Spallation reaction of ^{56}Fe on deuterium measured in inverse kinematics at the FRagment Separator at GSI

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for the CHARMS collaboration
http://www.gsi.de/charms

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Systematic study of spallation reactions

Technical applications:
transmutation of nuclear waste (ADS), production of RIBs, neutron sources, astrophysics and others

Need for **precise** evaluation of production **cross sections** and **velocity** for **all nuclei** produced in a **large range of energies** in **many materials**

Strategy: limited number of experiments for selected nuclei

Better insight in the reaction mechanisms: fission, fragmentation, multifragmentation, phase-transitions (superfluid-liquid, liquid-gas)

→ high predictive power of the nuclear-reaction codes (INCL+ABLA, ABRABLA)

Performed experiments in the spallation campaign

reaction partners		energy (*A* GeV)	products
^{197}Au	p	0.8	Z=18-55, 60-80
^{238}U	p	1	Z=7-92
^{238}U	d	1	Z=7-22, 23-93
^{208}Pb	p	0.5, 1	Z=23-56,69-83, Z=22-83
^{208}Pb	d	1	Z=22-83
^{136}Xe	p	0.2, 0.5, 1	Z=3-56
^{56}Fe	p	0.3, 0.5, 0.75, 1, 1.5	Z=3-27
^{56}Fe	d	0.5	Z=3-27

in black: already published in red: to be published

this work

Data accuracy:

Statistic: below 3%

Systematic: 9 - 15 %

More than **10,000** cross sections and velocity distributions measured !

Data available at: **www.gsi.de/charms/data.htm**

Motivation for this work: d+^{56}Fe at 0.5 A GeV

"Golden rule"

The total collision energy is the key factor determining the distribution of fragments produced by the spallation of a given nucleus.

How can we prove if this is true?

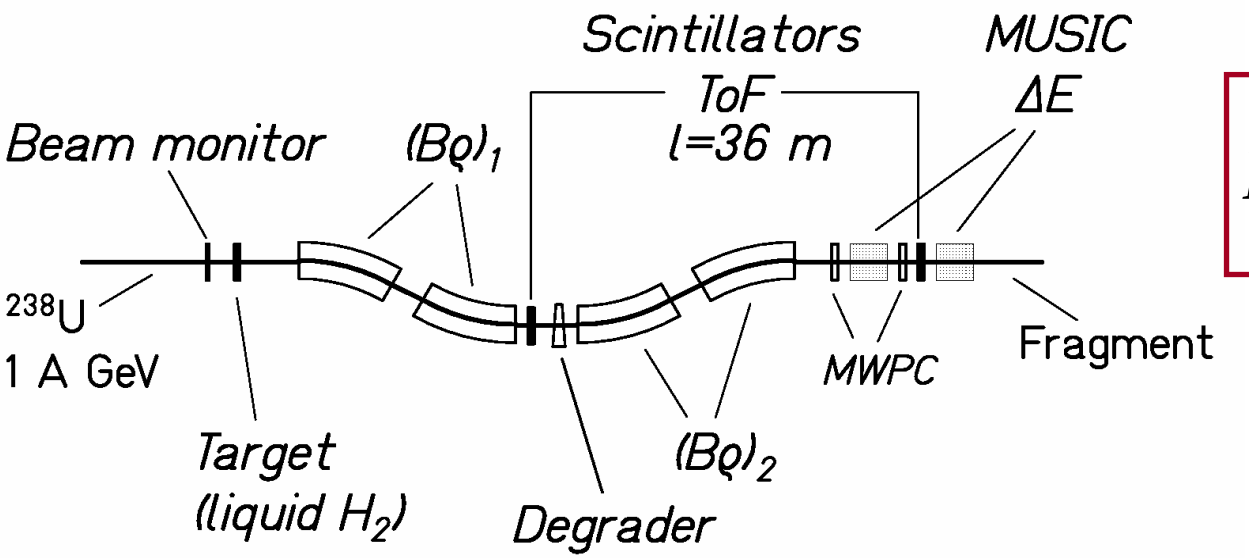
comparing different reactions with the same total energy:

p + ^{56}Fe at 1 A GeV

d + ^{56}Fe at 0.5 A GeV

Note: here the nucleon-nucleon collision occurs at double kinetic energy

Measurements in inverse kinematics at FRS



$$B\rho = \frac{m_0 c}{e} \cdot \frac{A}{Z} \cdot \beta \cdot \gamma$$

Resolution:

- $\Delta(\beta\gamma)/\beta\gamma \approx 5 \cdot 10^{-4}$
- $\Delta Z \approx 0.4$
- $\Delta A / A \approx 2.5 \cdot 10^{-3}$

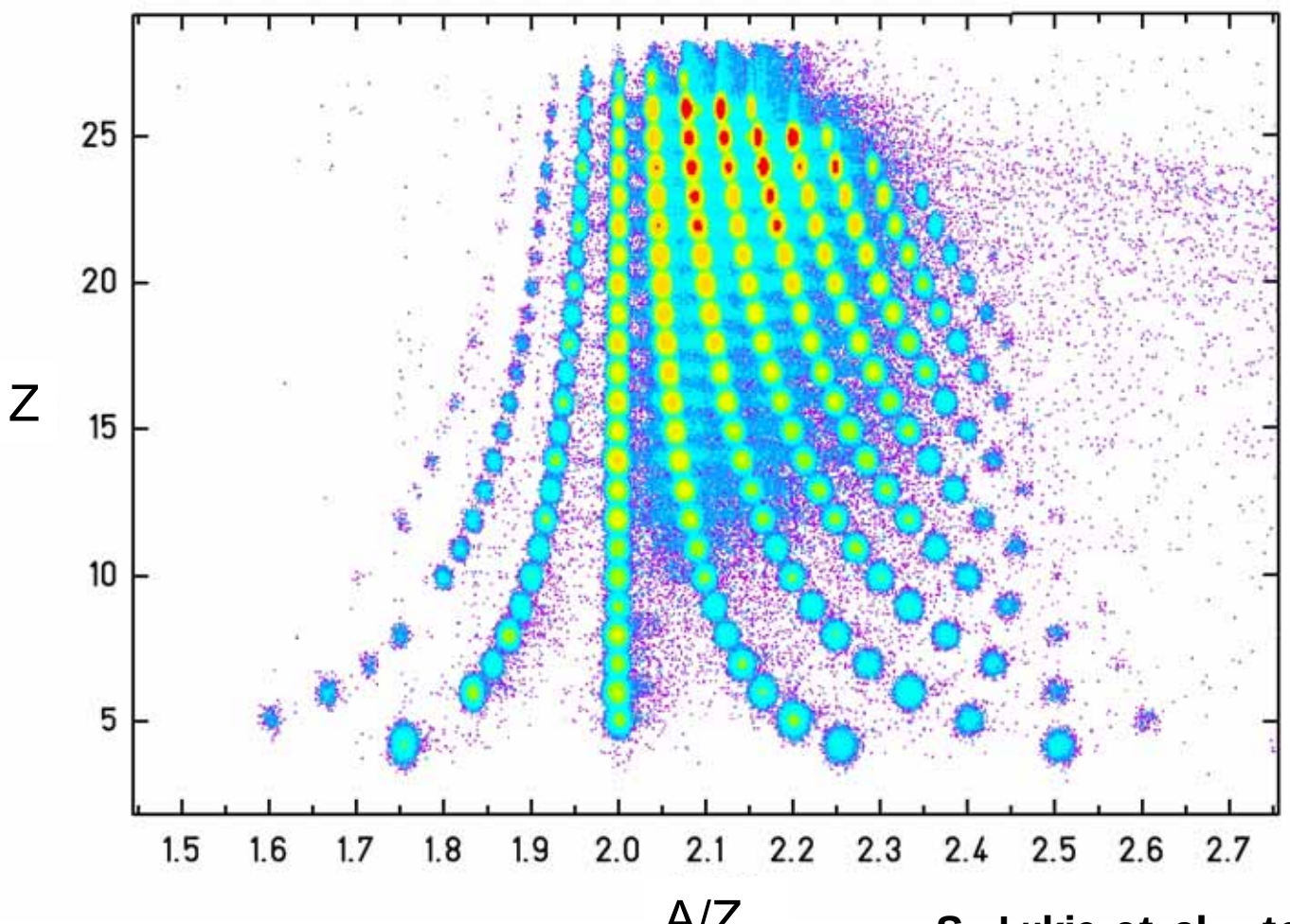
→ - Precise velocity measurement for every nuclide
- Disentangling different reaction mechanisms

→ Full identification of every product

Nuclide identification

production cross sections for all nuclei

$^{56}Fe + {}^{2}H$ at 0.5 *A* GeV



S. Lukic et al., to be submitted

Velocity distributions

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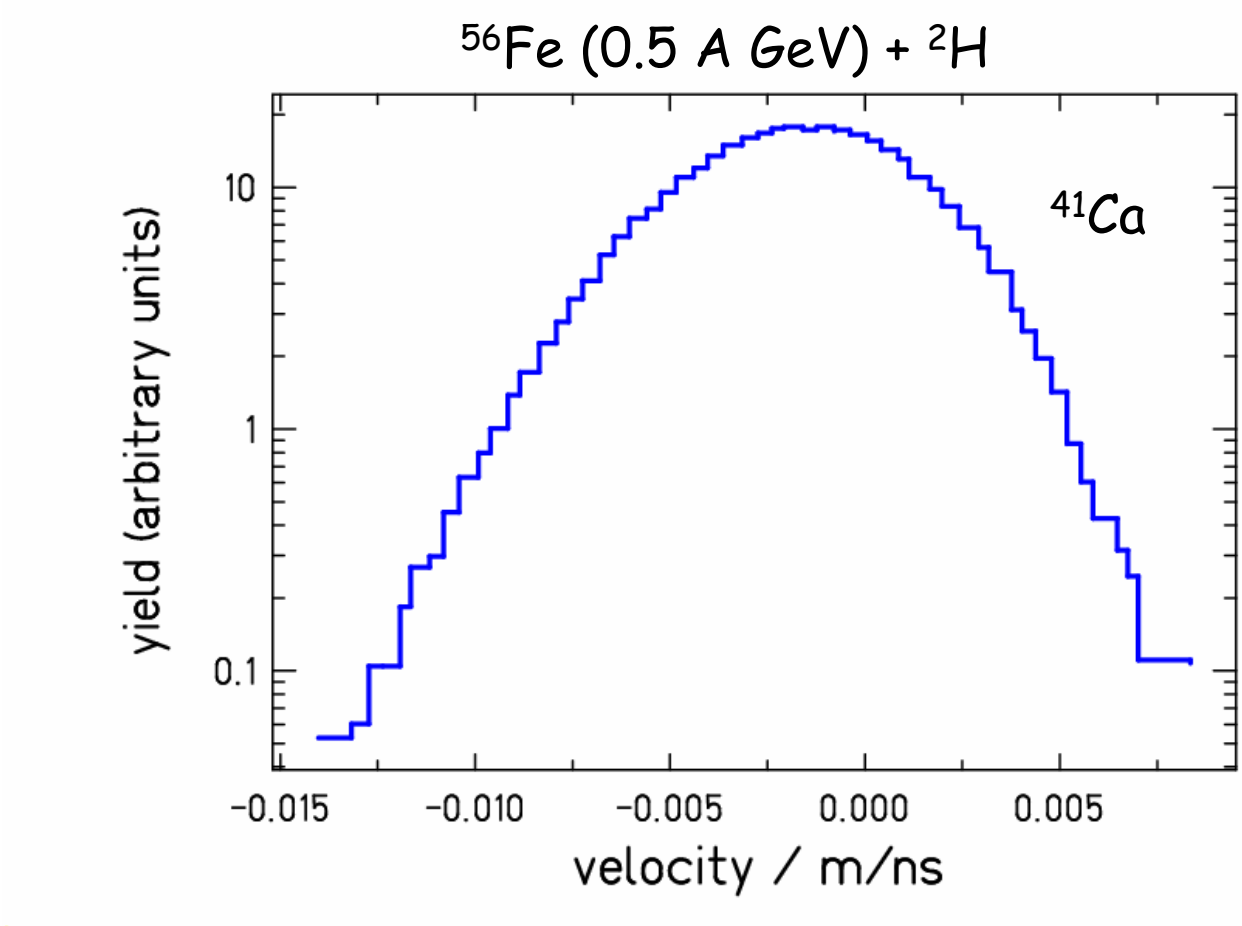
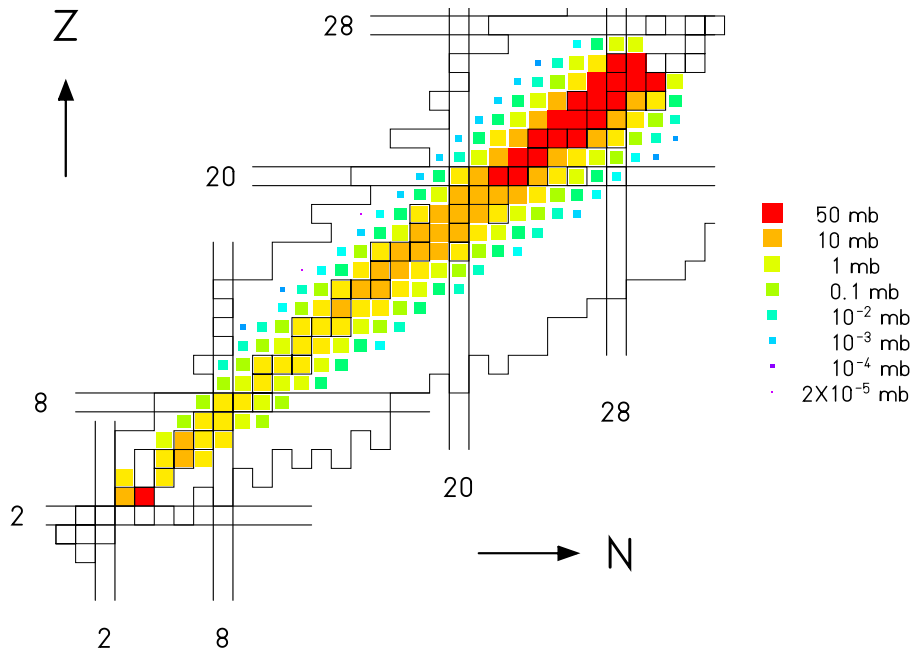
to be submitted



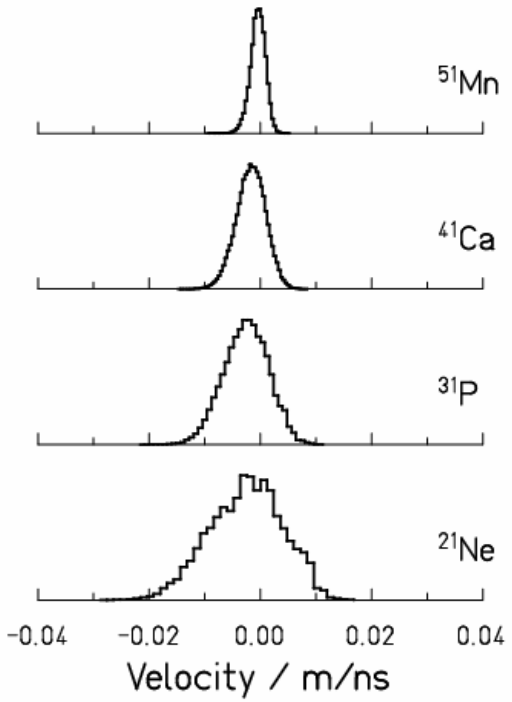
For each nucleus: production cross section, velocity distribution

Results: 0.5 *A* GeV ^{56}Fe on ^{2}H

Measured cross sections

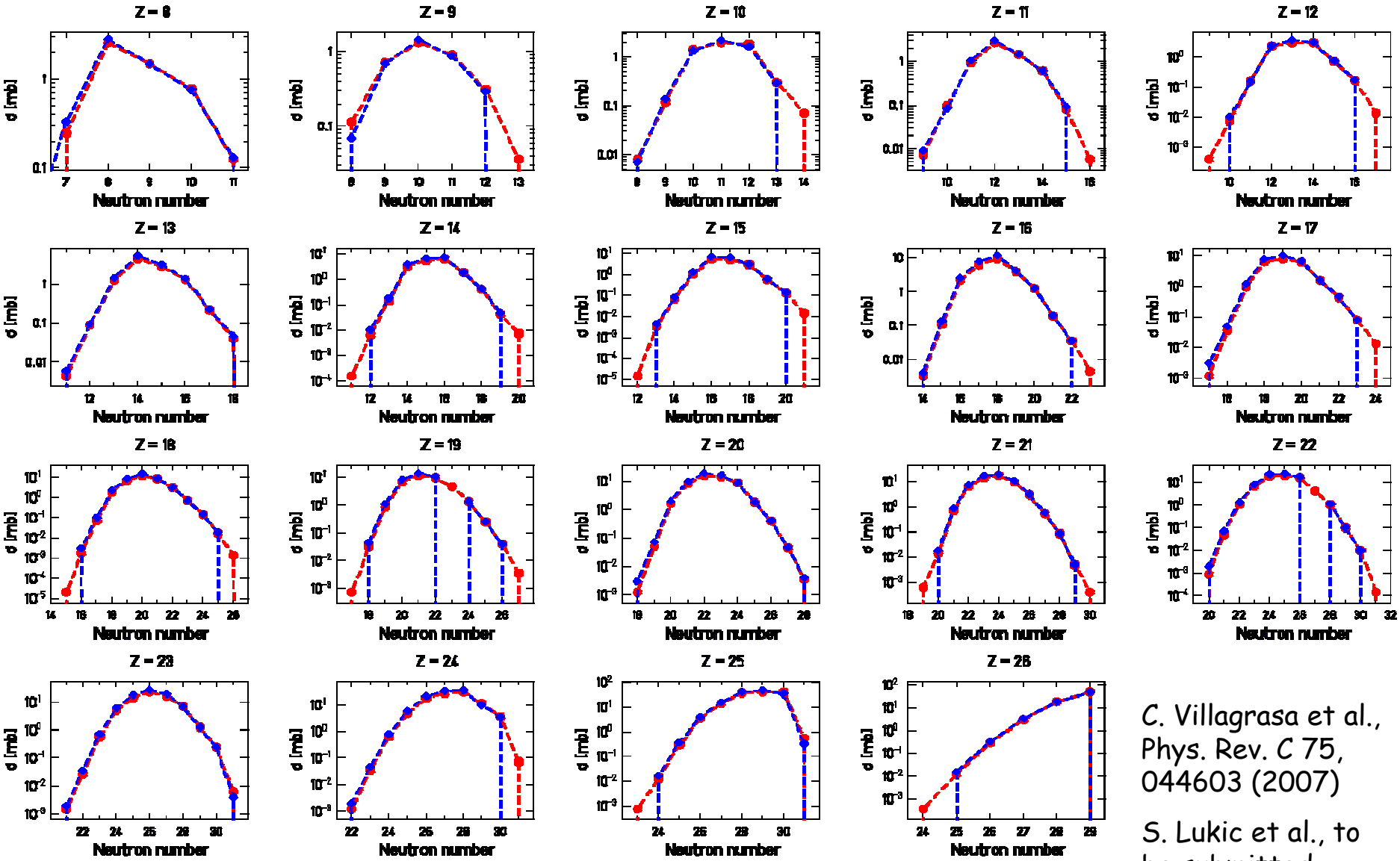


Measured velocities



S. Lukic et al., to be submitted

Comparison with 1 *A* GeV ^{56}Fe on ^{1}H

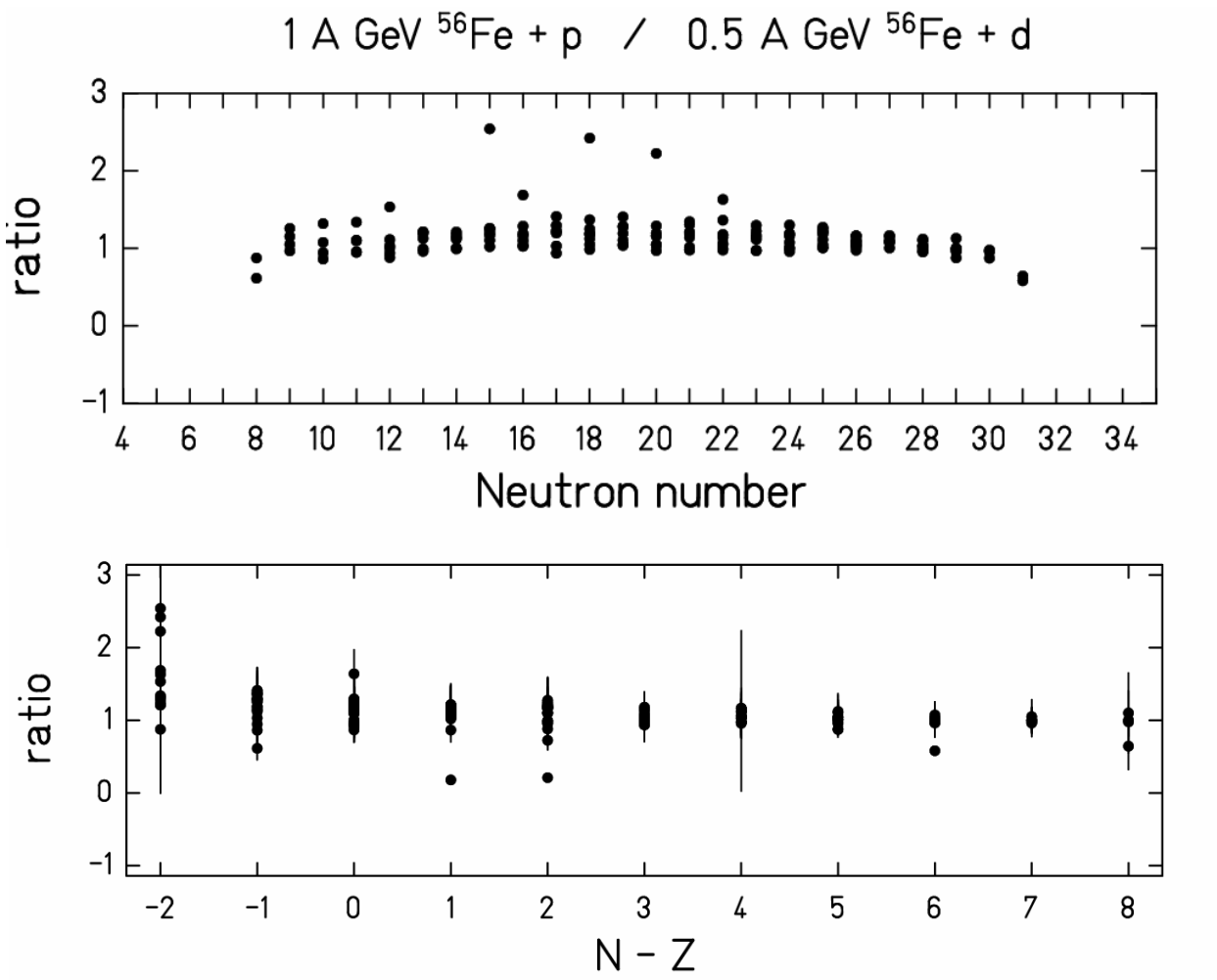


C. Villagrasa et al., Phys. Rev. C 75, 044603 (2007)

S. Lukic et al., to be submitted

0.5 *A* GeV ^{56}Fe on d 1 *A* GeV ^{56}Fe on p

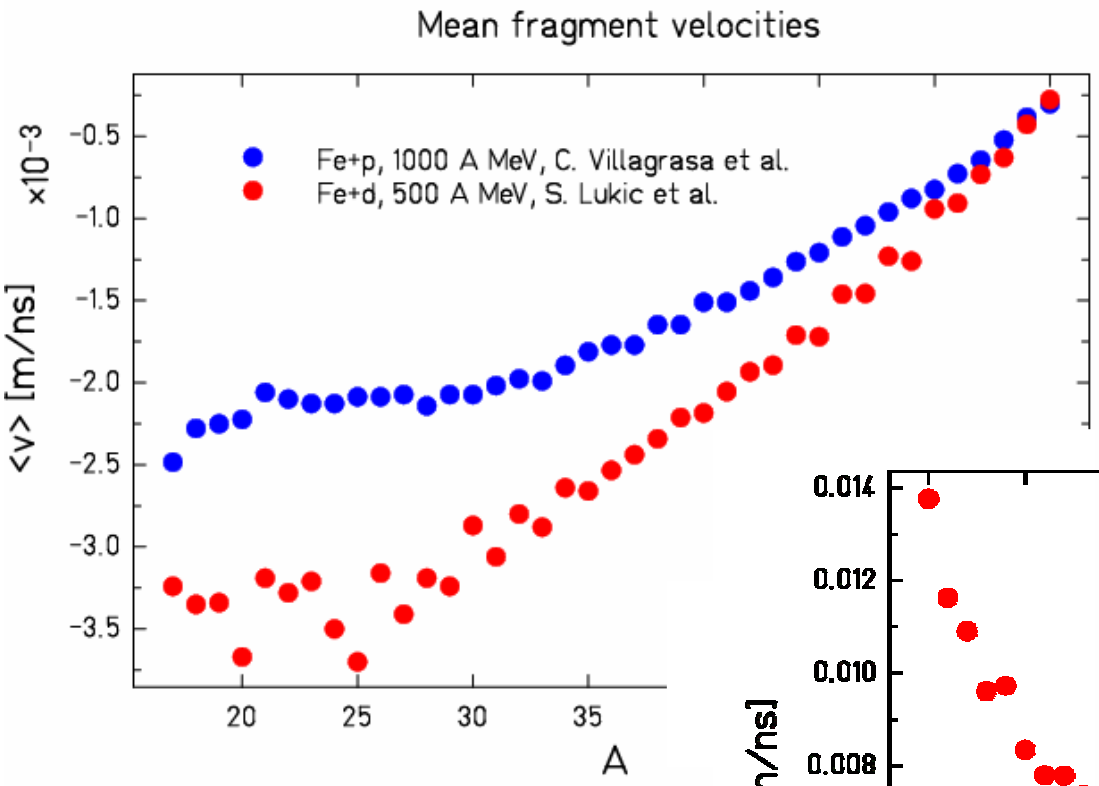
Comparison 1 *A* GeV ^{56}Fe on ^{1}H

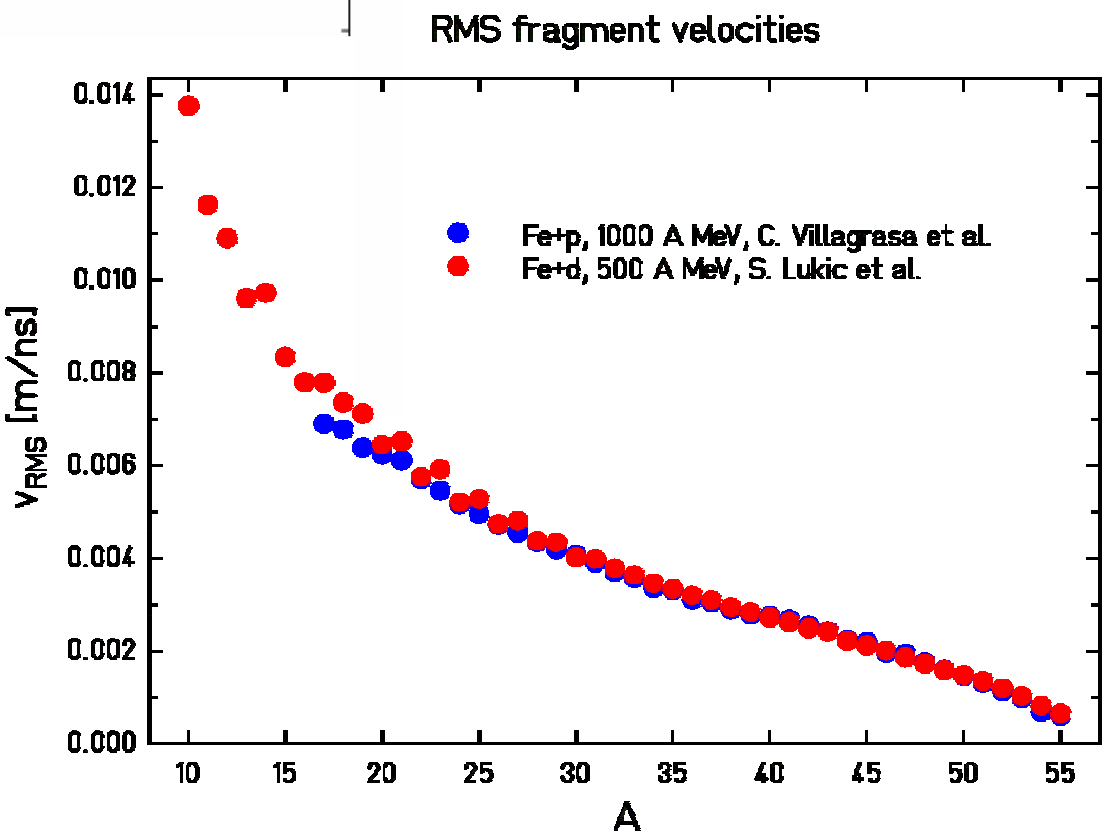


1 *A* GeV ^{56}Fe + p : C. Villagrasa et al., Phys. Rev. C 75, 044603 (2007)

0.5 *A* GeV ^{56}Fe + d : S. Lukic et al., to be submitted

Comparison with 1 *A* GeV ^{56}Fe on ^{1}H





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Phys. Rev. *C* 75, 044603 (2007)

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Conclusion

The experimental production cross-sections and velocities of the products of the reactions:

$p + {}^{56}Fe$ at 1 GeV

$d + {}^{56}Fe$ at 0.5 GeV

were compared.

The comparison confirmed what expected from theory: in spallation reactions

the total collision energy is the key factor for determining the distributions of final fragments

Collaboration

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A. Junghans - **Institüt für Strahlenphysik, Dresden**