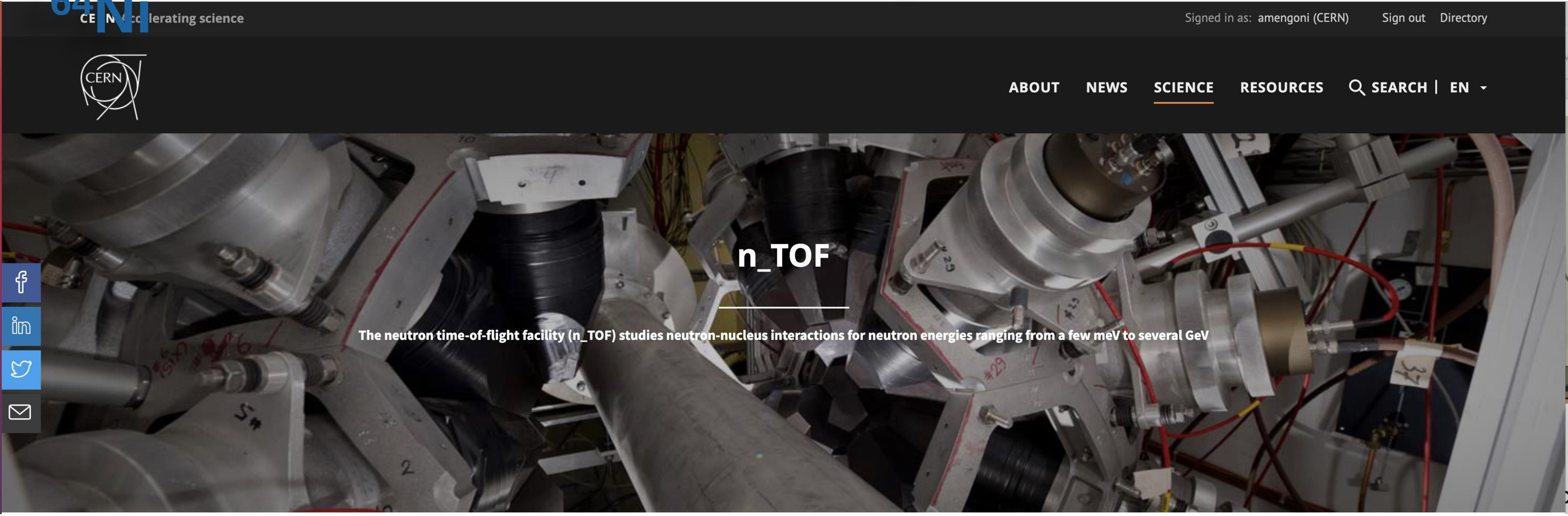
Addendum to the Proposal INTC-P-208 - Measurement of the neutron capture cross section of ^{64}Ni



Alberto Mengoni
on behalf of the n_TOF Collaboration

www.cern.ch/n_TOF

CERN-INTC-2006-012
INTC/P-208

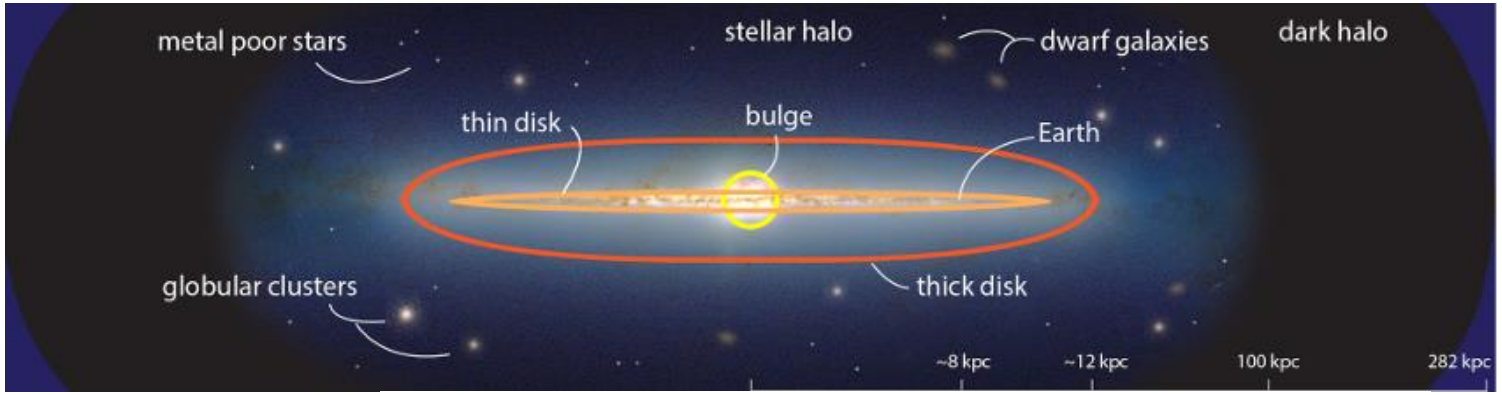
The role of Fe and Ni for *s*-process nucleosynthesis in the early Universe and for innovative nuclear technologies

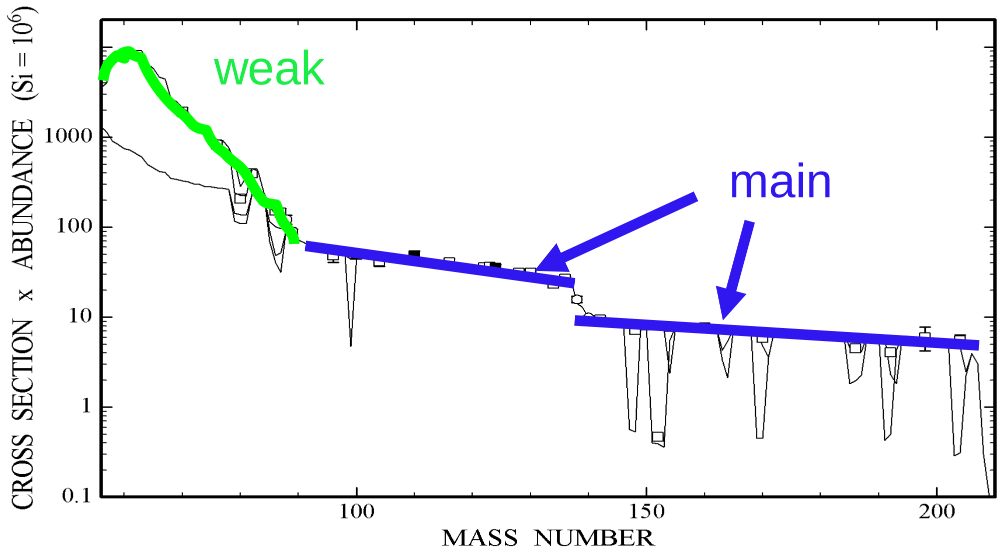
J.L. Tain*,[1] C. Domingo-Pardo,[1] F. Bečvář,[2] E. Berthoumieux,[3] F. Calviño,[4] D. Cano-Ott,[5] P. Cennini,[6] N. Colonna,[7] G. Cortes,[4] I. Dillmann,[8,9] W. Dridi,[3] E. González,[5] A. Guerra,[5] C. Guerrero,[5] F. Gunsing,[3] M. Heil†,[9] F. Käppeler,[9] D. Karadimos,[10] P. Koehler,[11] C. Lamboudis,[12] H. Leeb,[13] S. Marrone,[7] T. Martinez,[5] C. Massimi,[14] A. Mengoni,[15] P.M. Milazzo,[16] R. Plag,[9] G. Tagliente,[7] P. Vaz,[17] V. Vlachoudis‡,[6] and

The n_TOF Collaboration

Abstract

The early universe was enriched in heavy elements by massive stars via their *s*- and *r*-process contributions. Ultra metal-poor stars were found to show abundance patterns that scale exactly with the solar *r* component. While this holds exactly for elements heavier than barium, there is still confusion about significant discrepancies in the mass region below $A \leq 120$. It is known that massive stars contribute significantly to the abundances between Fe and Zr. This so-called weak *s*-process component was found to exhibit large uncertainties due to the poorly known cross sections, especially in the Fe-Ni region. In view of this problem it is proposed to perform accurate state-of-the art measurements on highly enriched samples of the stable Fe and Ni isotopes at the n_TOF facility. Transformation of these results into significantly improved stellar cross section rates will allow to disentangle the *s* and *r* contributions observed in the oldest stars for a reliable comparison with galactic chemical evolution models. These results are also very important for the design of advanced reactor concepts.





source: F Käppeler (Prog. Part. Nucl. Phys. 43, 1999)

weak: core He burning in massive stars (e.g. 8 solar masses)
main: He shell flashes in low mass TP-AGB stars

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Requested:
2×10^{18} protons/isotope to reach ~3% statistical uncertainty

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^{62}Ni(n,γ) and ^{63}Ni(n,γ) cross sections measured at the n_TOF facility at CERN
C. Lederer, C. Massimi, E. Berthoumieux, N. Colonna, R. Dressler, C. Guerrero, F. Gunsing, F. Käppeler, N. Kivel, M. Pignatari, et al. (The n_TOF Collaboration)
Physical Review C **89**, 025810 (2014)
10.1103/PhysRevC.89.025810
Erratum: Physical Review C **92**, 019903 (2015)
10.1103/PhysRevC.92.019903

Measurement of the ^{54,57}Fe(n,γ) Cross Section in the Resolved Resonance Region at CERN n_TOF
G. Giubrone, C. Domingo-Pardo, J.L. Tain, C. Lederer, S. Altstadt, J. Andrzejewski, L. Audouin, M. Barbagallo, V. Bécares, F. Bečvář, et al. (The n_TOF Collaboration)
Nuclear Data Sheets **119**, 117-120 (2014)
10.1016/j.nds.2014.08.033

Experimental neutron capture data of Ni-58 from the CERN n_TOF facility
P. Žugec, M. Barbagallo, N. Colonna, D. Bosnar, S. Altstadt, J. Andrzejewski, L. Audouin, V. Bécares, F. Bečvář, F. Belloni, et al. (The n_TOF Collaboration)
Physical Review C **89**, 014605 (2014)
10.1103/PhysRevC.89.014605

Neutron Capture Reactions on Fe and Ni Isotopes for the Astrophysical s-process
C. Lederer, G. Giubrone, C. Massimi, P. Žugec, M. Barbagallo, N. Colonna, C. Domingo-Pardo, C. Guerrero, F. Gunsing, F. Käppeler, et al. (The n_TOF Collaboration)
Nuclear Data Sheets **120**, 201-204 (2014)
10.1016/j.nds.2014.07.046

Neutron Capture Cross Section of Unstable Ni-63: Implications for Stellar Nucleosynthesis
C. Lederer, C. Massimi, S. Altstadt, J. Andrzejewski, L. Audouin, M. Barbagallo, V. Bécares, F. Bečvář, F. Belloni, E. Berthoumieux, et al. (The n_TOF Collaboration)
Physical Review Letters **110**, 022501 (2013)
10.1103/PhysRevLett.110.022501

The Role of Fe and Ni for s-process Nucleosynthesis and Innovative Nuclear Technologies
G. Giubrone, J. L. Tain, C. Lederer, A. Pavlik, A. Wallner, S. Andriamonje, M. Brugger, M. Calviani, F. Cerutti, E. Chiaveri, et al. (The n_TOF Collaboration)
Journal of the Korean Physical Society **59**, 2106-2109 (2011)
10.3938/jkps.59.2106

^{54,57}Fe(n,γ)
^{58,62,63}Ni(n,γ) already measured and published

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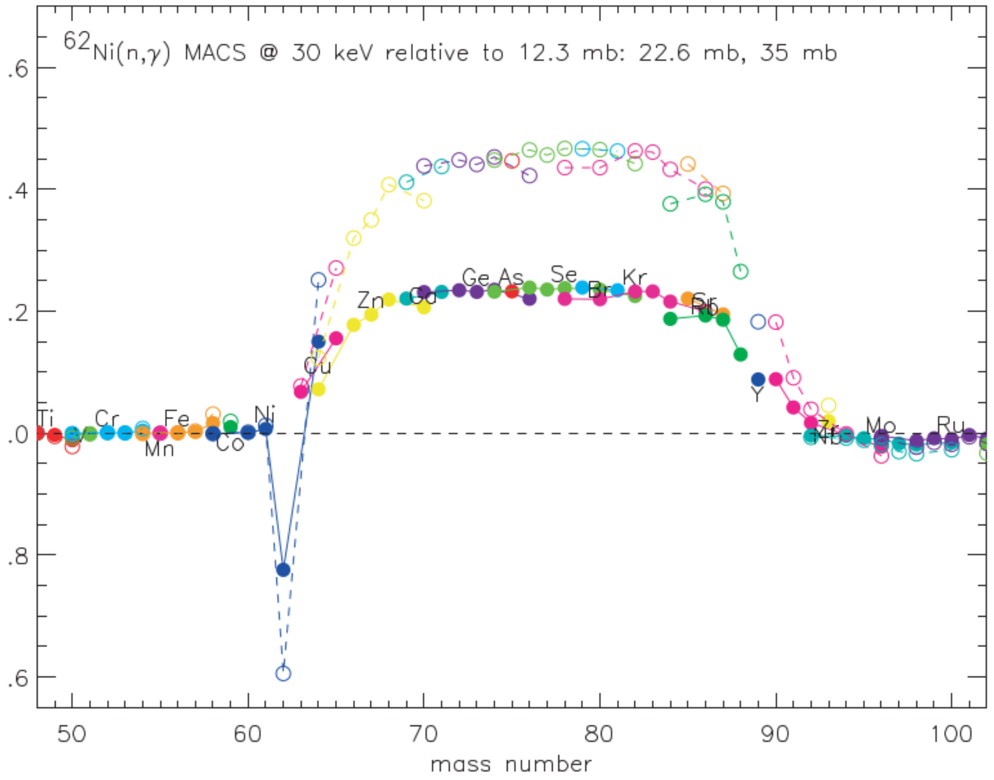

FIG. 3: The effect of cross section uncertainties on the *s*-process efficiency in massive stars illustrated at the example of ^{62}Ni [13] (see text).

Requested:
2 x 10^{18} protons/isotope to reach ~3% statistical uncertainty

Addendum to the Proposal INTC-P-208 - Measurement of the neutron capture cross section of ^{64}Ni

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Addendum of the Proposal INTC-P-208

Measurement of the neutron capture cross section of ^{64}Ni

G. Tagliente[1], G. Cescutti[2,3], N. Colonna[1], S. Cristallo[4,5], D. Diacono[1], C. Lederer-Wood[6], C. Massimi[7,8], M. Mastromarco[1,9], A.M. Mazzone[1,10], P.M. Milazzo[3], N. Sosnin[11], D. Vescovi[12]

The following document is an addendum to the proposal INTC-P-208 [1], approved in 2006, concerning the measurement of the neutron capture cross-section of highly enriched samples of the stable Fe and Ni isotopes. The proposed measurements aimed at improving the existing cross section data of interest for the *s*-process nucleosynthesis in *Massive* stars and for innovative nuclear technologies.
In the past years the neutron capture cross sections of the ^{54,57}Fe, ^{58,62,63}Ni isotopes has been successfully performed at the n_TOF experimental area 1 (EAR1), the results of this work together with the astrophysical implications are reported in several publications and conference proceedings [2,3,4].
The measurement of the ^{64}Ni(n,γ) has been postponed in the past due to the cost of the sample, while now it can be performed using small quantities of ^{64}Ni, taking advantage of the higher neutron flux available in the n_TOF experimental area 2 (EAR2).

Together with the astrophysical motivations exhaustively mentioned in the original proposal [1], a further important reason for measuring neutron capture reactions of the ^{64}Ni is that the Maxwellian Averaged Cross Section (MACS) suffers for severe discrepancies, amongst the databases available in literature, as showed in Fig 1.

Addendum to the Proposal INTC-P-208 - Measurement of the neutron capture cross section of ^{64}N -

Moreover, recent magnetic Asymptotic Giant Branch models [5] were found to be in disagreement with respect to nickel isotopic ratios measurements in presolar SiC grains (see Fig. 2). Note that other nickel isotopic ratios are well matched by theoretical models.

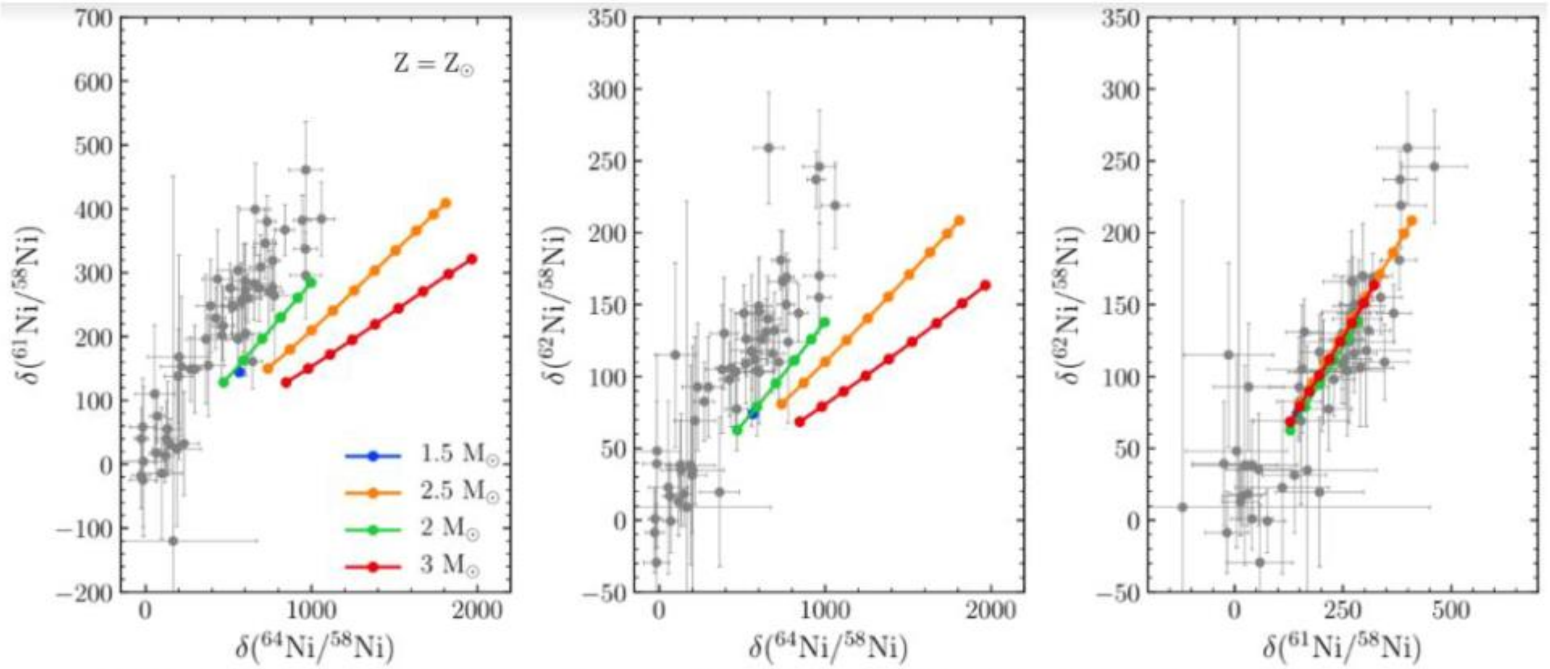

Figure 2 Comparison between theoretical AGB models and presolar grain measurements.

Addendum to the Proposal INTC-P-208 - Measurement of the neutron capture cross section of ^{64}Ni

Availability of Ni-64 sample material

ISOFLEX USA
Isotopes for Science, Medicine and Industry

P.O. Box 29475
San Francisco CA 94129 USA
Tel: 415-440-4433 Fax: 415-563-4433
Email: iusa@isoflex.com
FEIN: 20-8066748

QUOTATION

Confidential Business Matter

DATE: June 30, 2021
QUOTE NUMBER: 210630-I/R
SELLER CONTACT: Allan Pashkovski

BUYER:
Attn: Dr. Giuseppe Tagliente
INFN Bari
Via Orabona, 4
Bari 70125
Italy
giuseppe.tagliente@ba.infn.it
Tel. +390805442351

CONSIGNEE / SHIP TO:
TBD

QUOTATION SUMMARY

DESCRIPTION	PROPOSED DELIVERY	QUANTITY	UNIT PRICE	SUBTOTAL
Nickel-64 (Ni-64), metal powder **Isotopic Enrichment:** 99,33atom% **Harmonized Code:** - 2845.90.0000 (USA)	~4 weeks ARO	2000 mg	$31.50 per mg	$63,000.00

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Università di Trieste, Dipartimento di Fisica, Trieste, Italy
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Istituto Nazionale di Fisica Nucleare, Sez. di Bologna, Italy
Università di Bologna, Dipartimento di Fisica e Astronomia, Bologna, Italy
Università degli Studi di Bari, Dipartimento Interateneo di Fisica, Bari, Italy
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University of Manchester, United Kingdom
Goethe University Frankfurt, Max-von-Laue-Strasse 1, Frankfurt am Main 60438, Germany

CERN

nTOF

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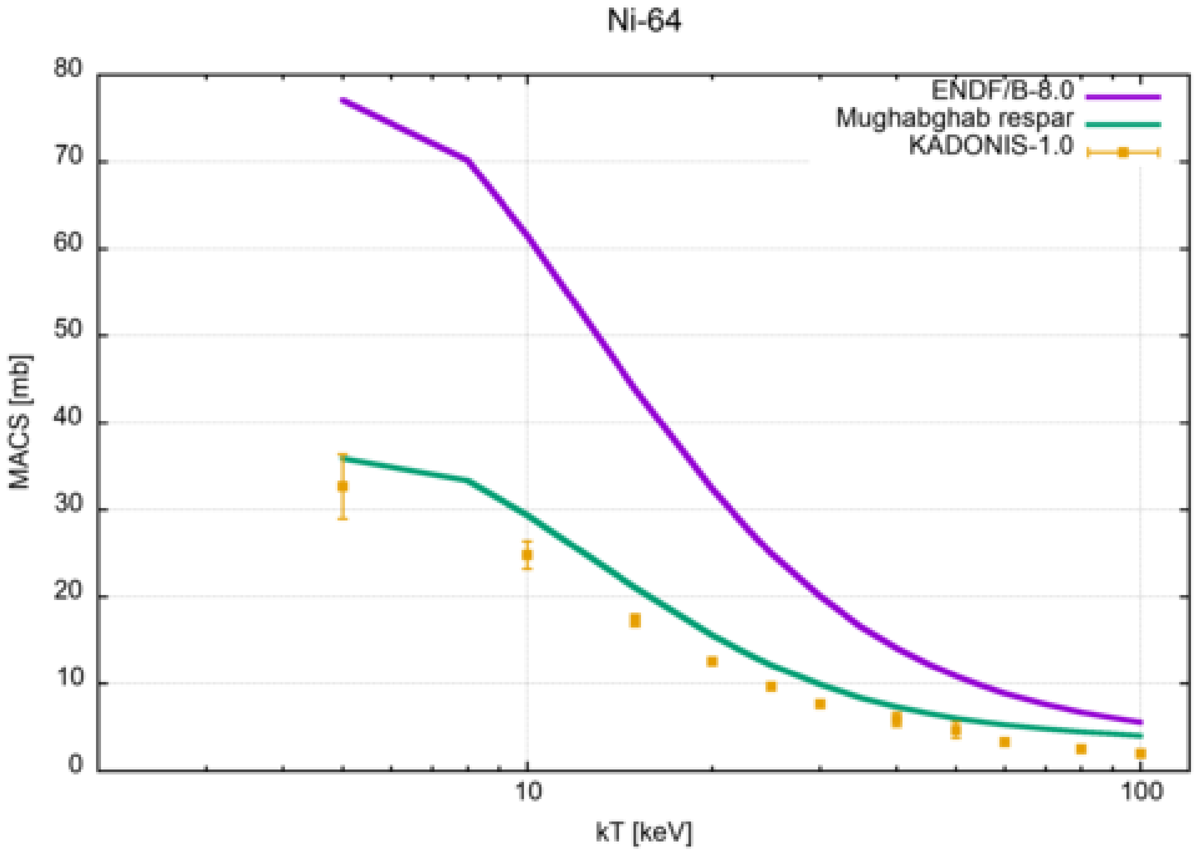
Significant discrepancies on data previously available



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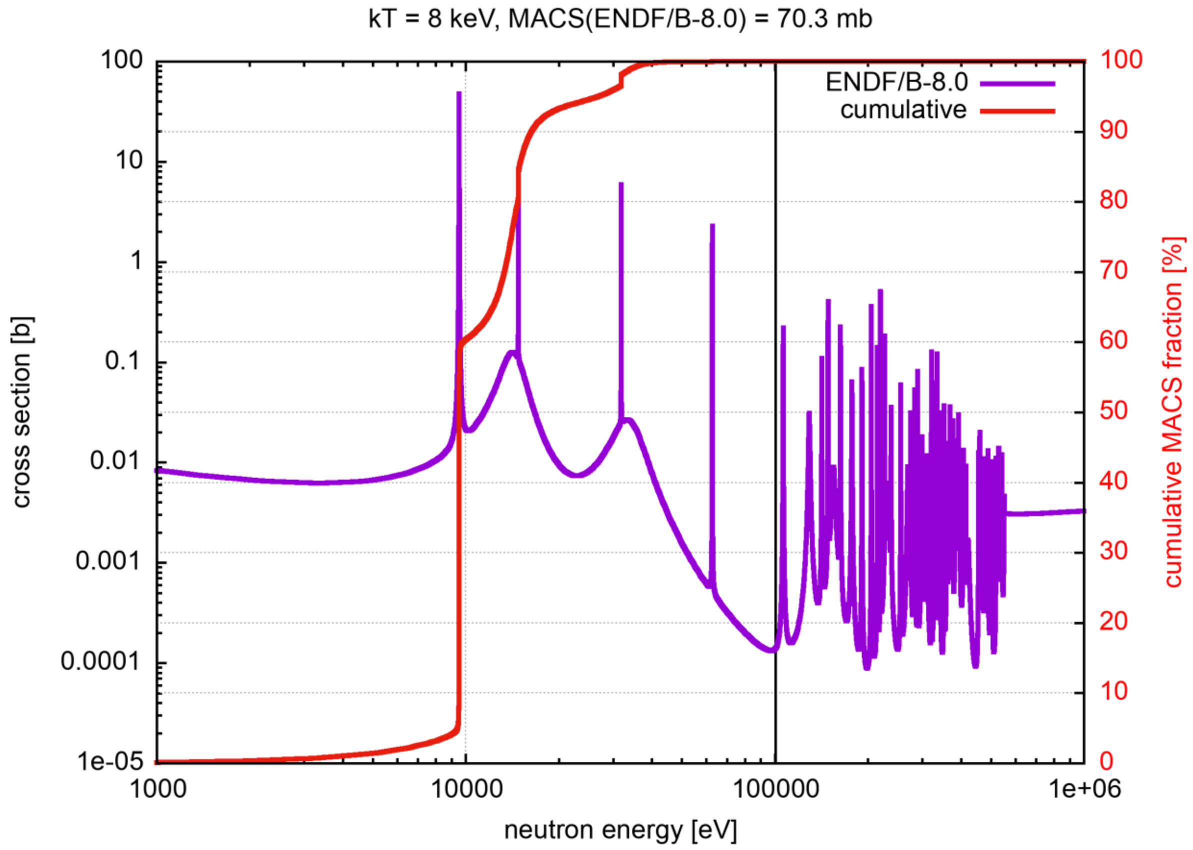

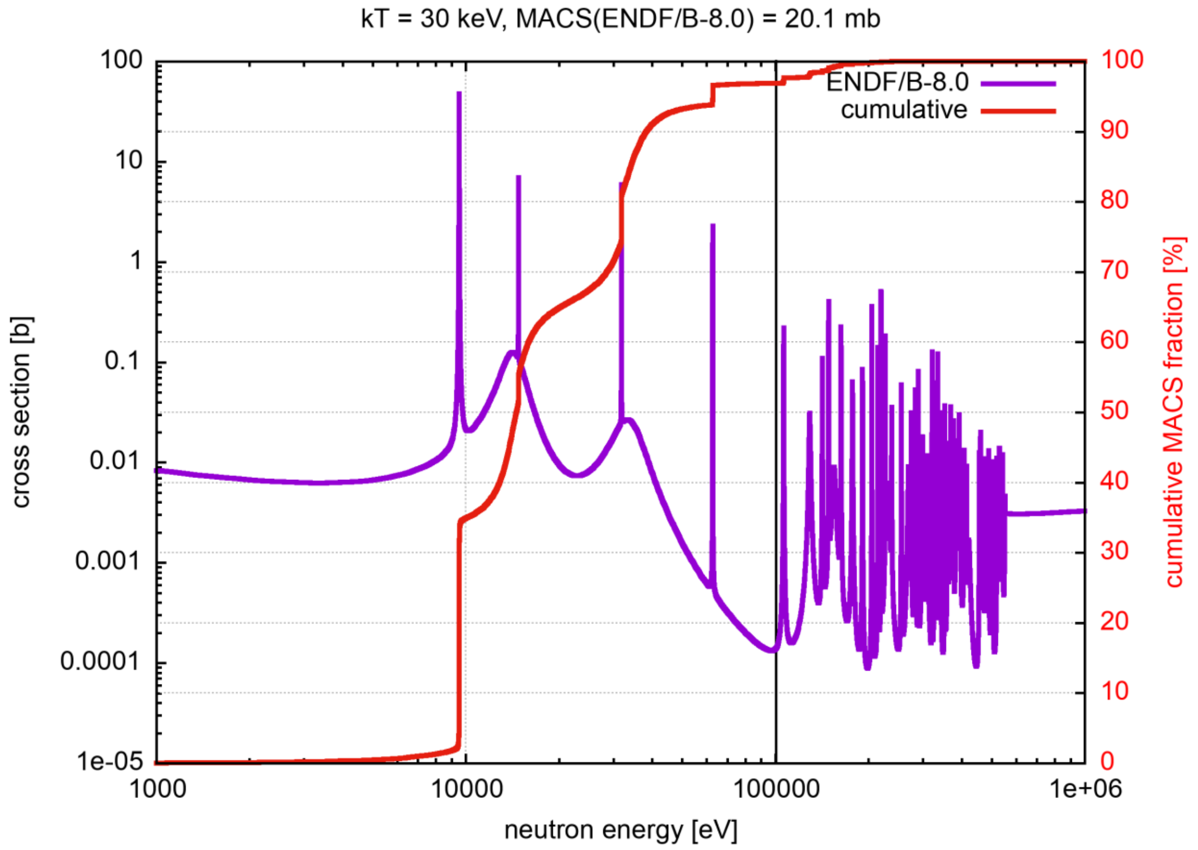

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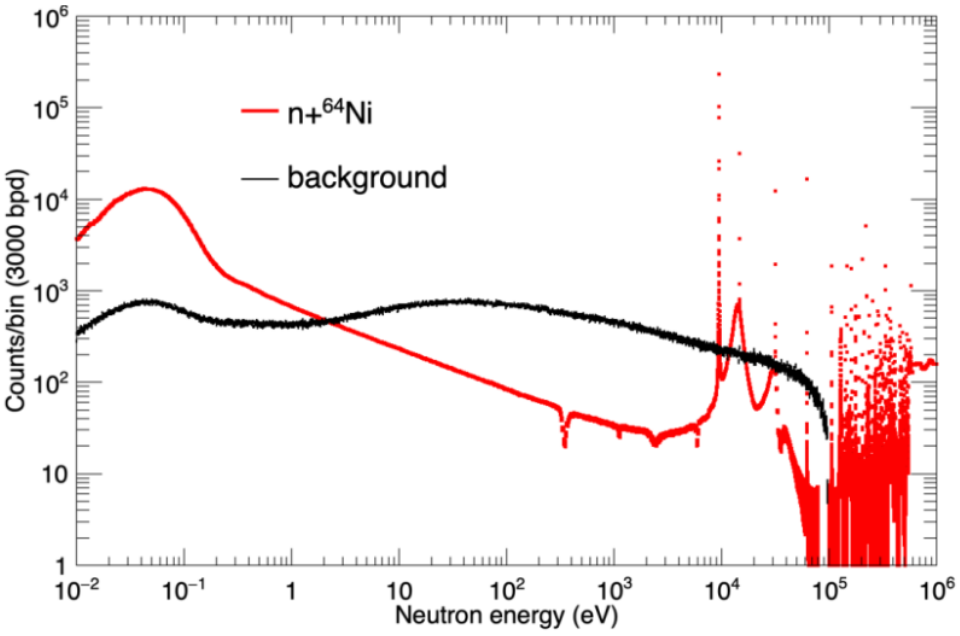

Figure 3. Expected counting rate for the ^{64}Ni using mono-isotopic sample of 200 mg in EAR2. In the calculation the neutron irradiation corresponds to an intensity of 1.0 x 10^{18} protons. The black line represents the expected background level during measurement.

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University of Manchester, United Kingdom
Goethe University Frankfurt, Max-von-Laue-Strasse 1, Frankfurt am Main 60438, Germany

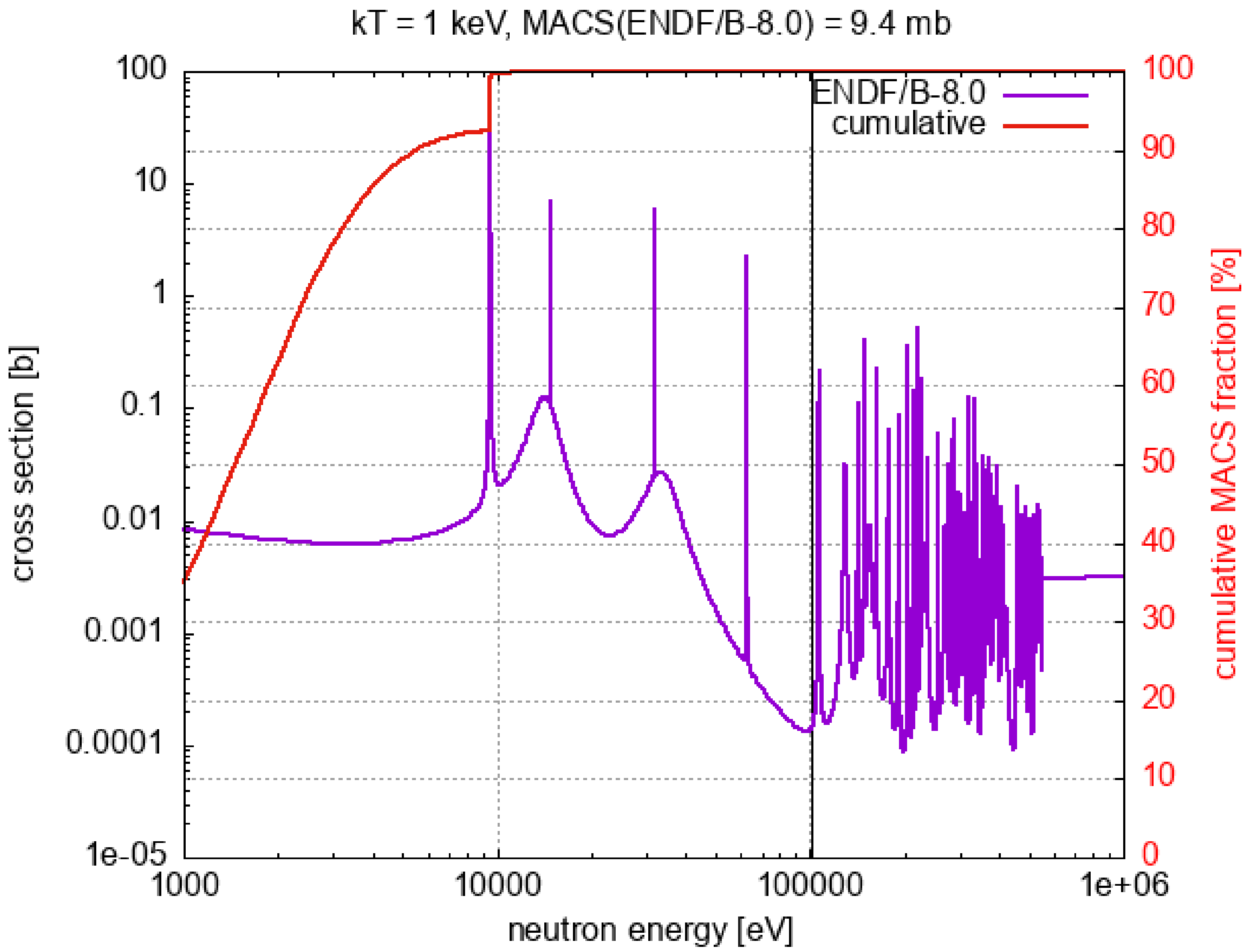
Request:

1.5 x 10^{18} protons in EAR2 to reach ~5% statistical uncertainty

(reduced with respect to the original proposal due to the higher neuron flux in EAR2)

The End

Addendum to the Proposal INTC-P-208 - Measurement of the neutron capture cross section of ^{64}Ni



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$^{64}_{28}Ni$ $^{64}_{28}Ni$

THERMAL CROSS SECTIONS

σ_γ^0=1.63±0.02 b
σ_s^0=0.014±0.005 b
σ_t^0=1.64±0.02 b
b_{coh}=−0.38±0.07 fm
g_γ =1.004
R' =6.97±0.30 fm

RESONANCE PROPERTIES

D_0=21.1±2.0 keV
D_1= 9.2±0.6 keV
S_0=2.6±0.7
S_1=0.77±0.14
I_γ=1.07±0.15 b
I_γ^c=0.76±0.06 b
$\sigma_\gamma{}^c$(5 keV) =26.1±5.2 mb
σ_γ(30 keV)=7.66±0.26 mb
$\sigma_\gamma{}^c$(30 keV) =8.7±0.6 mb

RESONANCE PARAMETERS

I^π = 0+ %Abn = 0.926 Sn = 6098.09±0.14 keV
σ_γ(+) = 0.72 b σ_γ(B) = 0.91 b σ_γ(D) = 1.37 b

E_0 (keV)	J	l	$g\Gamma_n$ (eV)	Γ_γ (eV)	$g\Gamma_n^0$ (eV)	$g\Gamma_n^1$ (eV)	$g\Gamma_n\Gamma_\gamma/\Gamma$ (eV)
−1.01	1/2	0		(1.04)	0.19		
9.571±0.100	(3/2)	[1]	(7)	0.4			
14.3 ±0.2	1/2	0	2900 ±500	1.01 ±0.07	24 ±4		1.01±0.07
14.8 ±0.1	(1/2)	[1]	(10)	0.25			
31.8 ±0.1	(3/2)	[1]	(10)	0.41			
33.81 ±0.04	1/2	0	8900 ±500	1.16 ±0.08	48 ±3		1.16±0.08
62.8 ±0.4	(3/2)	[1]	(20)	0.44			
106.52 ±0.08		1	110 ± 30			2.6 ±0.7	
129.32 ±0.03	1/2	0	1400 ± 50		3.89 ±0.14		
141.5 ±0.1		1	170 ± 20			2.7 ±0.3	
148.8 ±0.1	1/2	0	80 ± 20		0.21 ±0.05		
155.0 ±0.1	1/2	0	3950 ±100		10.0 ±0.3		
163.2 ±0.1	1/2	0	160 ± 20		0.40 ±0.05		
177.7 ±0.1	1/2	0	470 ± 30		1.11 ±0.07		
191.0 ±0.2		1	140 ± 30			1.5 ±0.3	
205.3 ±0.2	1/2	0	60 ± 20		0.13 ±0.04		