The $^{59}Cu(p,\alpha)$ cross section and its implications for nucleosynthesis in core collapse supernovae

CERN-INTC-2015-036 ; INTC-P-441

C. Lederer[1], M. Aliotta[1], T. Davinson[1], D. Doherty2, A. Estrade[1], C. Griffin[1], T. Kemp[1], M. Kowalska[3], S.J. Lonsdale[1], V. Margerin[1], A. Murphy[1], C. Weiss[3], F. Wenander[3], P.J. Woods[1], L. Zhang[1]

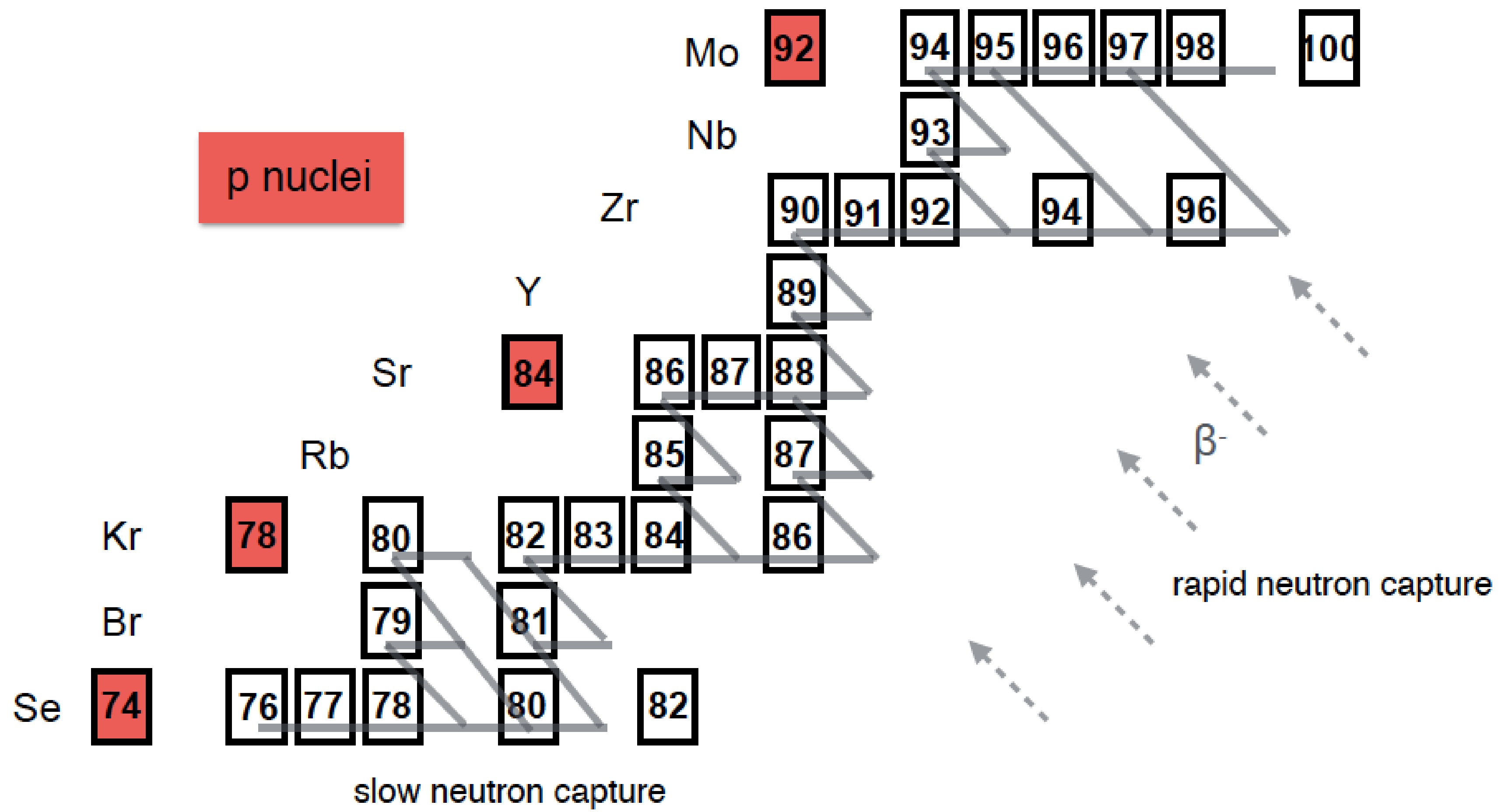
[1]University of Edinburgh, [2]CEA-Saclay, [3]CERN

INTC open session, July 1st 2015, CERN

Der Wissenschaftsfonds.

Formation of rare, proton-rich nuclei

- Some rare, heavy isotopes on the proton-rich side cannot be produced by neutron capture reactions ('p-nuclei')
- They are thought to be produced in supernova explostions by photodisintegration reactions, but stellar models fail to reproduce the high abundances of some lighter p-nuclei



Formation of rare, proton-rich nuclei

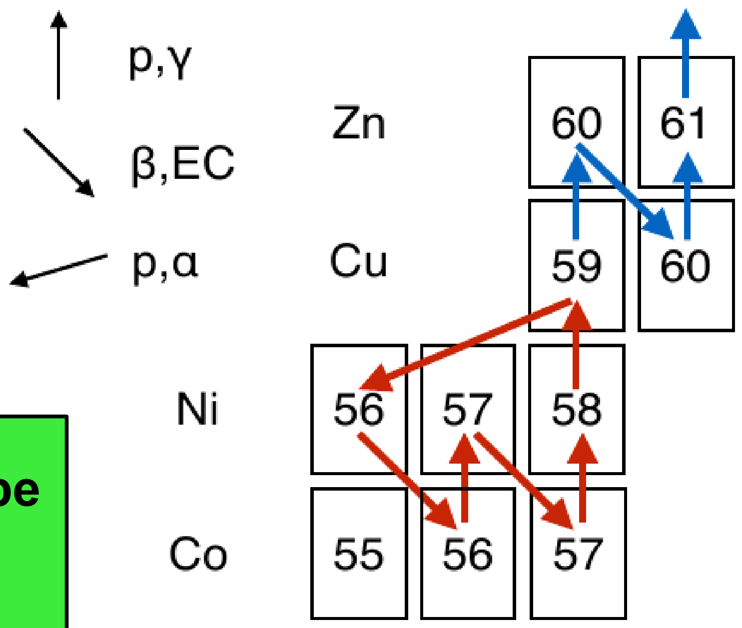
- Possible production of light p nuclei in the νp process: Synthesis of A<100 in proton-rich supernova ejecta by proton and α capture reactions. Neutrino interactions create free neutrons that can bridge bottlenecks via (n,p) reactions (Fröhlich et al, Phys. Rev. Lett. 96, 2006)

Formation of rare, proton-rich nuclei

- Possible production of light p nuclei in the νp process: Synthesis of A<100 in proton-rich supernova ejecta by proton and α capture reactions. Neutrino interactions create free neutrons that can bridge bottlenecks via (n,p) reactions (Fröhlich et al, Phys. Rev. Lett. 96, 2006)

- Recent study by Arcones et al.:

Competition between (p,α) and (p,γ) on ^{59}Cu sets temperature where heavy element formation starts
(A. Arcones et al, ApJ 750, 2012)



high temperature (above ~3 GK)
low temperature

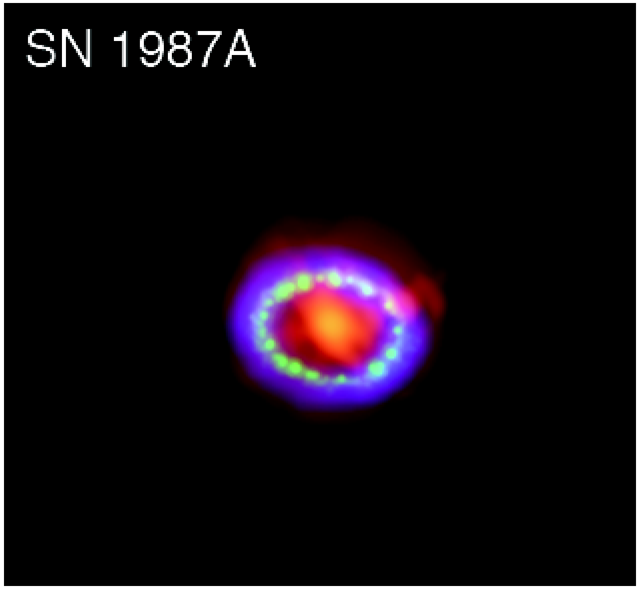
'^{59}Cu(p,α)^{56}Ni is a key reaction that needs to be measured'

A. Arcones (private communication, 2014)
C. Fröhlich (p-process workshop, Cyprus, 2015)

Formation of cosmic X-ray emitters

• Search for ^{55}Fe in SN 1987A by CHANDRA mission - no detection, inconsistent with models

Leising, ApJ 651, 1019 (2006)



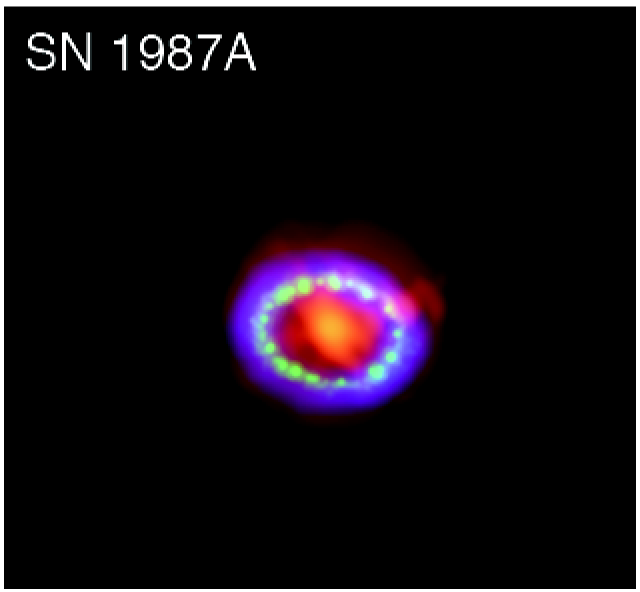
• $^{59}Cu(p,\alpha)$ reaction rate has high impact on abundances of the X ray emitters ^{55}Fe and ^{59}Ni produced in supernovae

Jordan, Gupta and Meyer, Phys Rev C 68, 065801 (2003)

Formation of cosmic X-ray emitters

• Search for ^{55}Fe in SN 1987A by CHANDRA mission - no detection, inconsistent with models

Leising, ApJ 651, 1019 (2006)



• $^{59}Cu(p,\alpha)$ reaction rate has high impact on abundances of the X ray emitters ^{55}Fe and ^{59}Ni produced in supernovae

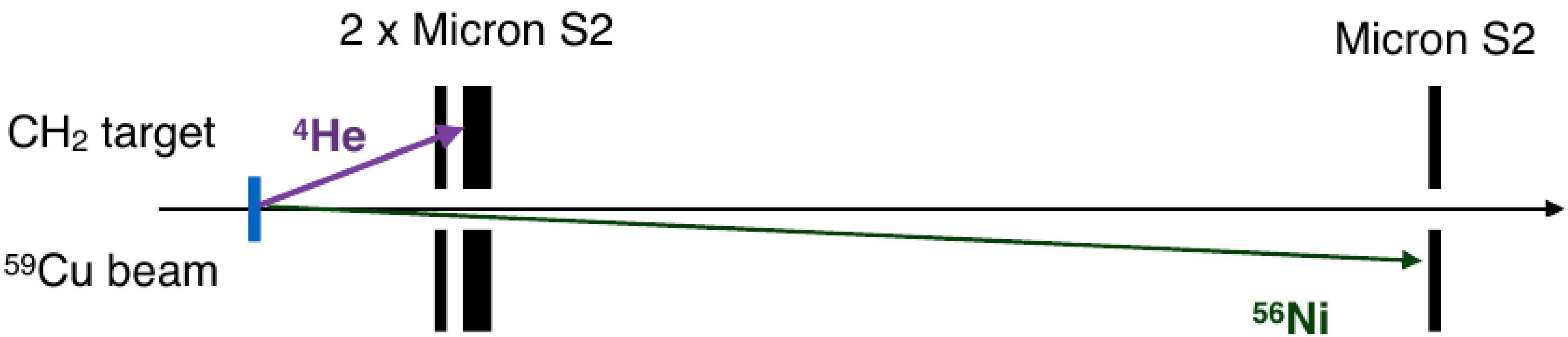
Jordan, Gupta and Meyer, Phys Rev C 68, 065801 (2003)

The new HIE-ISOLDE facility provides the unique opportunity to study the $^{59}Cu(p,\alpha)^{56}Ni$ reaction <u>directly</u> at astrophysical energies

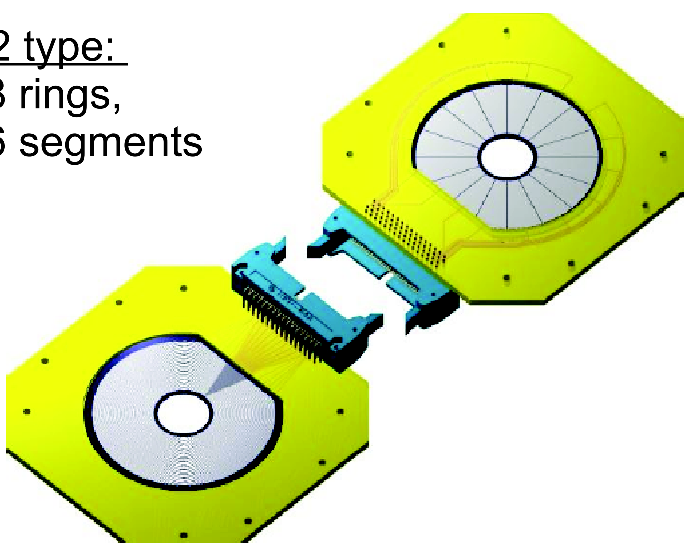
Proposed Experimental Setup

Detection of ^{4}He and heavy recoil in coincidence (PRL 108, 242701 (2012)):

- ^{4}He detection: Micron S2 type Silicon detectors arranged as ΔE-E telescope, 70 μm and 1000 μm thickness (angular coverage in lab 5-41 degrees)
- ^{56}Ni detection: S2 type detector, 70 μm thick (angular coverage in lab 1.5-5 degrees)

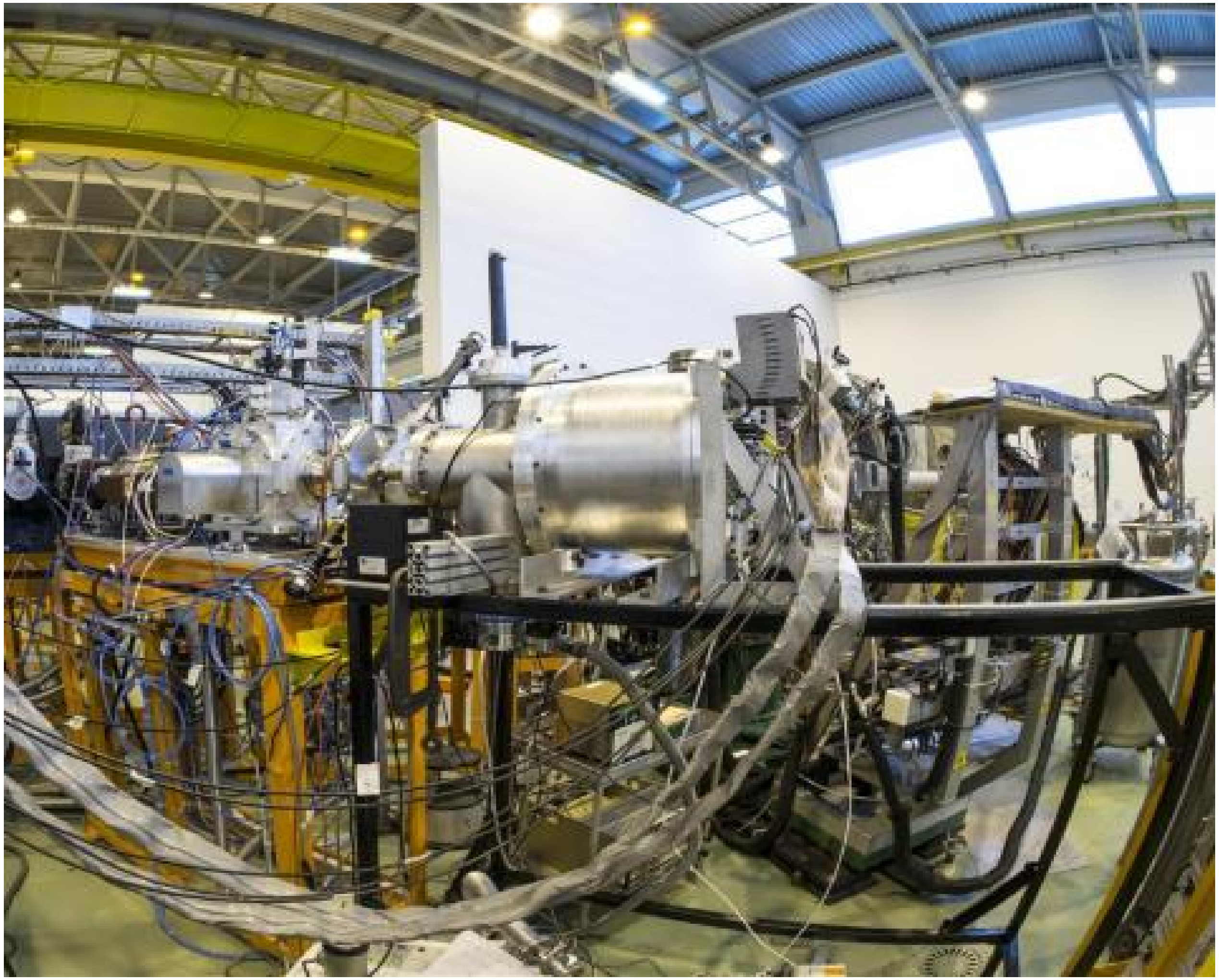


<u>S2 type:</u>
48 rings,
16 segments



Detectors, targets, reaction chamber and DAQ will be provided by Edinburgh

Reaction Chamber Dimension



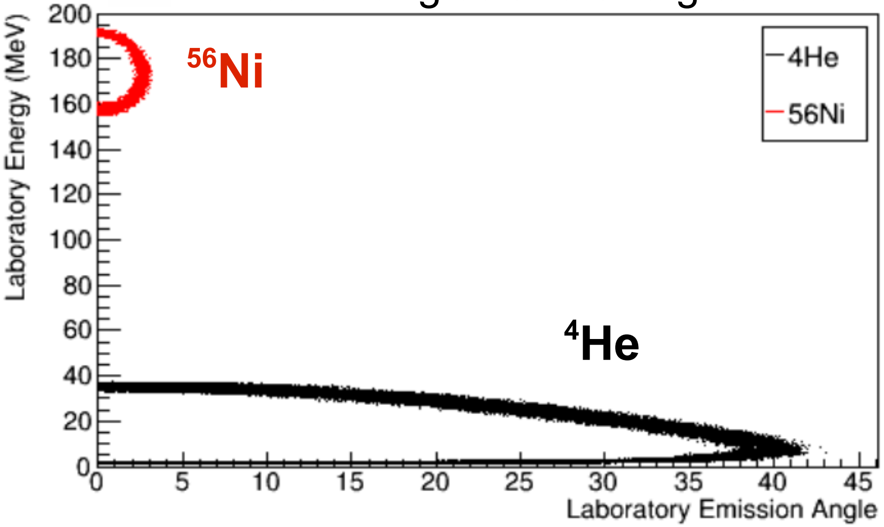
Slightly longer version of chamber used for $^{44}Ti(\alpha,p)$ experiment INTC-P-335

Approximate dimensions:
Max. diameter: 40 cm
Length: 1.2 m, extending to 2.5 m

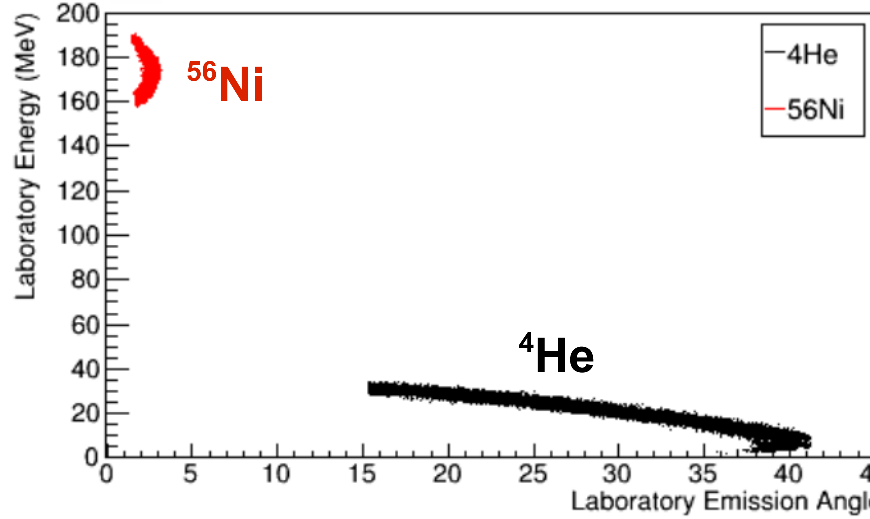
Reaction Kinematics and Efficiency

Example: 212 MeV ^{59}Cu beam (laboratory energy), 2.4 mm FWHM; energy losses in target taken into account

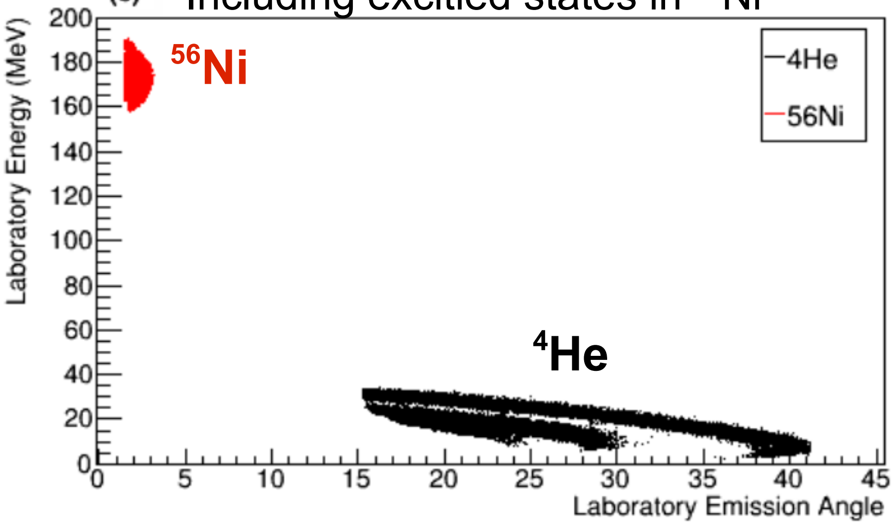
(a) Emission angles and energies



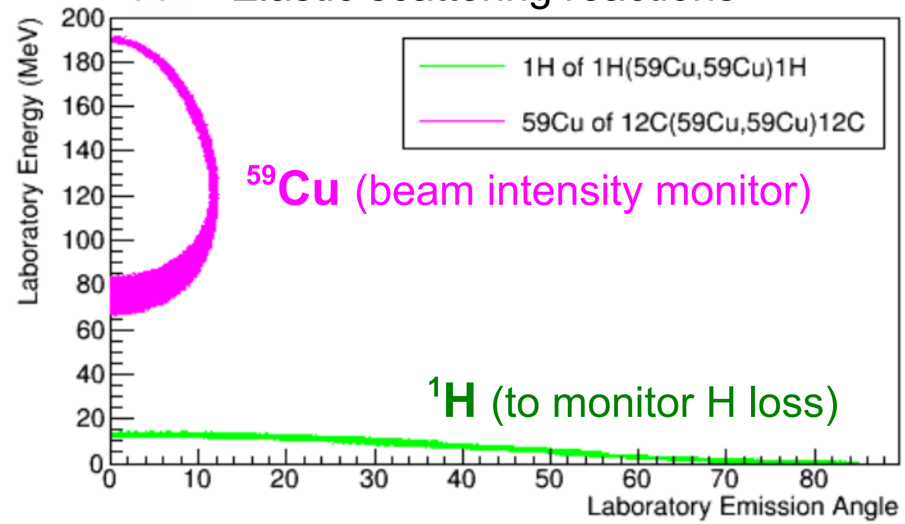
(b) Emission angles and energies reaching the detectors in coincidence: 30% efficiency



(c) Including excitied states in ^{56}Ni



(d) Elastic scattering reactions



Beam Time Request

- Beam energies from 3.6 - 5 MeV/u to cover stellar temperatures from 2.5 - 4 GK
- 2.1E5 ^{59}Cu ions per second on CH_2 target (at experimental station, yield: 7E6/μC)
- 30% efficiency for coincidences
- Reaction cross section as calculated by the NON-SMOKER code
- 2h of background runs for each beam energy (Background measurements with target of the same thickness containing Carbon (CD_2))

E_B (MeV)	E_B (MeV/u)	E_{cm} (MeV)	Cross Section (mb)	Shifts	Counts	Statistical uncertainty (%)
295	5.0	4.6-5.0	2.0	2	290	6
277	4.7	4.3-4.7	1.3	3	300	6
259	4.4	4.0-4.4	0.7	4	220	7
236	4.0	3.6-4.0	0.3	5	105	10
212	3.6	3.2-3.6	0.1	5	45	15

Total request: 24 shifts (19 for (p,α) measurement, 1 for setting up in beam, 4 for beam energy changes)

EXTRA SLIDES

A. Arcones et al, ApJ 750, 2012

High temperature (3.3 GK)

Low temperature (2.2 GK)