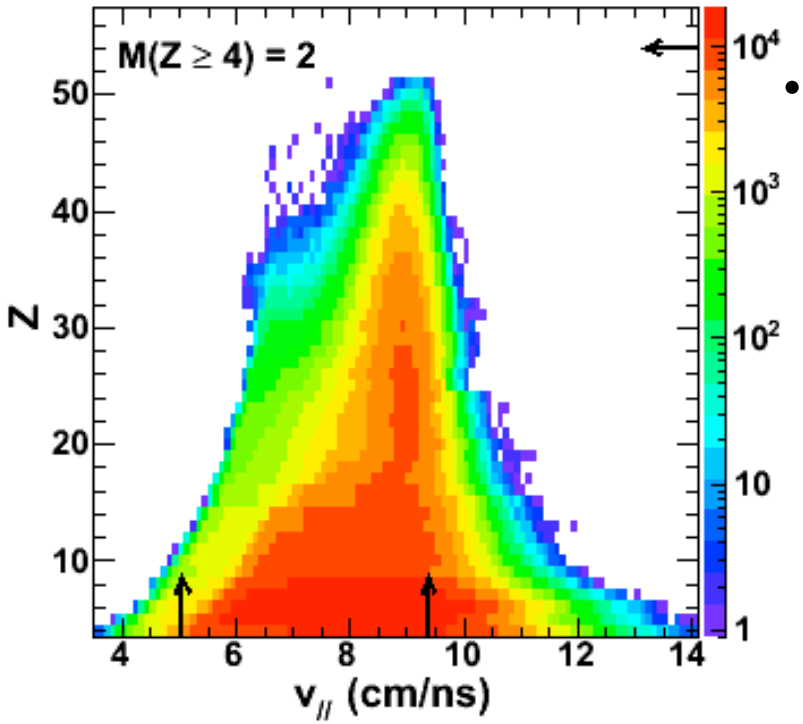

- Two fragment events characterized by large remanent PLF

A.B. McIntosh, PhD Thesis, Indiana University, 2010
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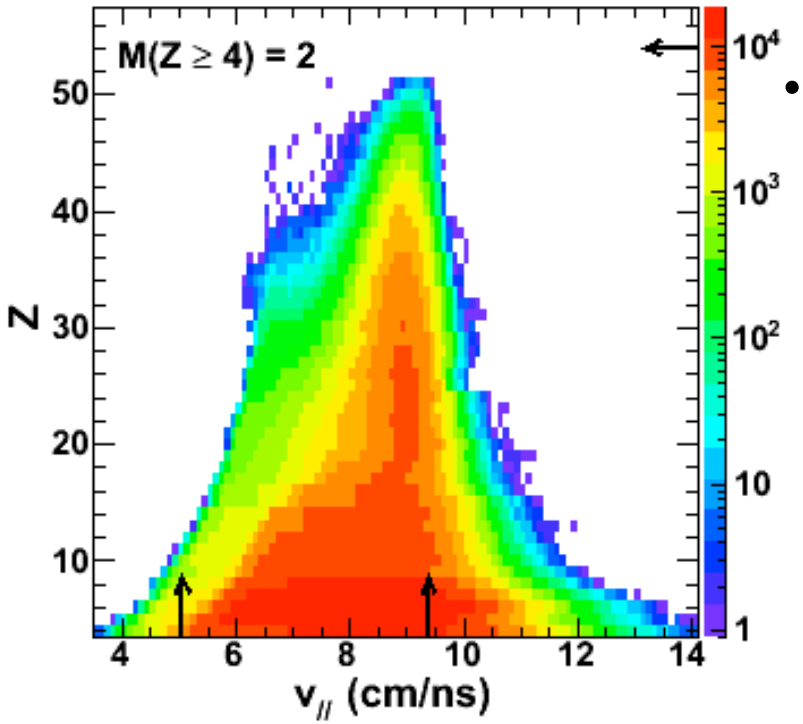

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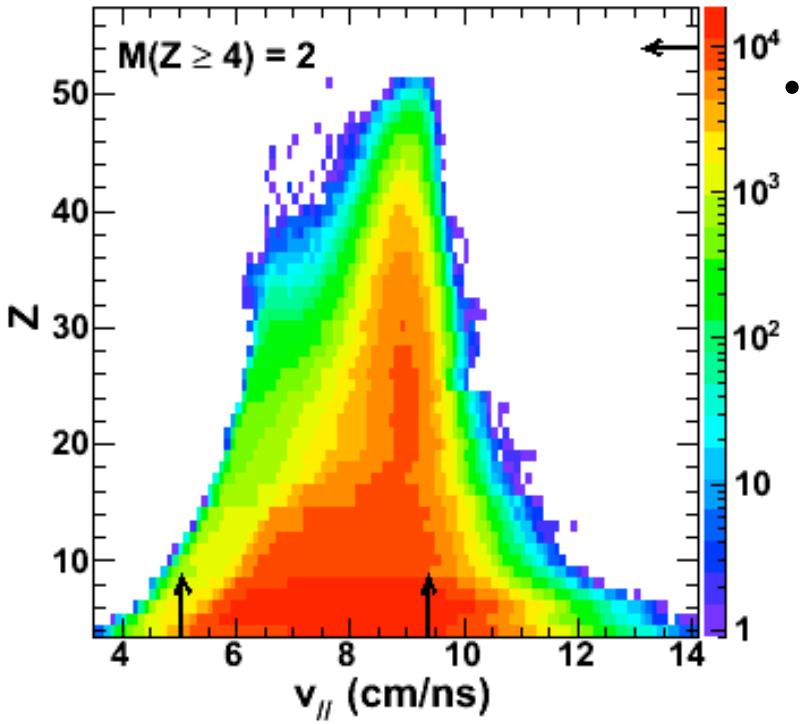

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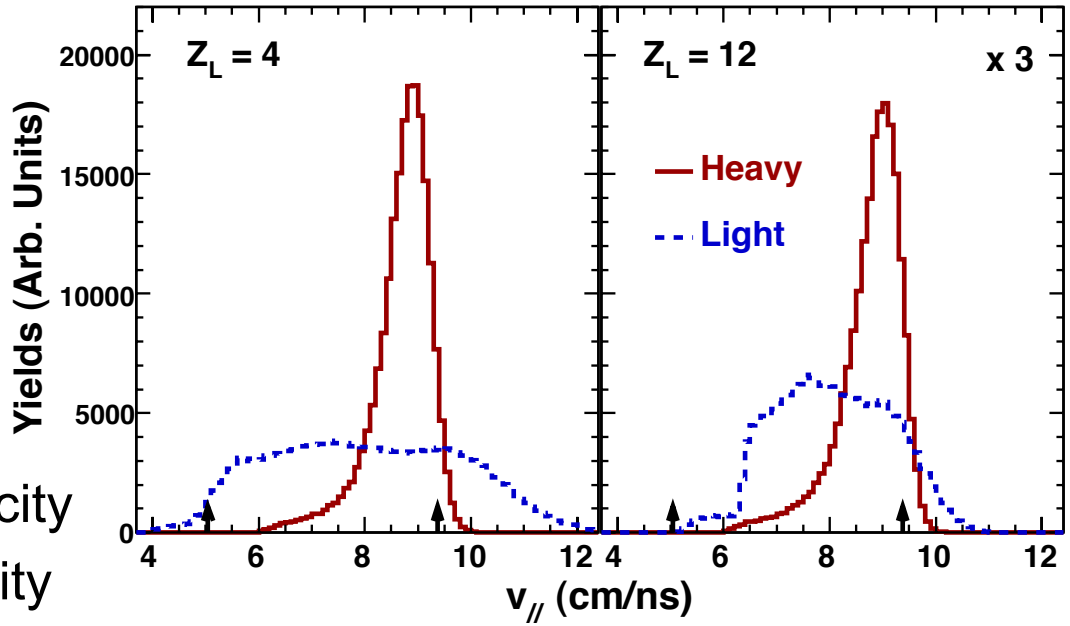

- Heavy fragment near beam velocity
- Light fragment **NOT** at mid-rapidity

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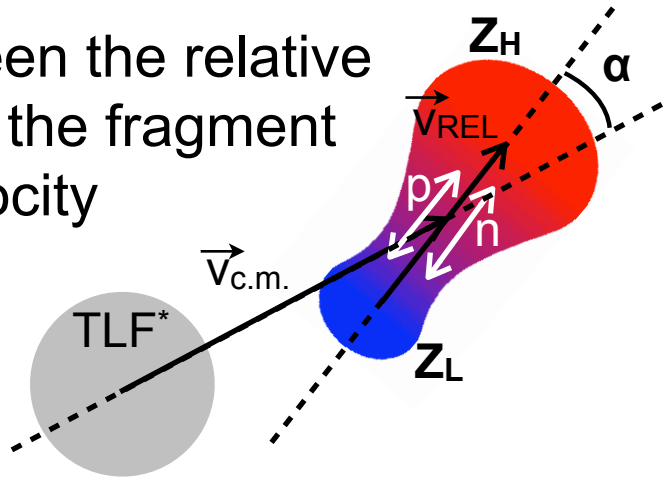
Aligned Decay

Angle between the relative velocity and the fragment "parent" velocity



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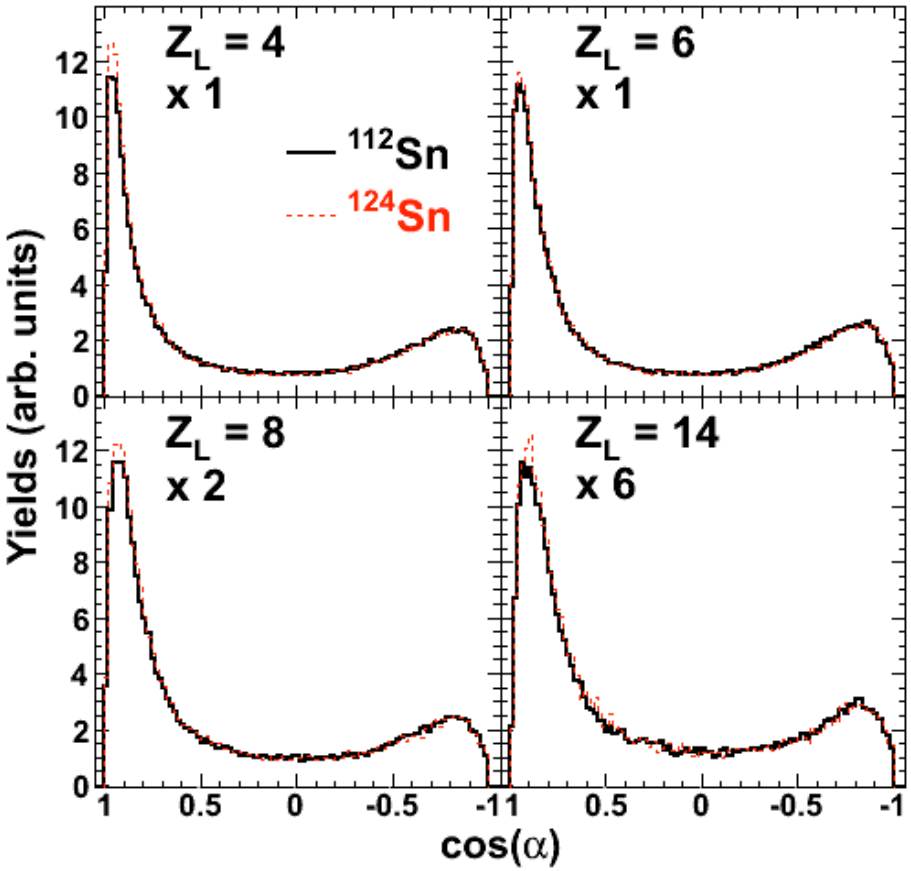

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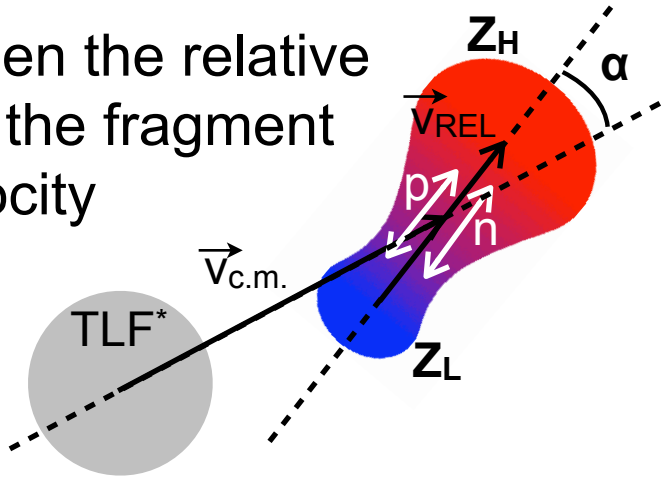

- Asymmetric angular distributions
- Larger asymmetry for lighter Z_L
- Asymmetry persists up to Z_L = 18
- Distributions similar for n-rich target

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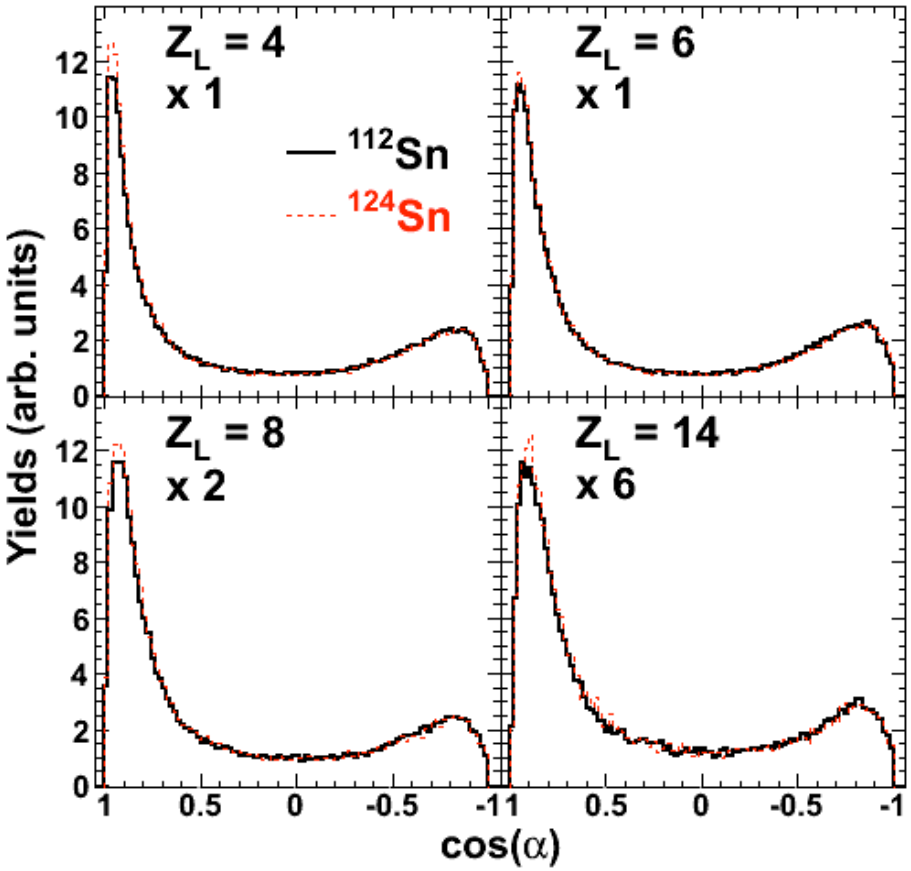
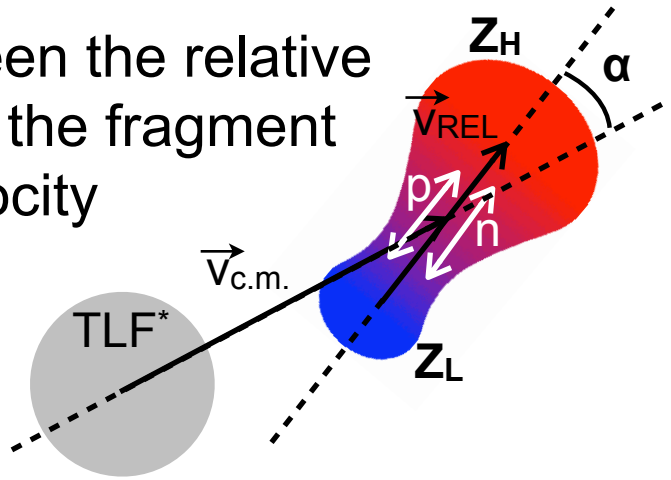
^{124}Xe + Sn



Angle between the relative velocity and the fragment "parent" velocity

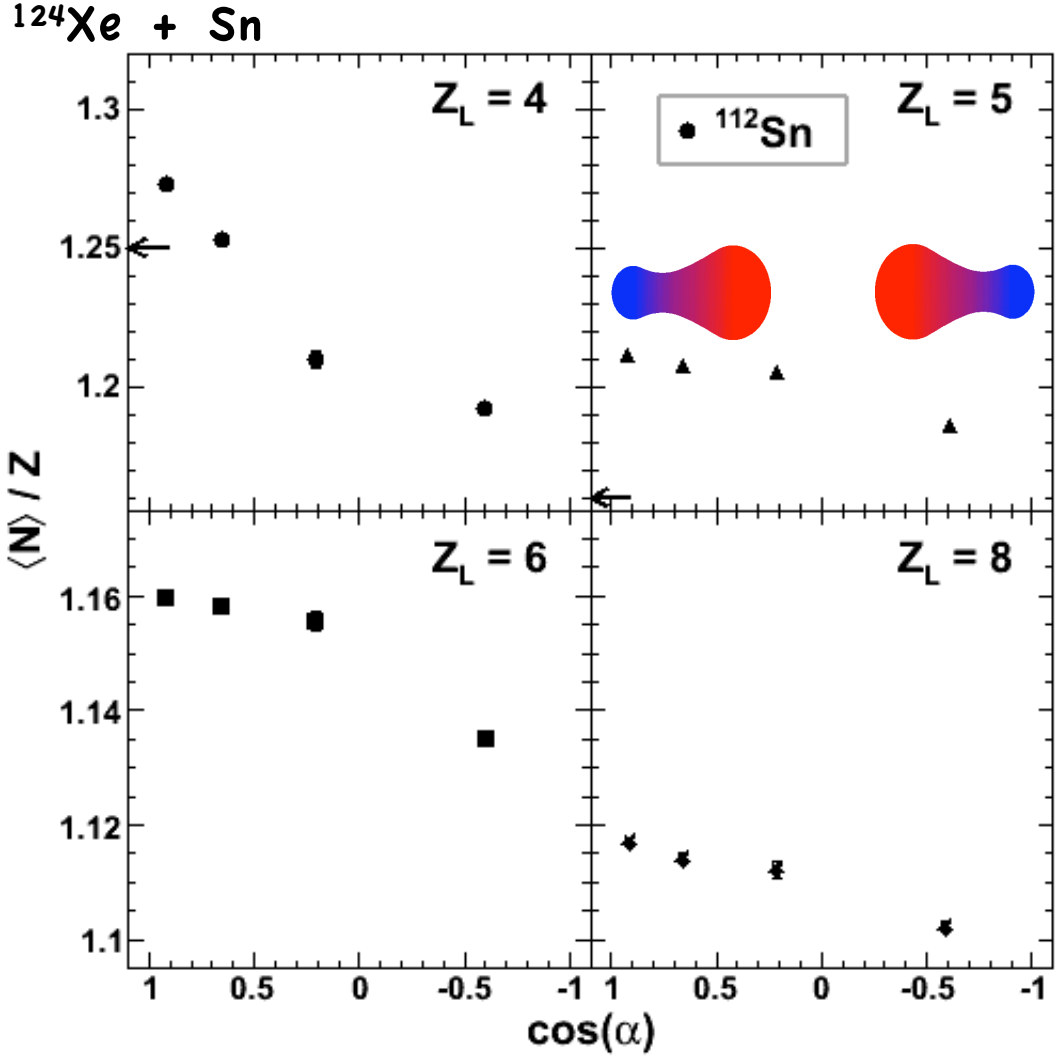


- Asymmetric angular distributions
- Larger asymmetry for lighter Z_L
- Asymmetry persists up to Z_L = 18
- Distributions similar for n-rich target

✎ *Backward enhancement observed in Sn+Ni for change of target and projectile**

*^{112}Sn + ^{58}Ni & ^{124}Sn + ^{64}Ni:
P. Russotto *et al.*, PRC **81**, 064605 (2010)

Isotopic Composition vs Rotation Angle



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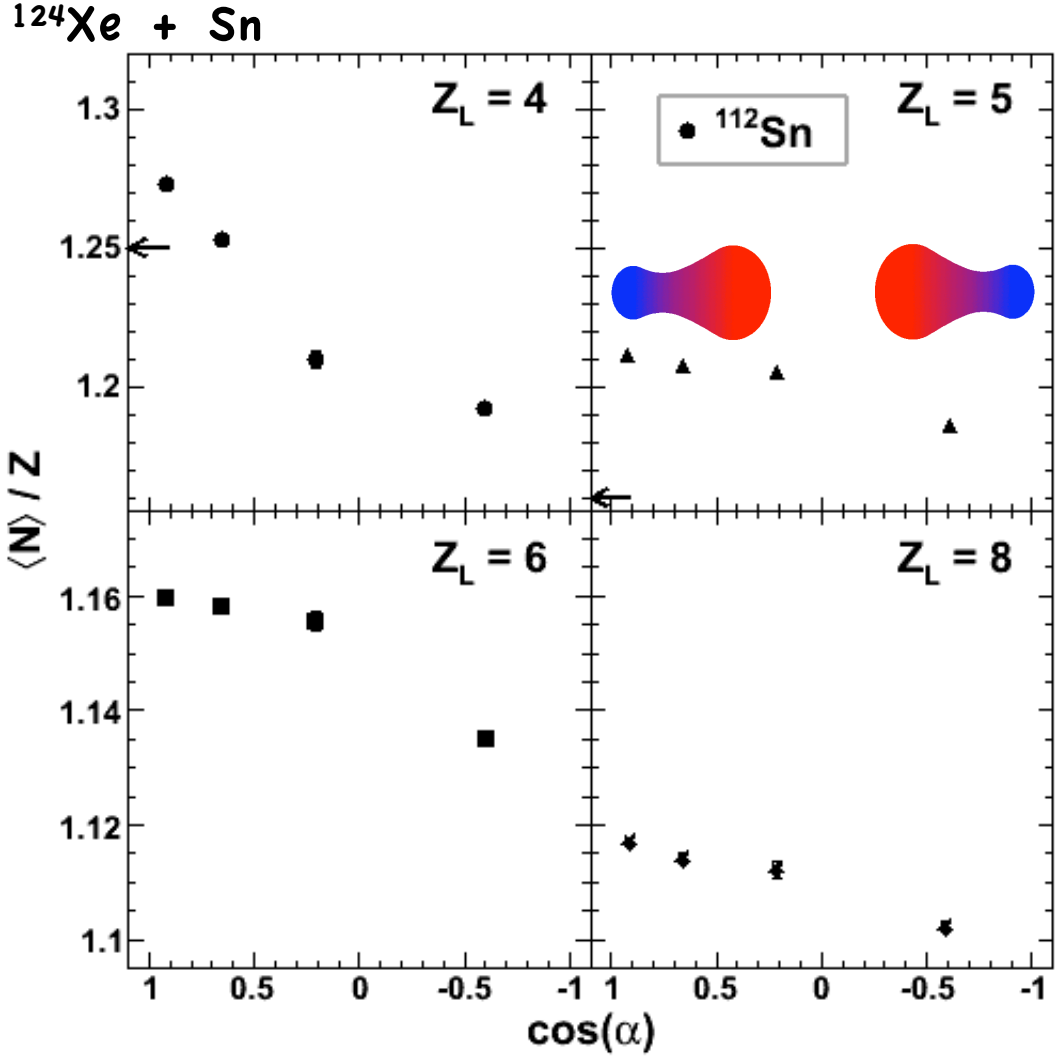

- Backward emission neutron-rich relative to forward emission

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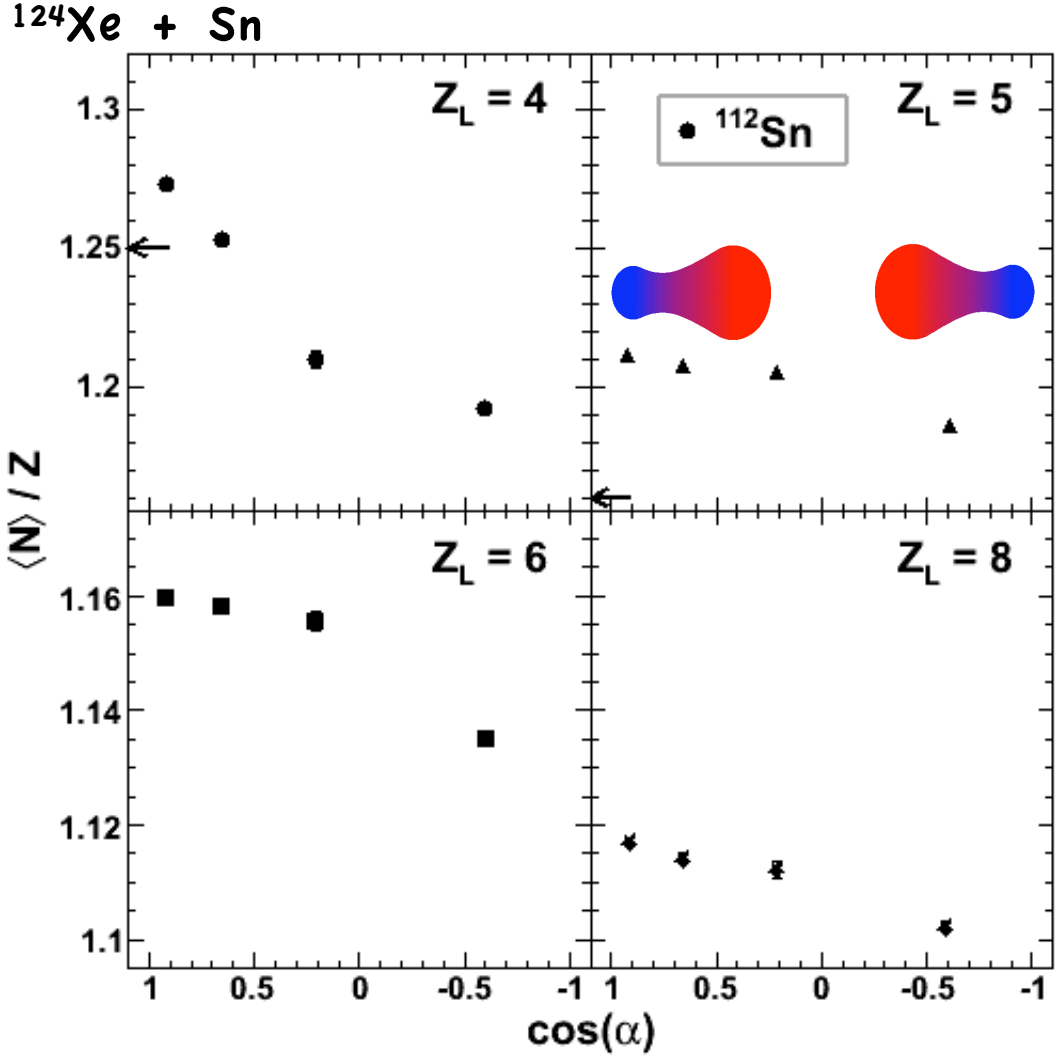

- Backward emission neutron-rich relative to forward emission
- Fragment neutron content enhanced for larger alignment

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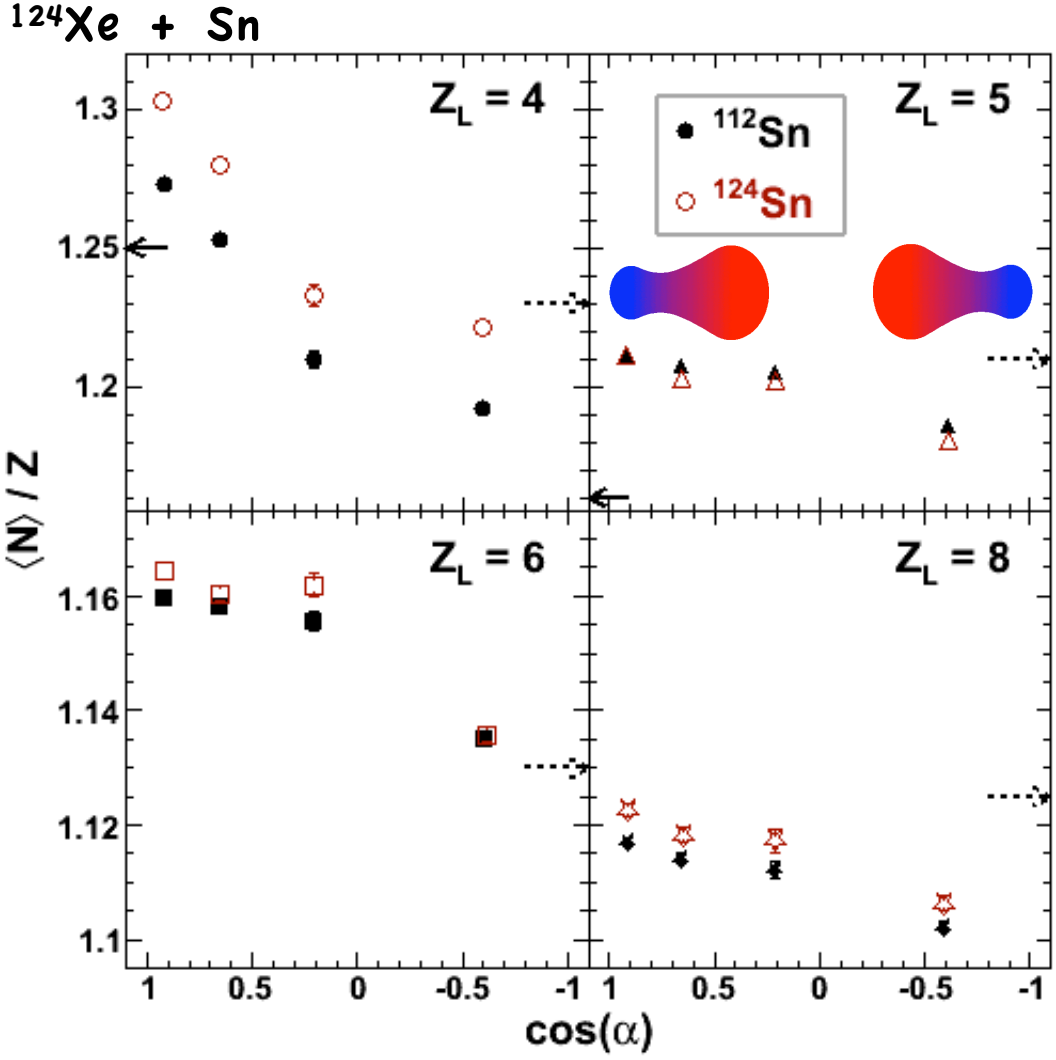
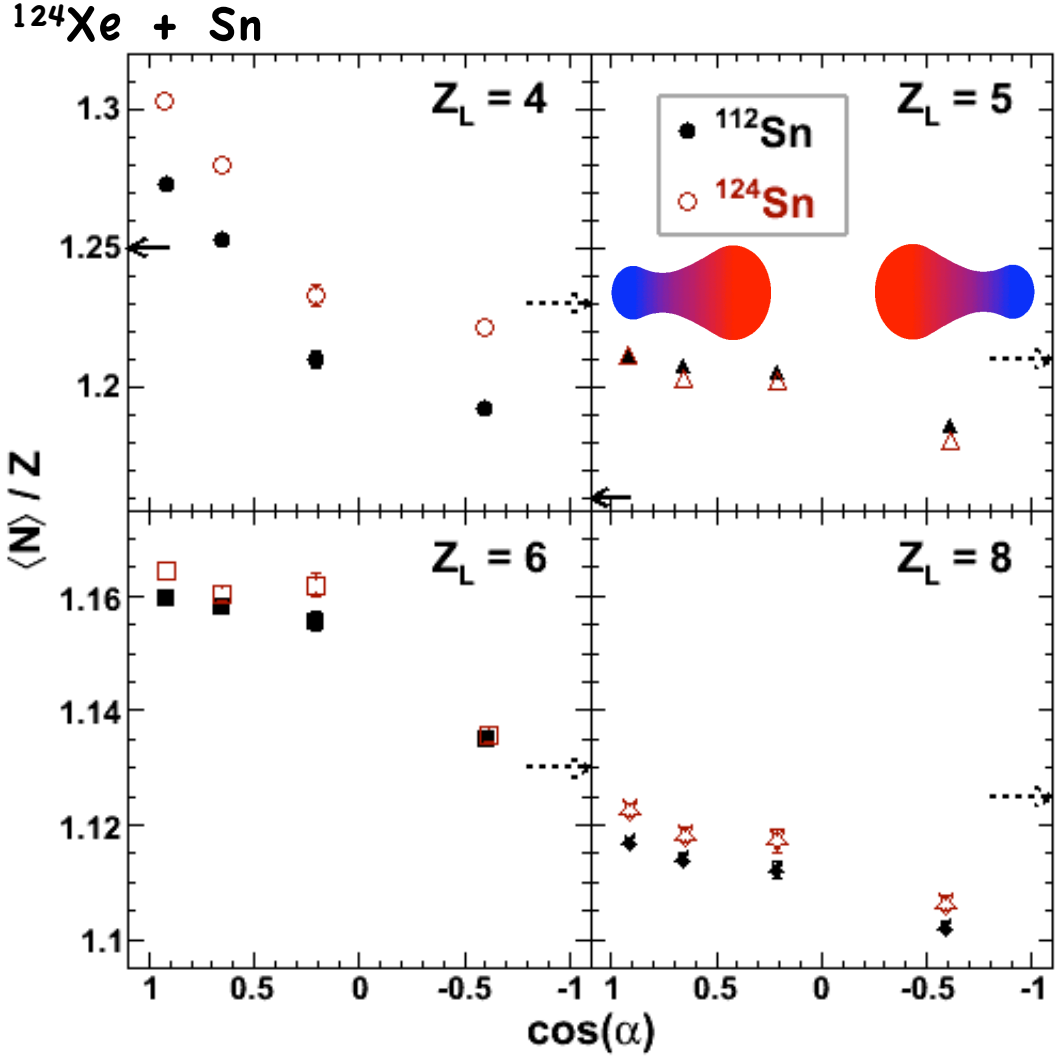


- Backward emission neutron-rich relative to forward emission
- Fragment neutron content enhanced for larger alignment
- Small target effect on the relative neutron composition

	^{124}Xe	^{124}Sn	^{112}Sn
N/Z	1.30	1.48	1.24

Isotopic Composition vs Rotation Angle



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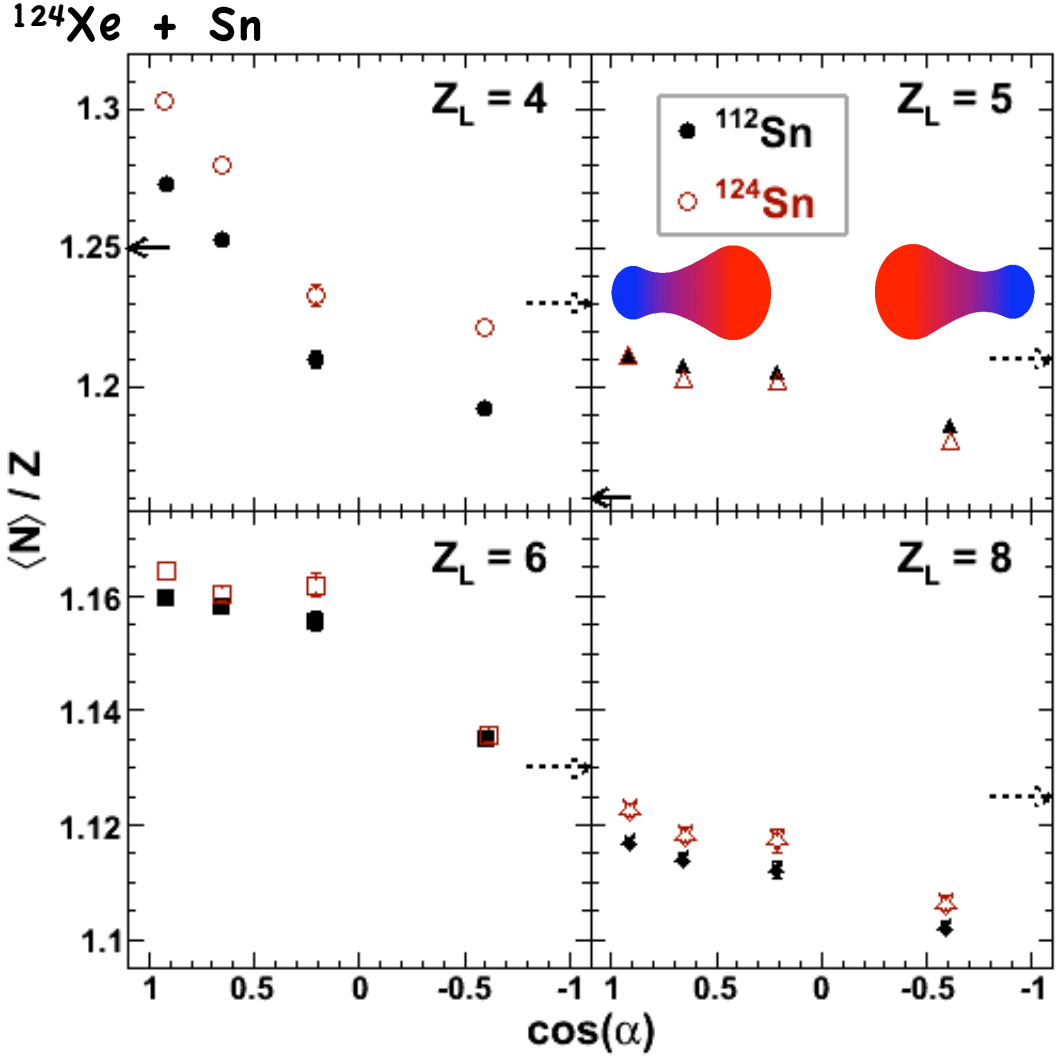


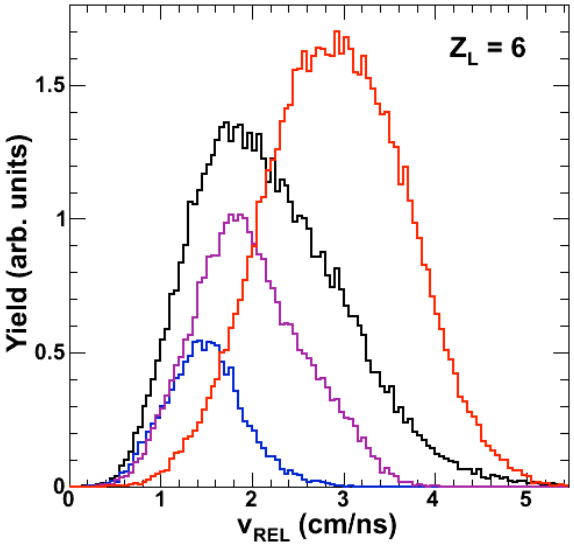
- Backward emission neutron-rich relative to forward emission
- Fragment neutron content enhanced for larger alignment
- Small target effect on the relative neutron composition
- Similar ⟨N⟩/Z observed in ^{124}Sn fragmentation @ 600 MeV/A*
- Same trend observed for Z=5-8 for ^{124}Sn + ^{64}Ni @ 35 MeV/A©

	^{124}Xe	^{124}Sn	^{112}Sn
N/Z	1.30	1.48	1.24

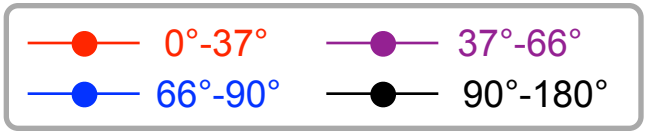
*: C. Sfienti *et al.*, PRL **102**, 152701 (2009)

©: E. De Filippo *et al.*, Phys. Rev. C **86**, 014610 (2012)

Relative Velocity Dependence



- Larger v_{REL} observed for larger alignment



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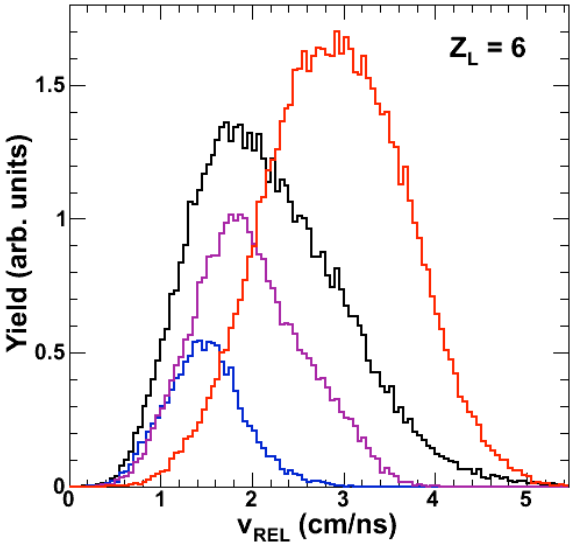

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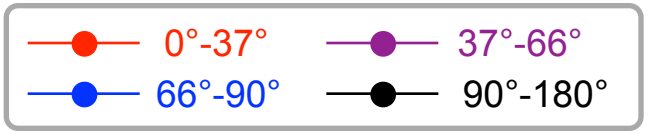

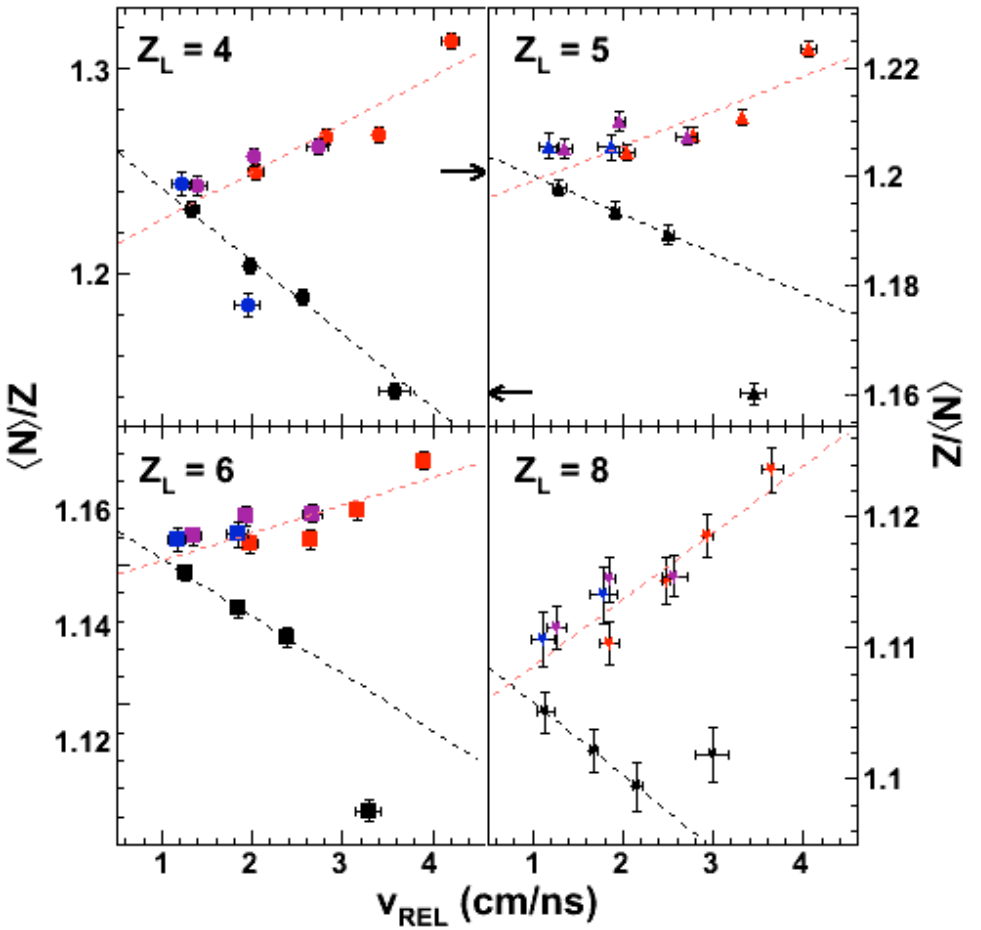

- ⟨N⟩/Z decreases with v_{REL} for forward decay (Coulomb effect)
- ⟨N⟩/Z increases with v_{REL} for backward decay

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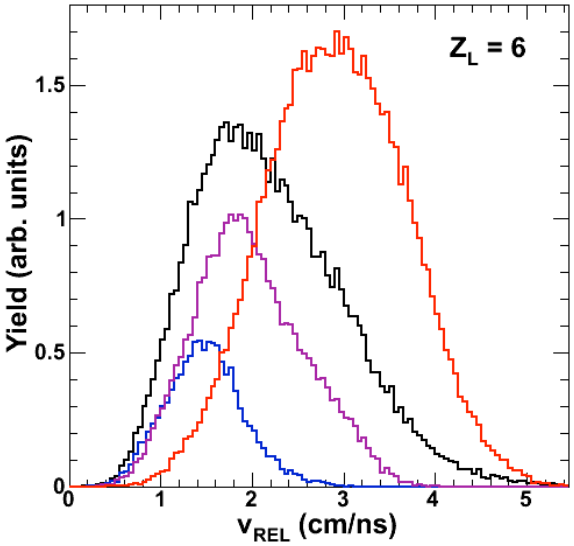

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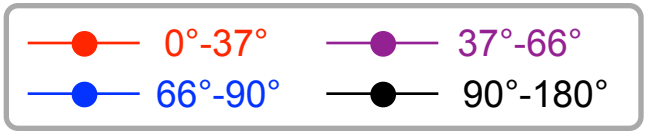
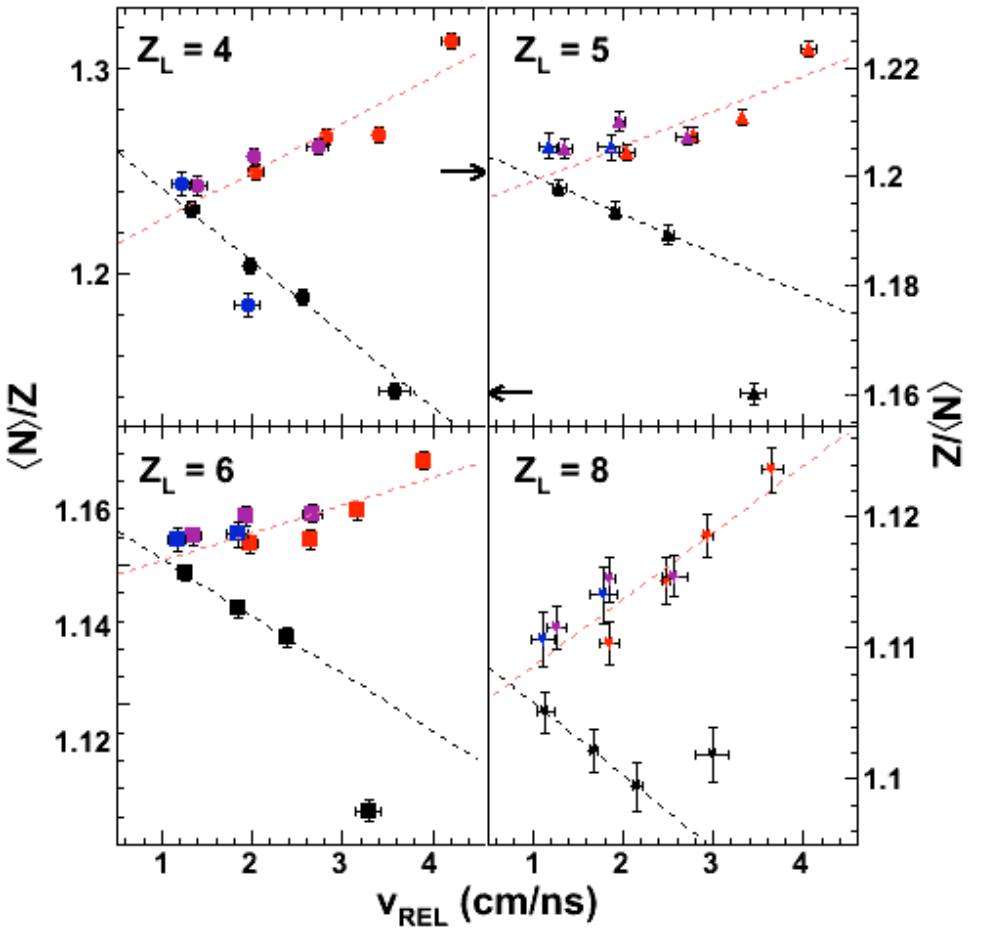
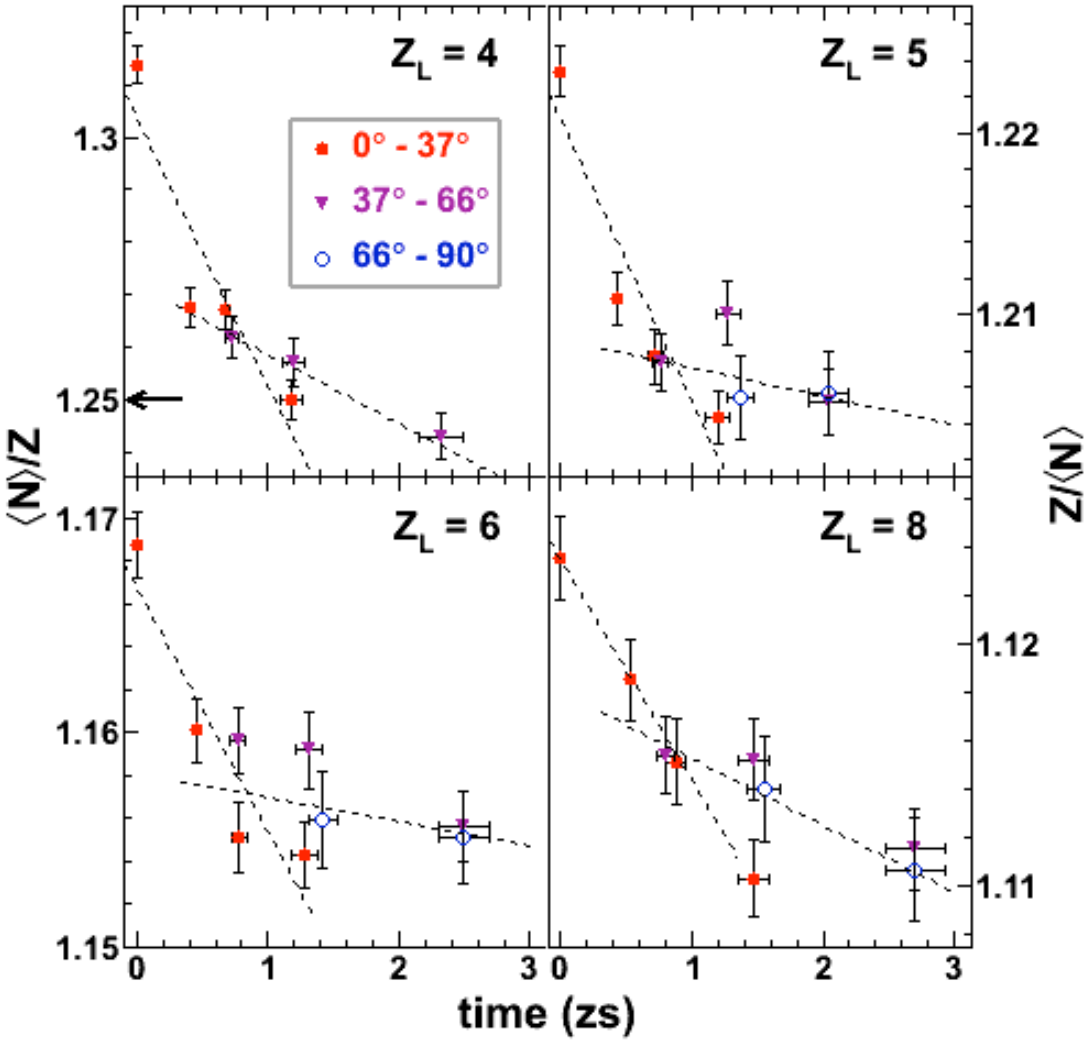




- ⟨N⟩/Z decreases with v_{REL} for forward decay (Coulomb effect)
- ⟨N⟩/Z increases with v_{REL} for backward decay
- All backward decays show the same dependence with v_{REL}

N/Z Time Dependence

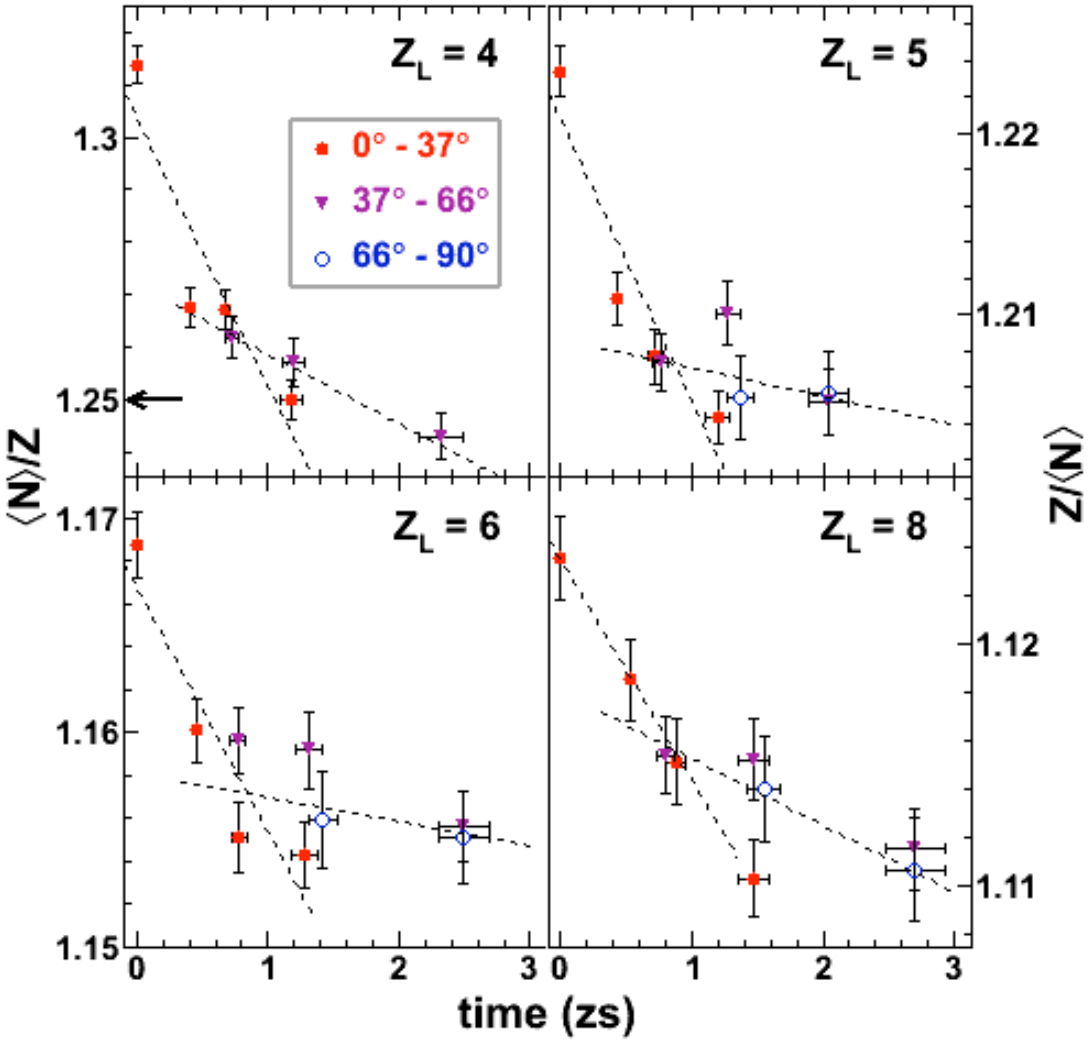
$^{124}Xe + {}^{112}Sn$



1 zs = 10^{-21} s = 300 fm/c

N/Z Time Dependence

$^{124}Xe + {}^{112}Sn$



- $Z_L = 4$
  - Strong time dependence
  - Two components

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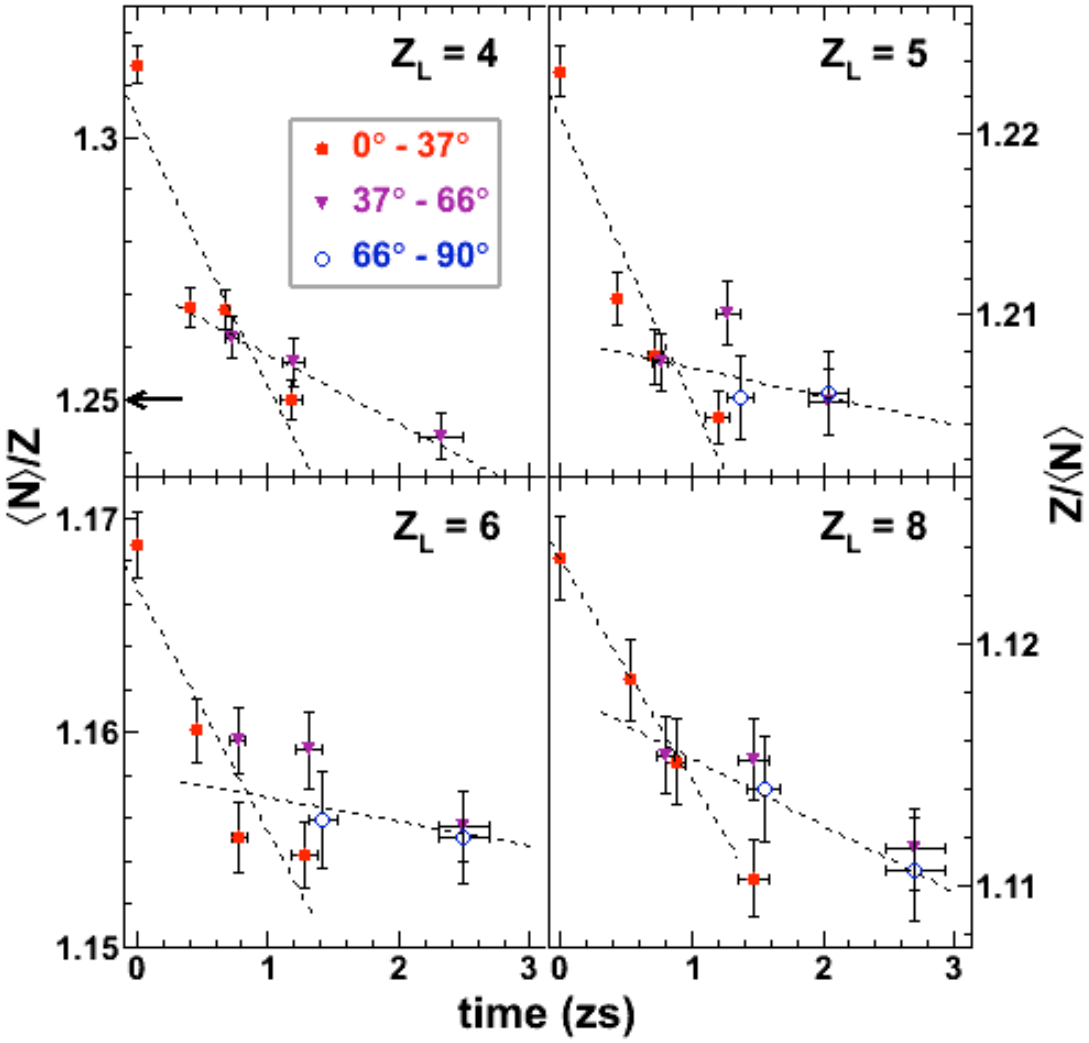

- **$Z_L = 4$**
  - Strong time dependence
  - Two components
- **$Z_L = 5,6$**
  - Time dependence not as pronounced as for $Z_L = 4$

1 zs = 10^{-21} s = 300 fm/c

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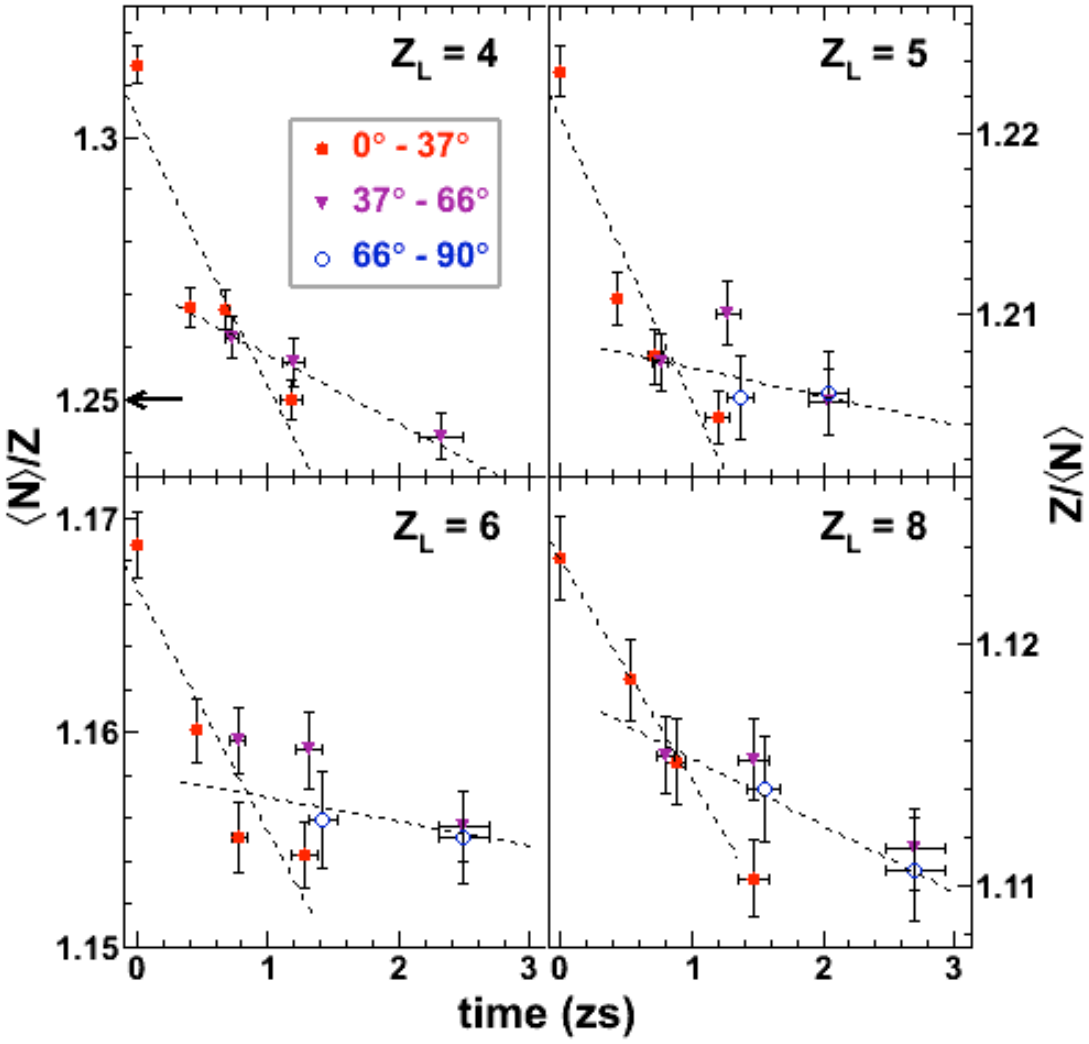

- **Z_L = 4**
  - Strong time dependence
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- **Z_L = 5,6**
  - Time dependence not as pronounced as for Z_L = 4
- **Z_L = 8**
  - Similar dependence for both short and long times

1 zs = 10^{-21} s = 300 fm/c

N/Z Time Dependence

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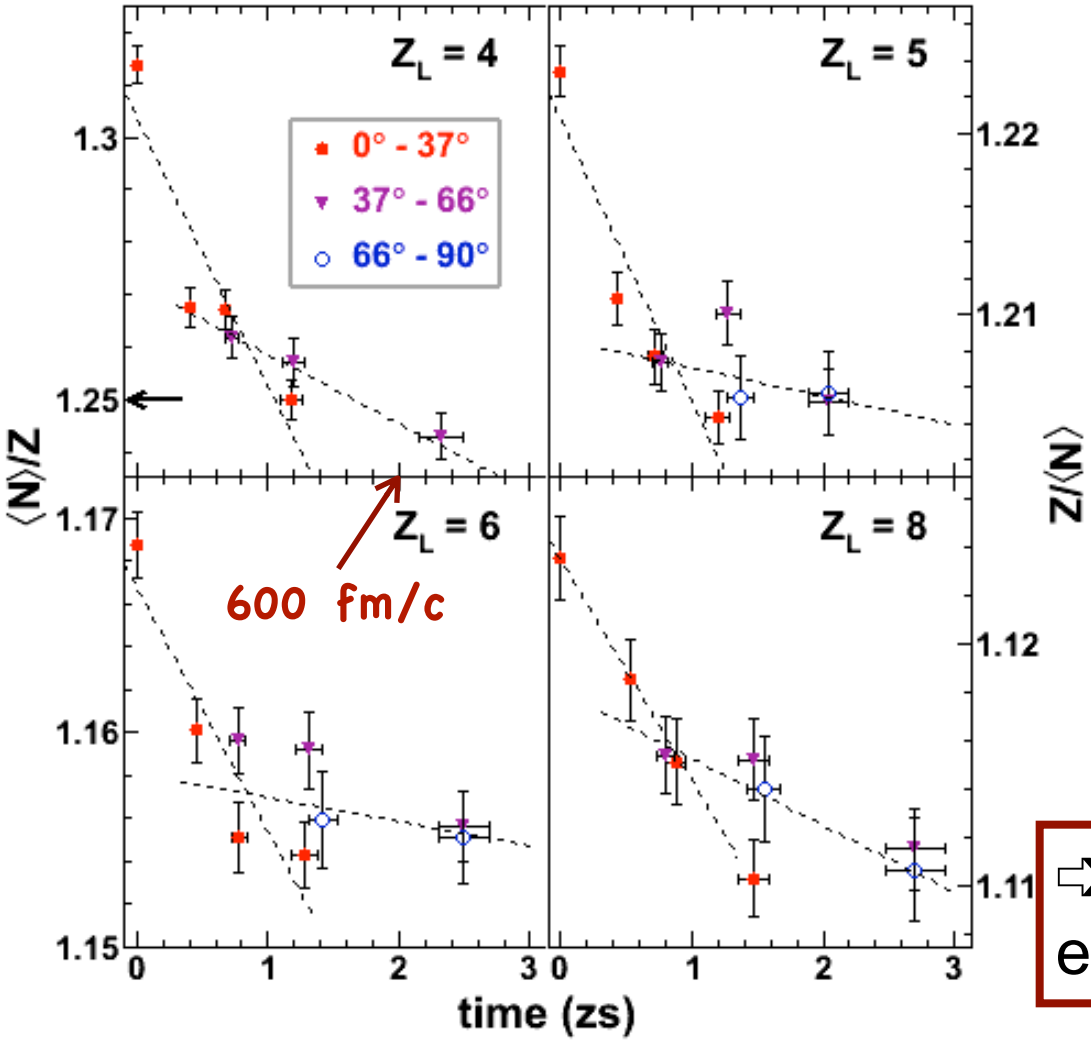

- **Z_L = 4**
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  - Two components
- **Z_L = 5,6**
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- **Z_L = 8**
  - Similar dependence for both short and long times

⇨ Persistence of N/Z equilibration over ***long*** times

1 zs = 10^{-21} s = 300 fm/c

Target Effect

Work in Progress

^{64}Zn + ^{27}Al, ^{64}Zn, ^{209}Bi @ 45 MeV/A

Angular coverage: θ_{Lab} = 3.5 - 30°

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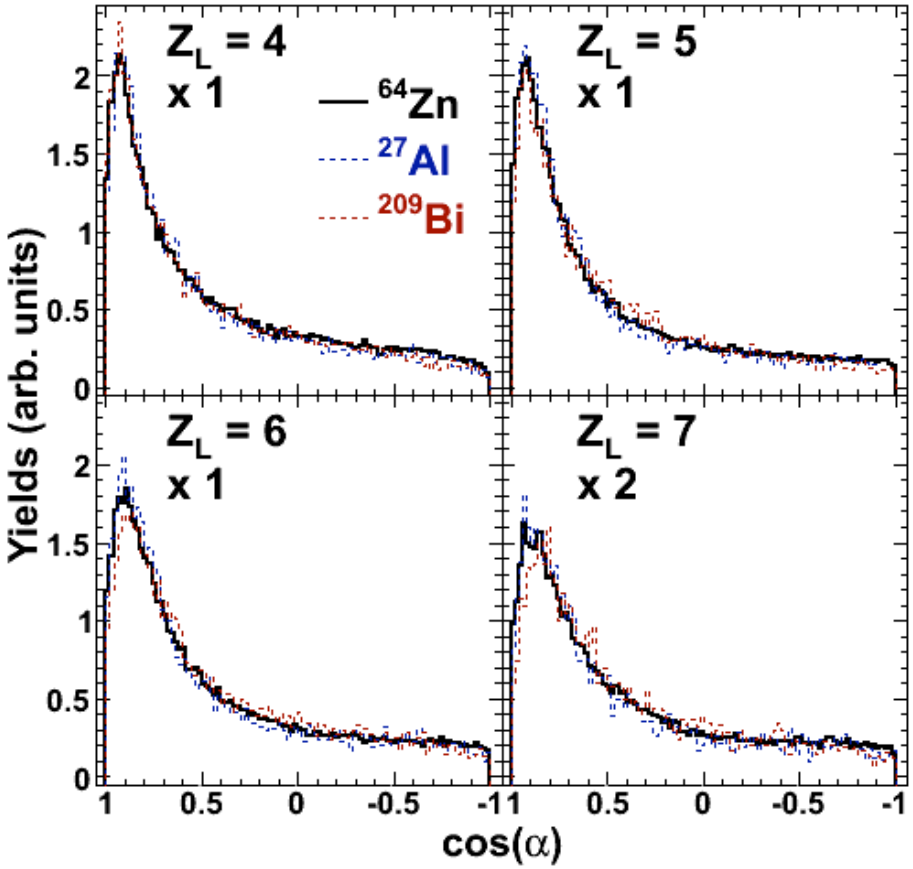
Work in Progress

^{64}Zn + ^{27}Al, ^{64}Zn, ^{209}Bi @ 45 MeV/A

Angular coverage: θ_{Lab} = 3.5 - 30°



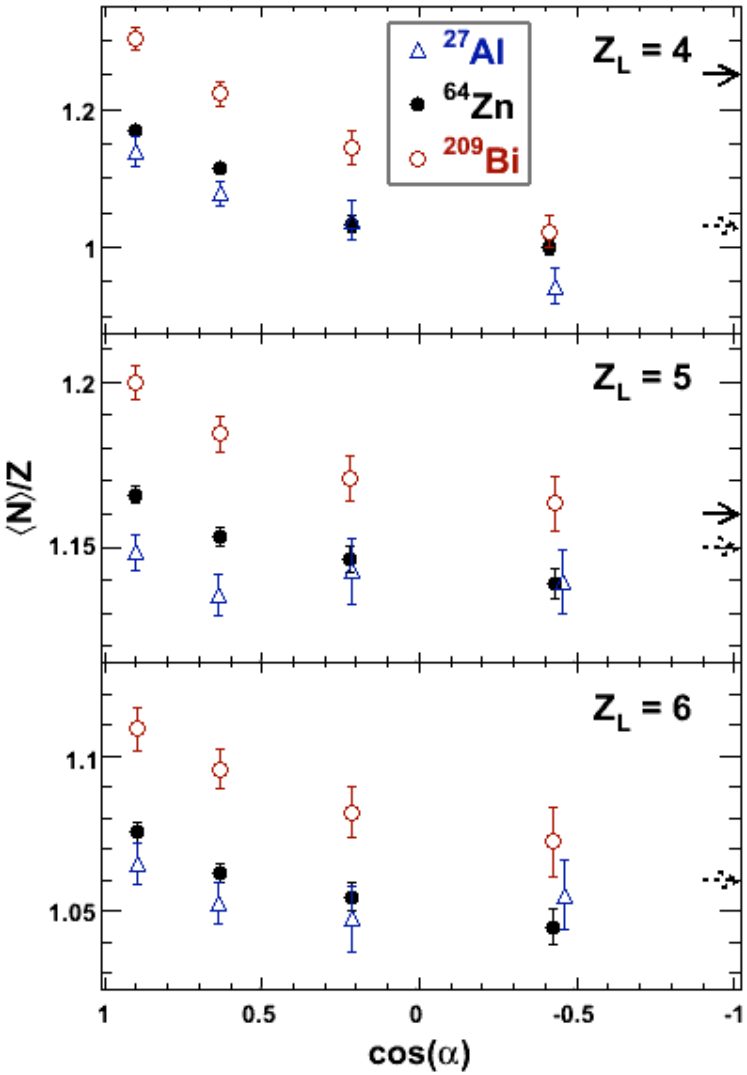
- Aligned decay observed for all targets
- Similar angular distributions

✎: Similar velocity damping and relative velocity

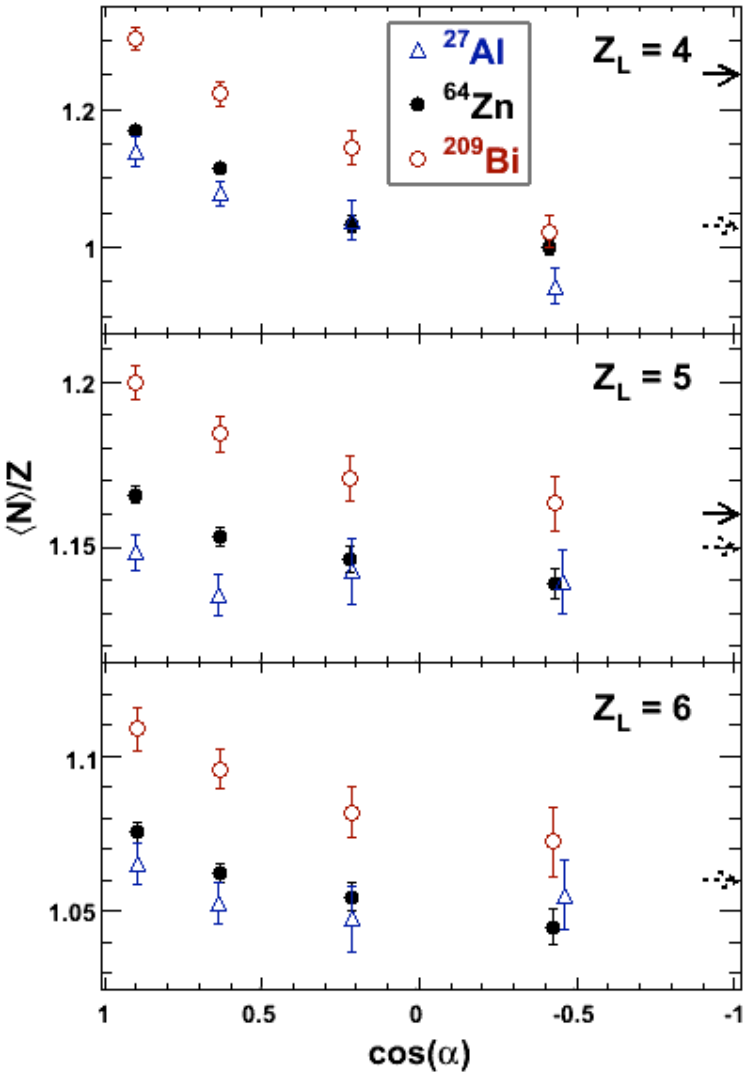
➜ Observations suggest that the binary system is prepared in a similar way for all targets

Target Effect on Isotopic Composition

Work in Progress



Target Effect on Isotopic Composition



- ⟨N⟩/Z dependence on angle

Work in Progress

⟶ : β-stable

N/Z(^{64}Zn): 1.13

⇢ : C. Sfienti *et al.*, PRL 102, 152701 (2009) for ^{124}La (N/Z = 1.175)

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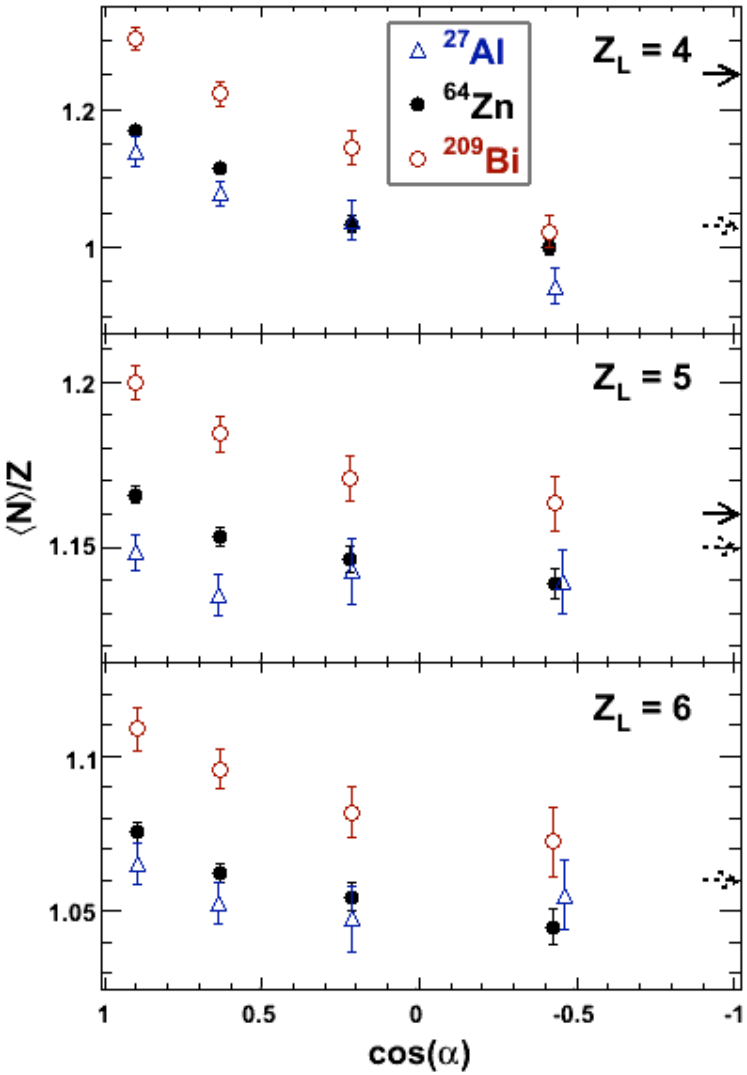

- ⟨N⟩/Z dependence on angle
- Larger fragment ⟨N⟩/Z for larger target

Work in Progress

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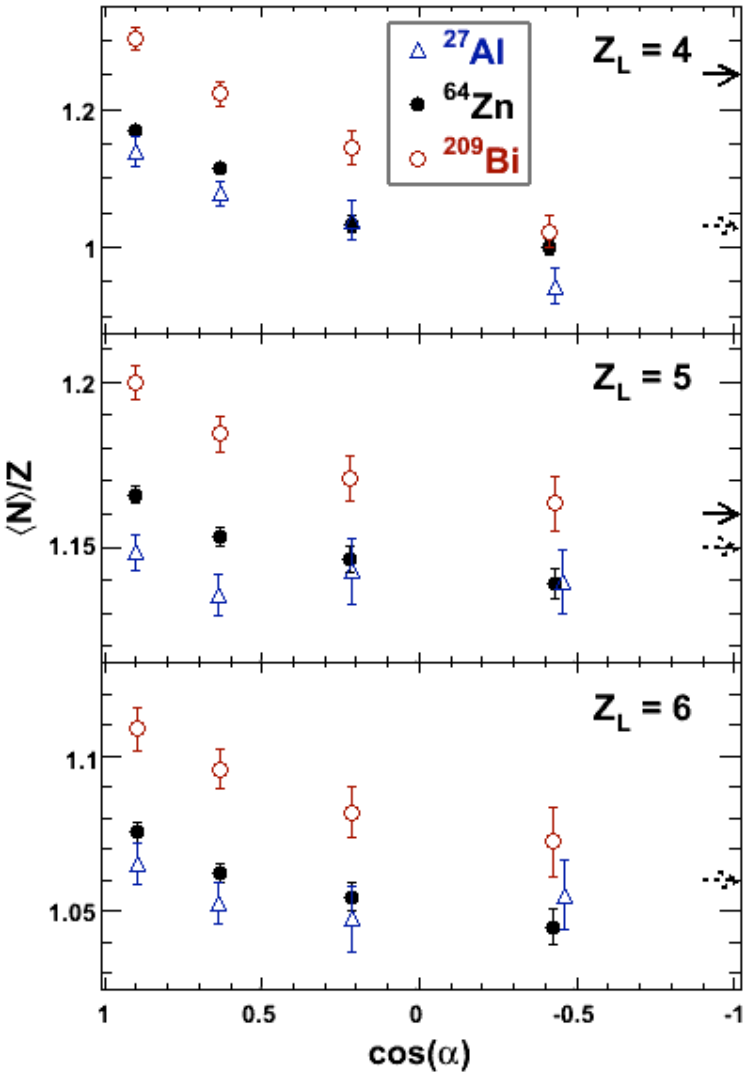

- ⟨N⟩/Z dependence on angle
- Larger fragment ⟨N⟩/Z for larger target
- ⟨N⟩/Z dependence on v_{REL} stronger for larger Z_{Target} for backward decay

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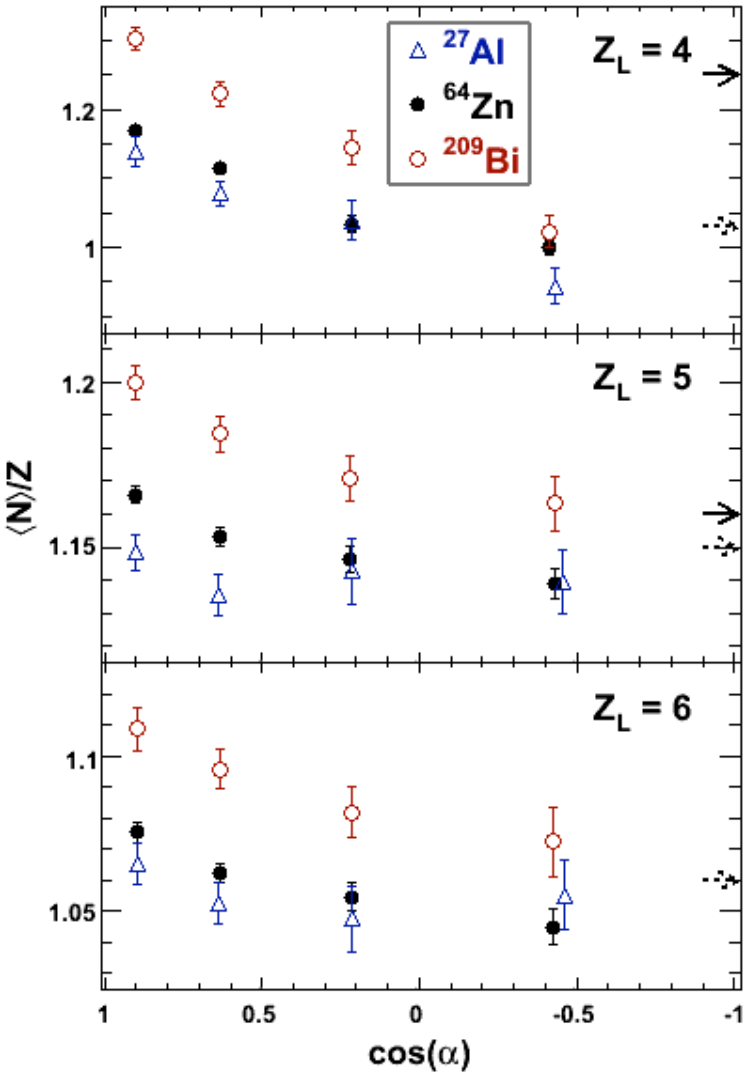
Target Effect on Isotopic Composition



Work in Progress

- ⟨N⟩/Z dependence on angle
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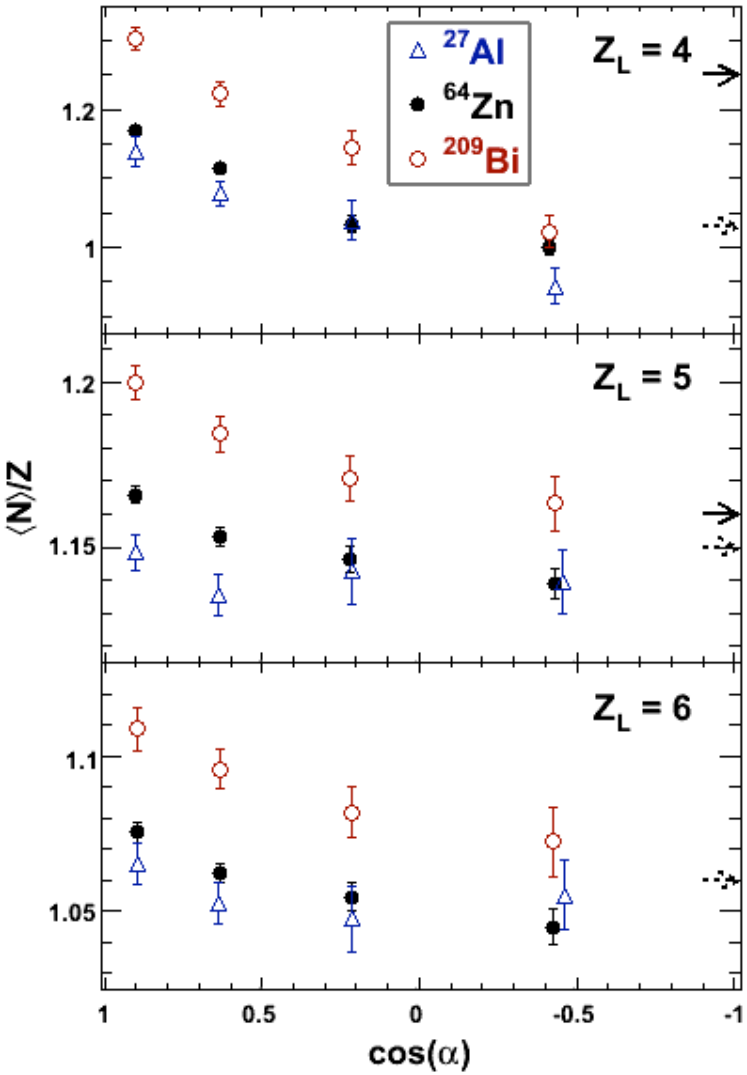

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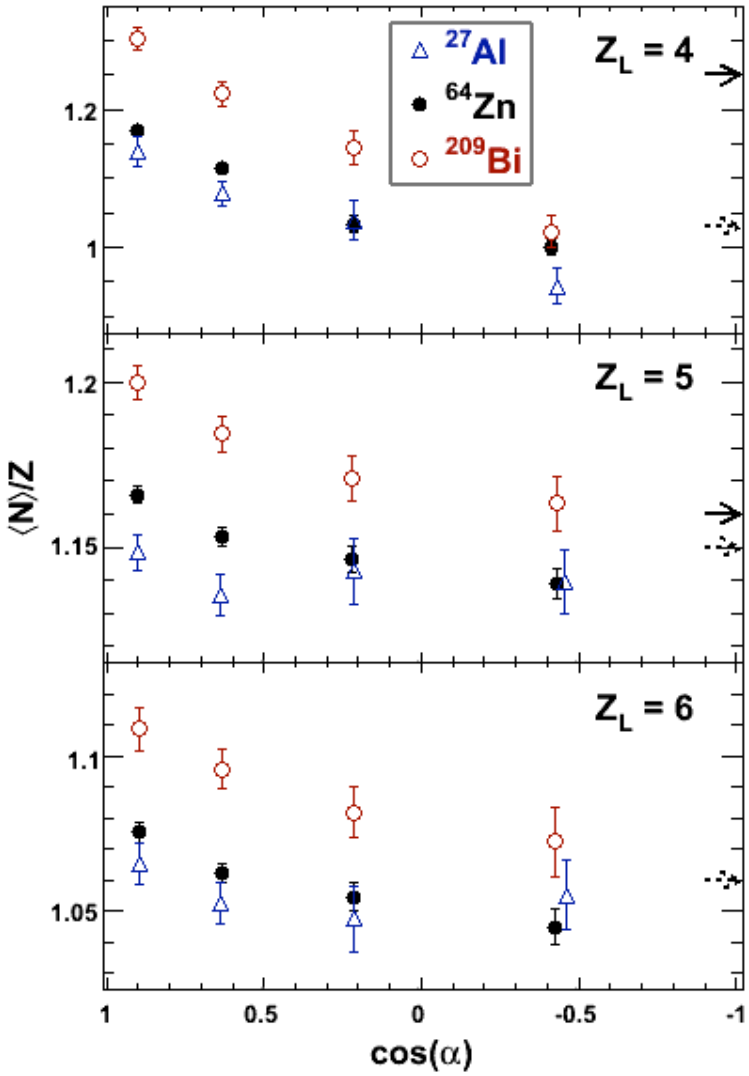

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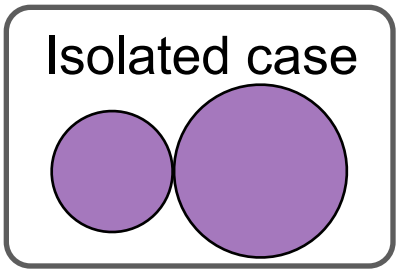
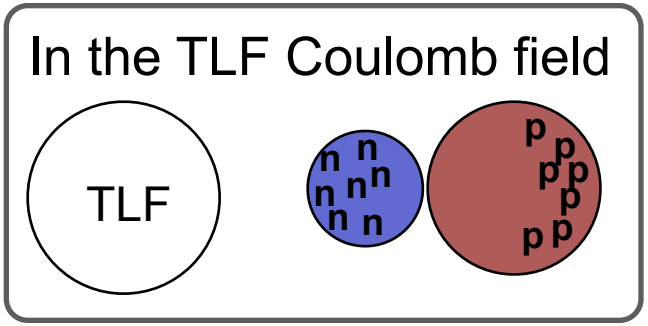
- Possible influences:
  1. Target as a source of neutrons
  2. Polarization induced by the target Coulomb field





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Conclusions

S. Hudan *et al.*, PRC **86**, 021603(R) (2012)

Conclusions

- The ⟨N⟩/Z of fragments emitted in dynamical decay is correlated with rotation angle.
- Different v_{REL} dependence are observed for forward and backward emission.
- Similar ⟨N⟩/Z increase with v_{REL} for all backward angles.
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- In the future, use of damped reactions at radioactive beam facilities?

S. Hudan *et al.*, PRC **86**, 021603(R) (2012)

Collaboration and Acknowledgements

- Indiana University: A.B. McIntosh, S. H., K.W. Brown, J. Black, D. Mercier, C.J. Metelko, B. Davin, R. Yanez, R.T. de Souza
- GANIL: A. Chbihi
- GSI: S. Bianchin, C. Schwarz, W. Trautmann
- Université Laval, Québec: M.O. Frégeau, J. Gauthier, F. Grenier , J. Moisan, R. Roy, D. Thériault
- Western Michigan University: M. Famiano
- Texas A&M University: S. Yennello's group

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- The support of the Cyclotron Institute at Texas A&M U.
- The DEMON collaboration

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