INDIRECT REACTION STUDIES FOR ASTROPHYSICS AT CMU

Georgios Perdikakis, Central Michigan University

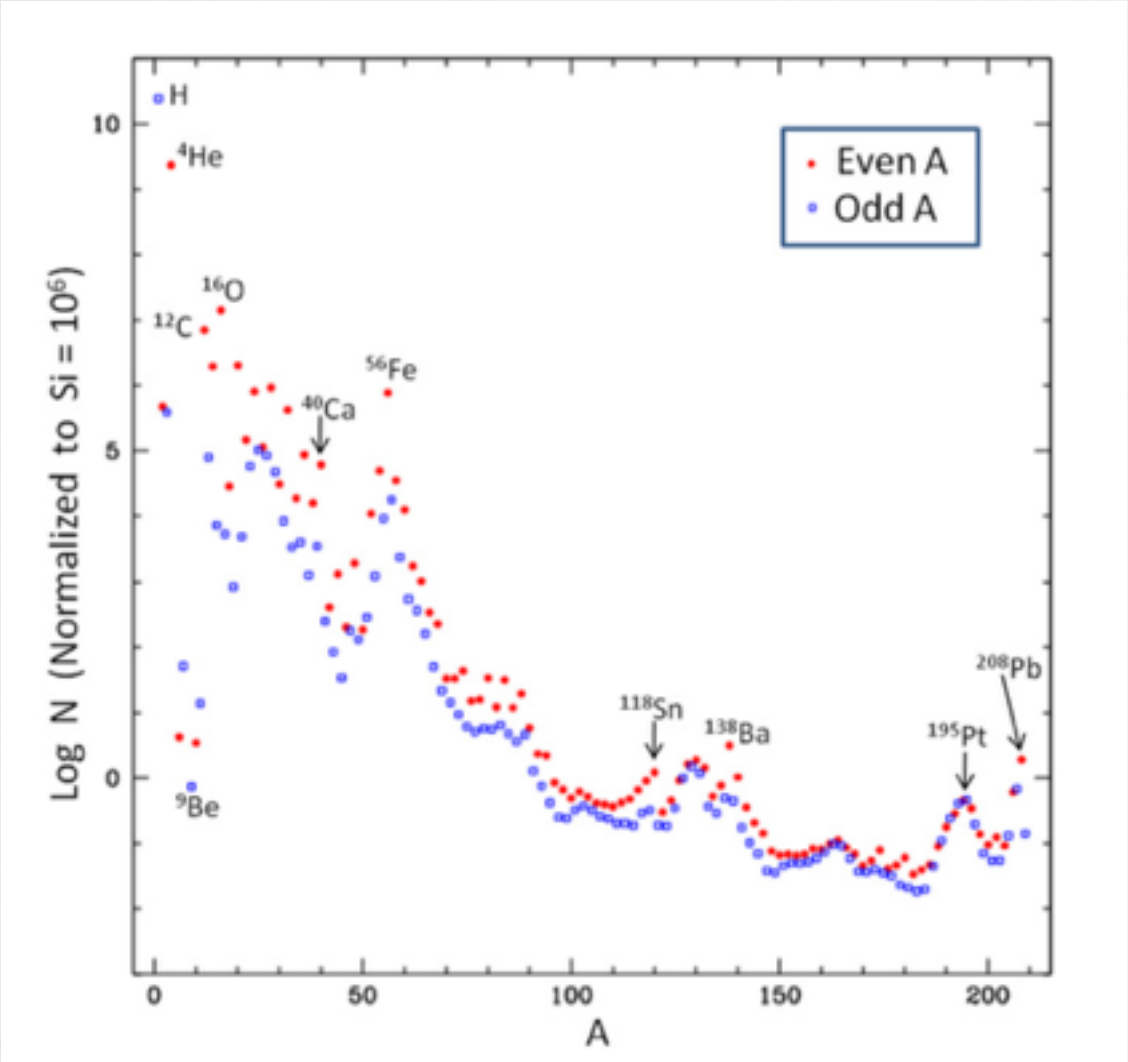
OUTLINE

Motivation

Reaction studies with light nuclei for r-process

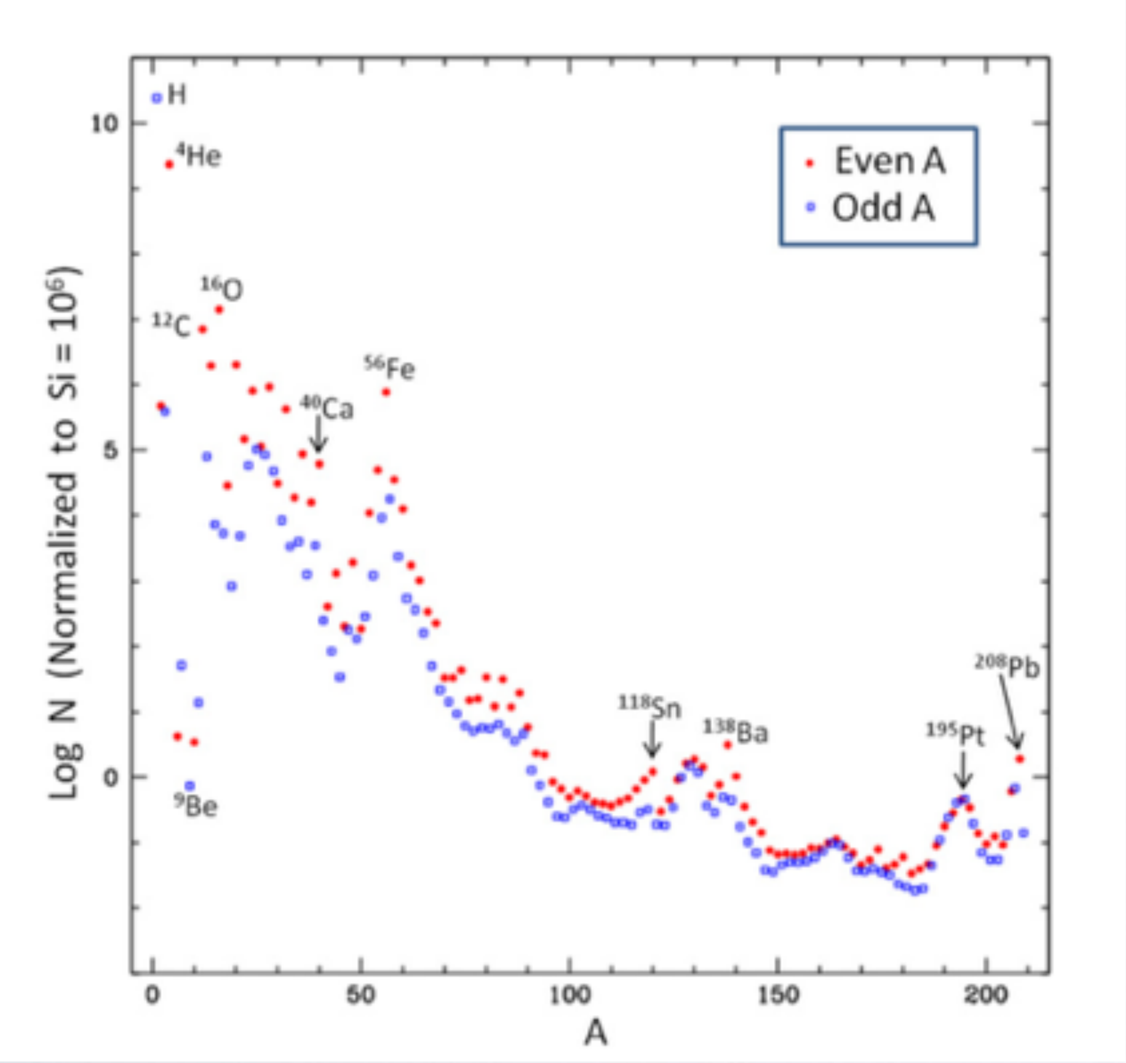
Reaction studies for νp-process

Summary



Log N (Normalized to Si = 10^6)
A
Even A
Odd A
H
4He
12C
16O
56Fe
40Ca
9Be
118Sn
138Ba
195Pt
208Pb
10
5
0
50
100
150
200

IS THERE AN R PROCESS?



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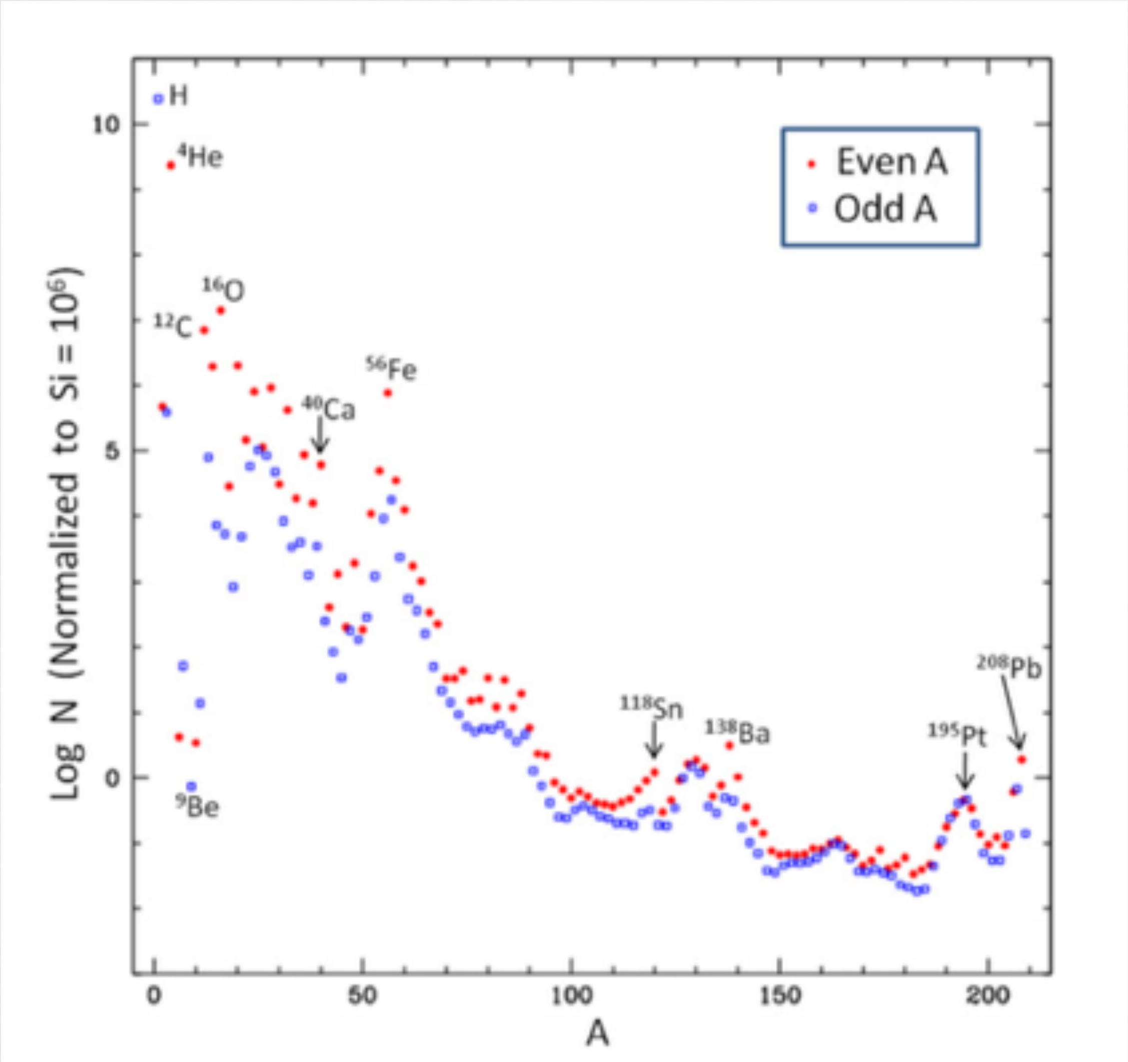

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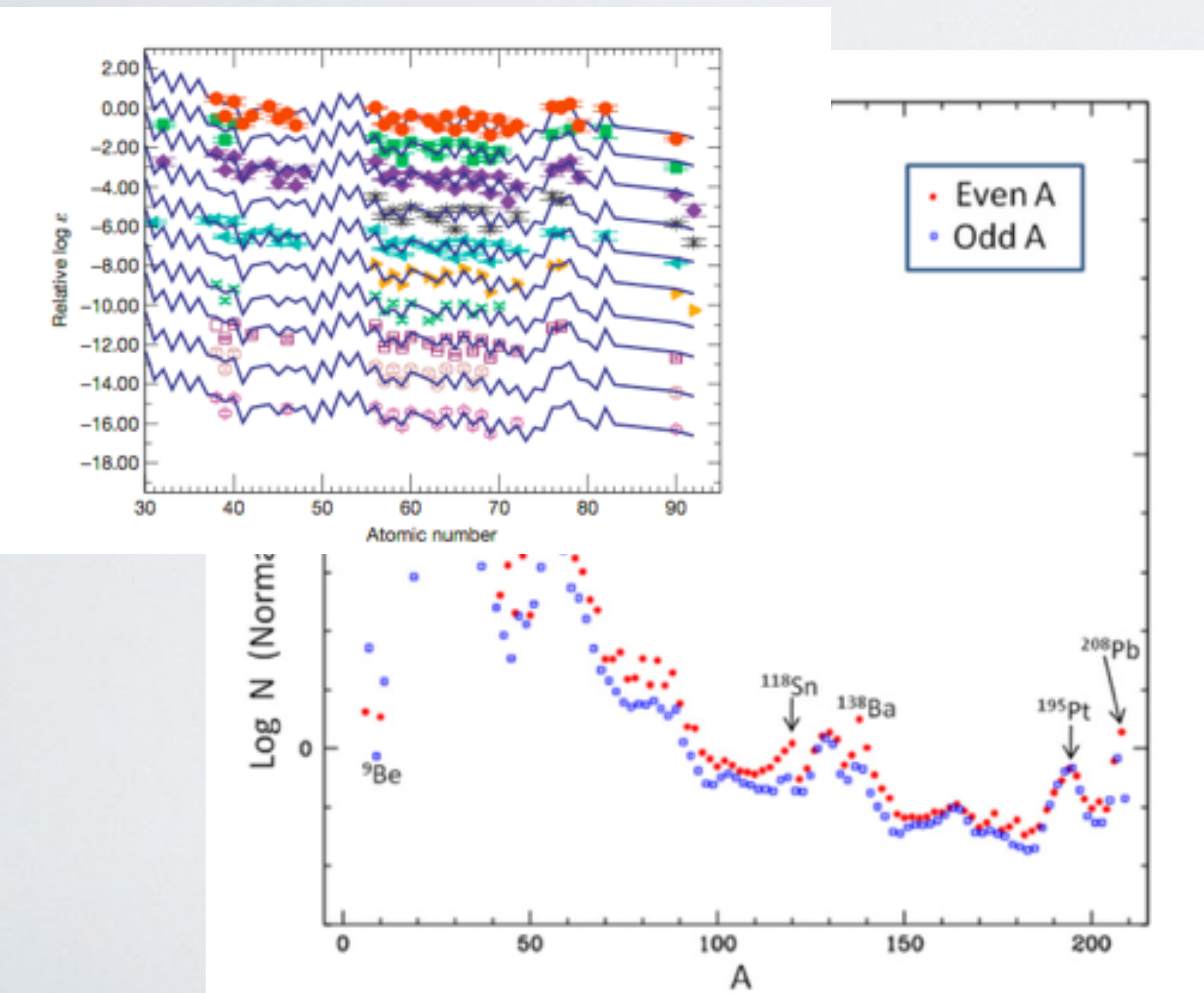

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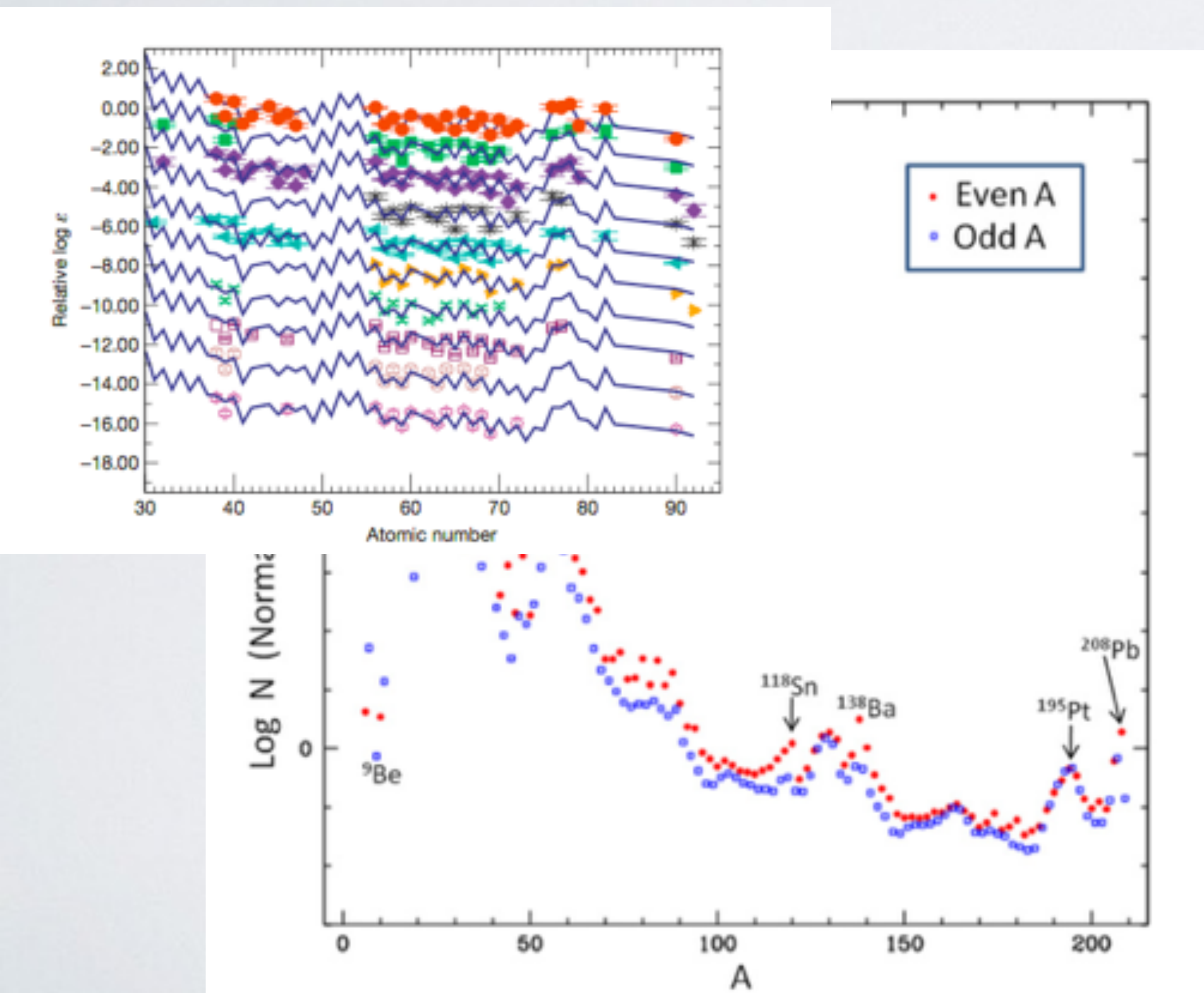

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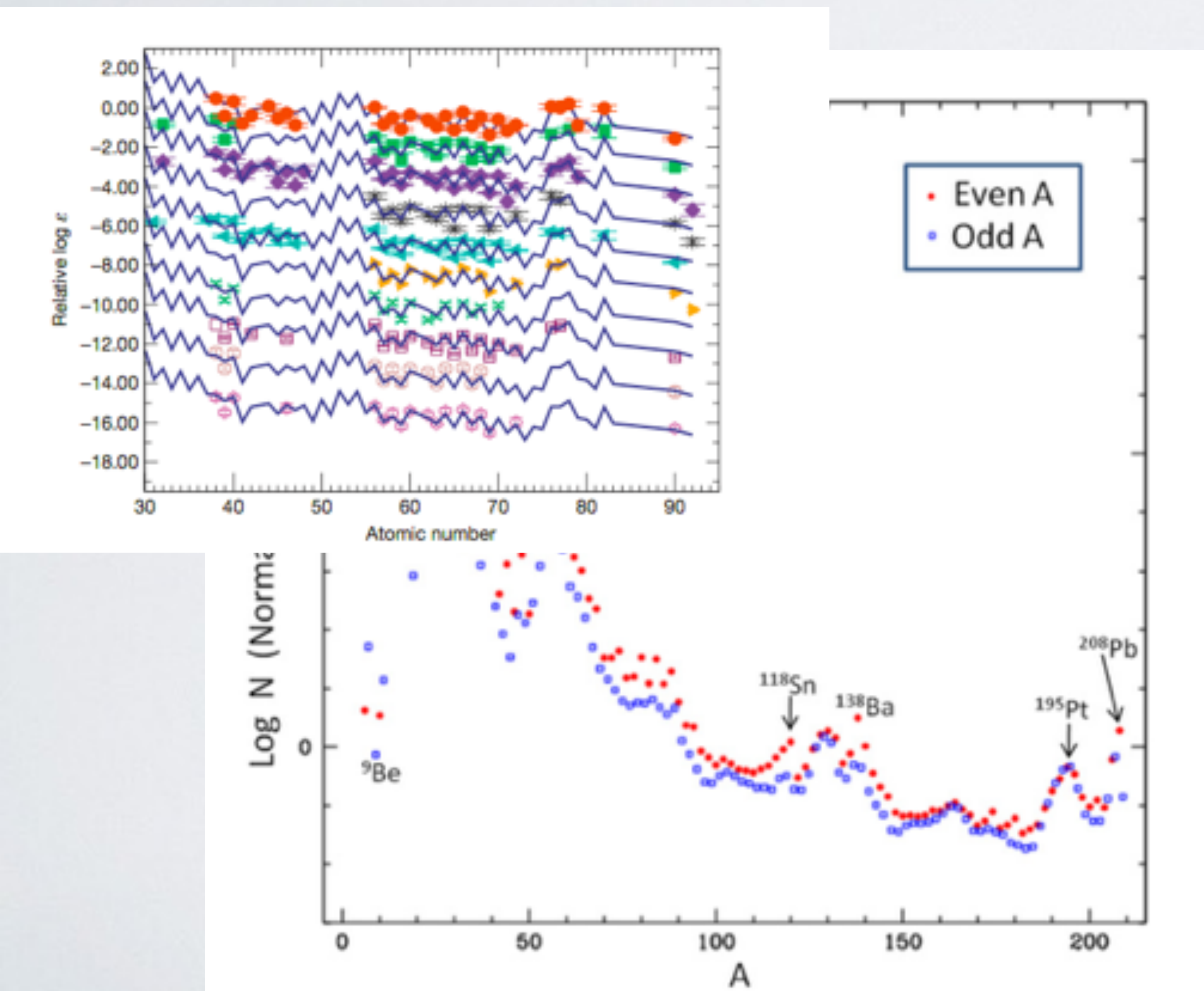

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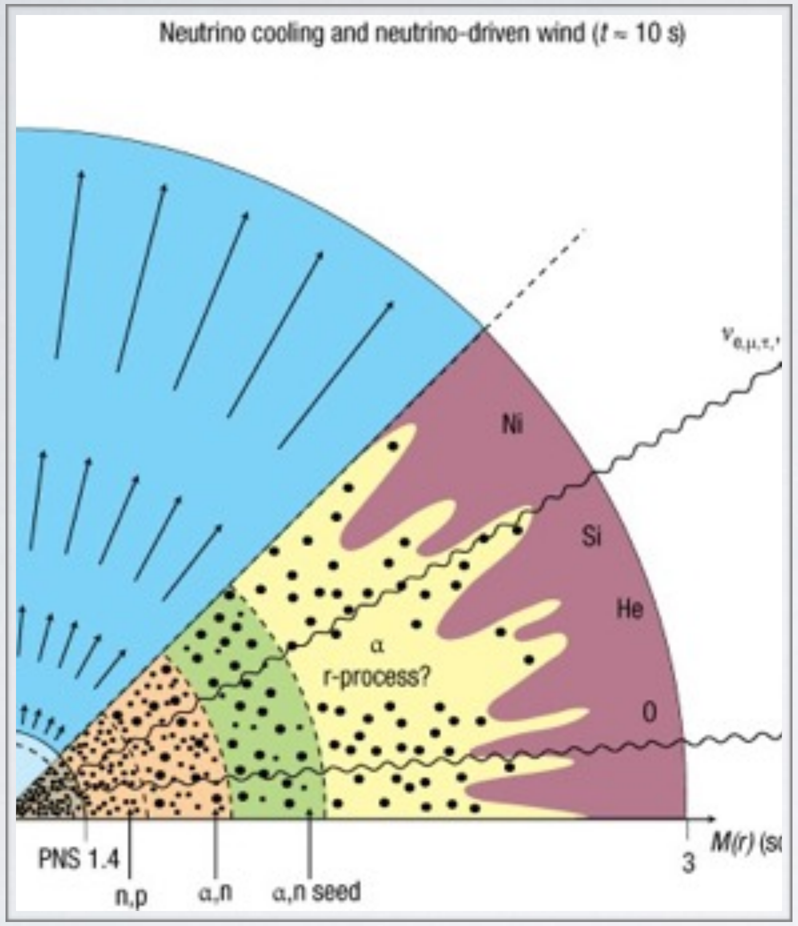
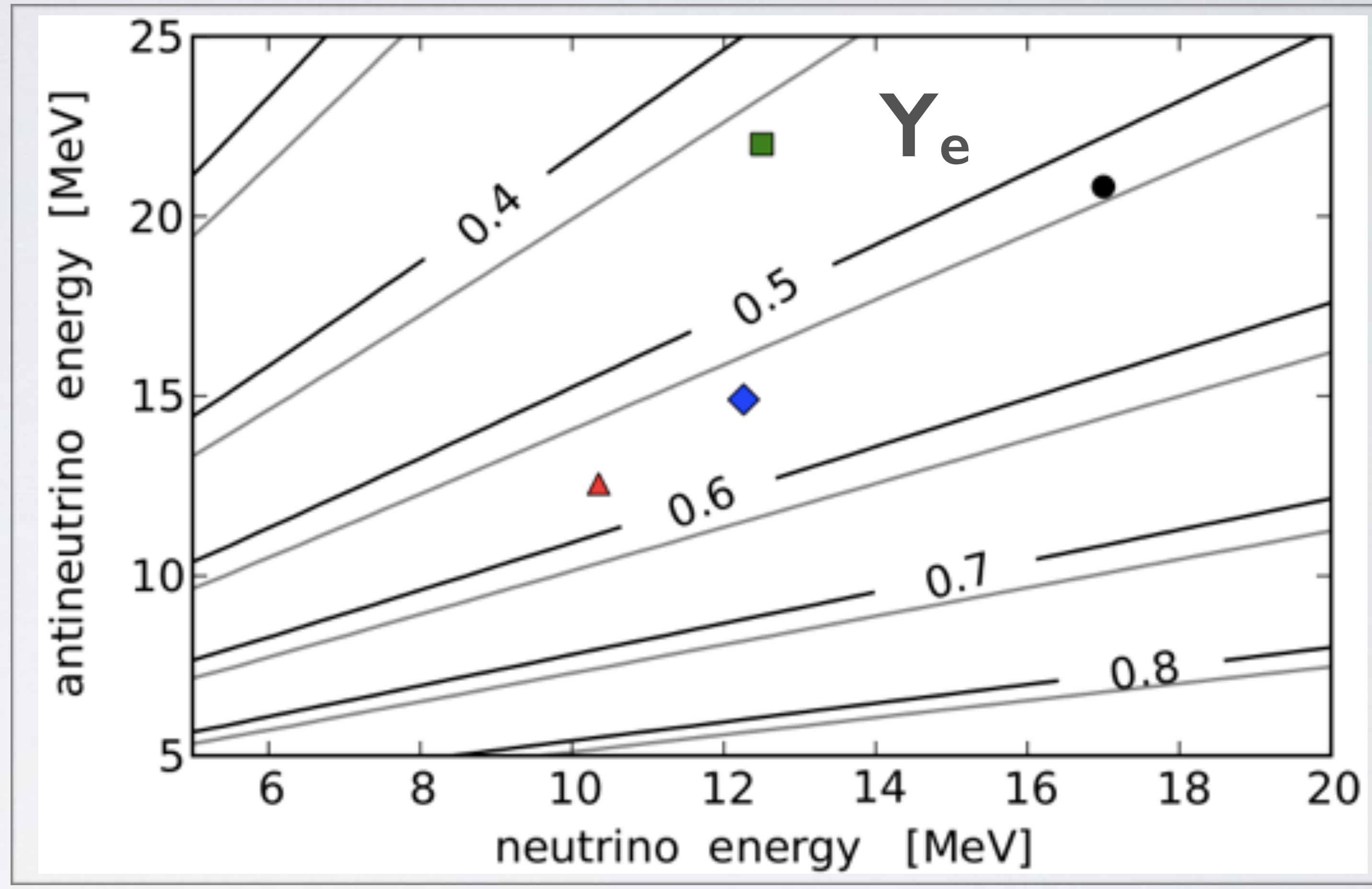


S. Woosley, H.T. Janka, 2005



A. Arcones, and F.K Thielemann, 2013

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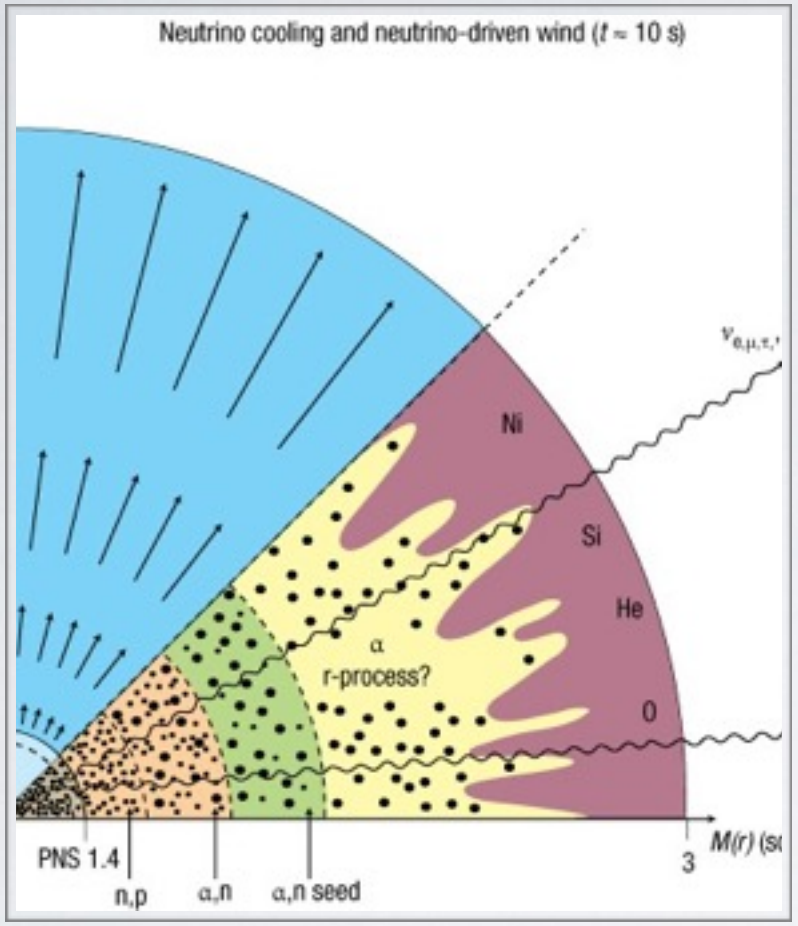

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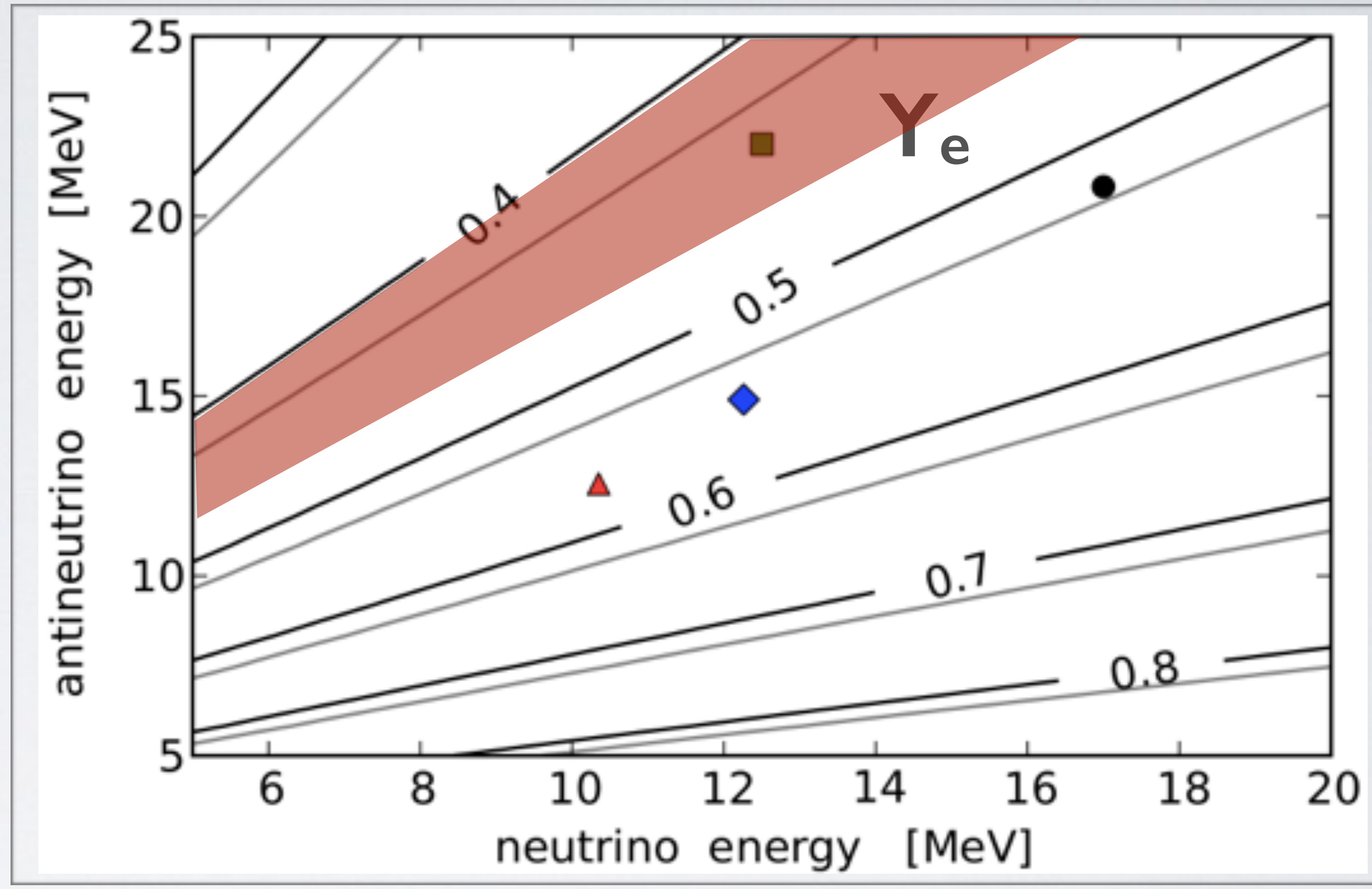

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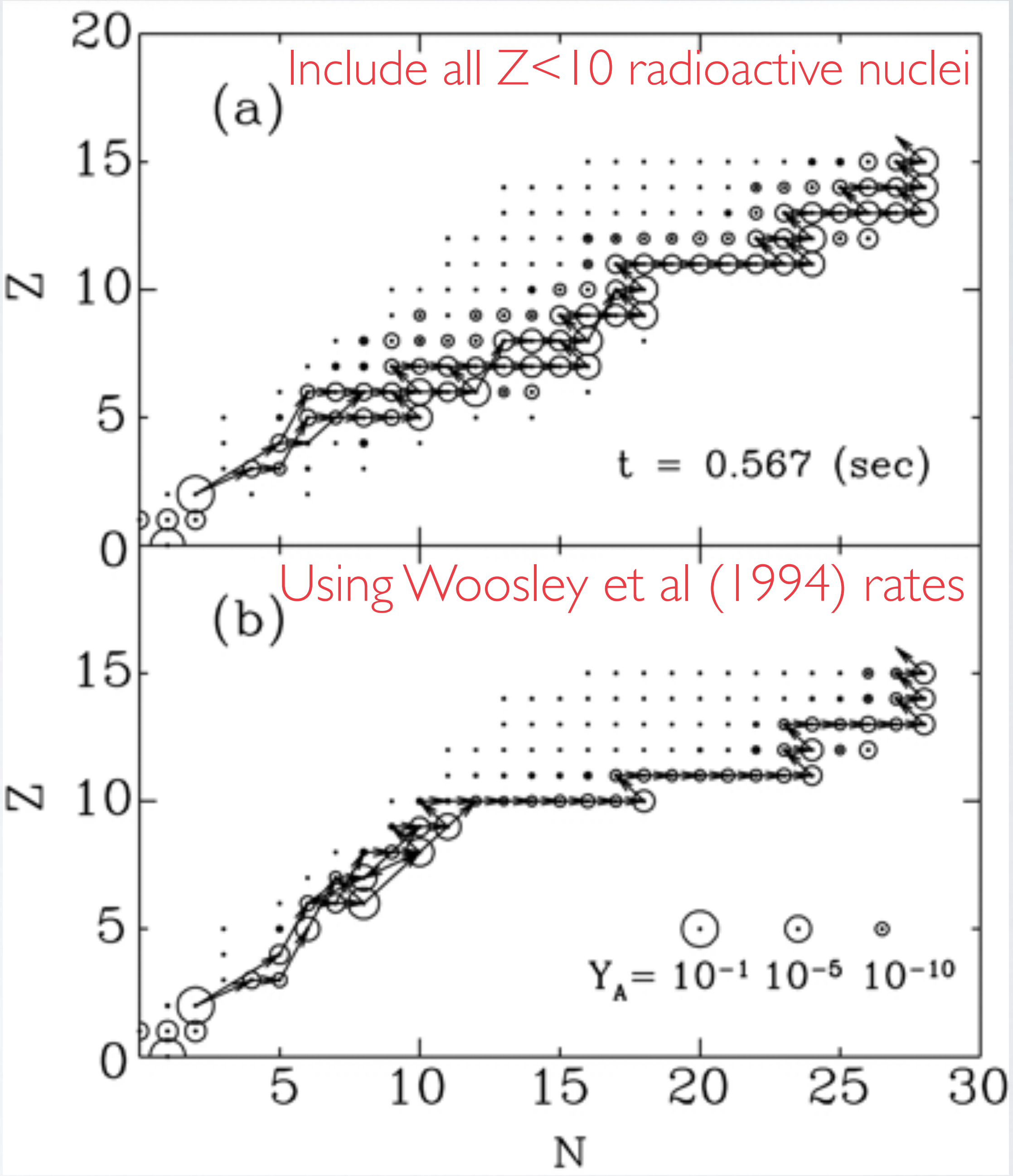
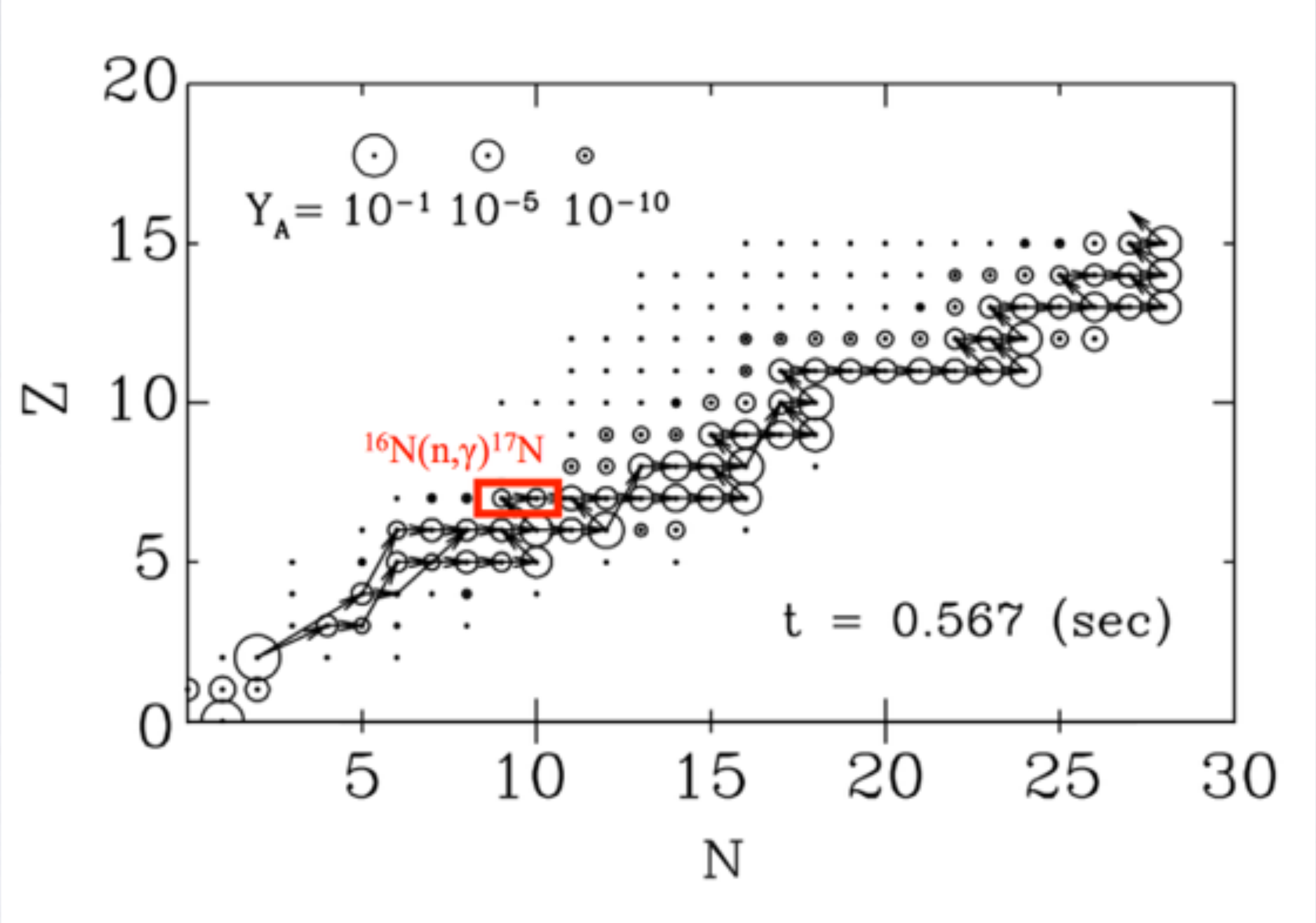
Inclusion of light nuclei reaction rates matters

- Y_e~0.4
- S/k~100-300
- Expansion timescale ~ 5ms
- accessible to RIB facilities
- test grounds for theory?



Terasawa et al 2001
Sasaqui et al 2005

$^{16}N(d,p)^{17}N$ - one neutron transfer

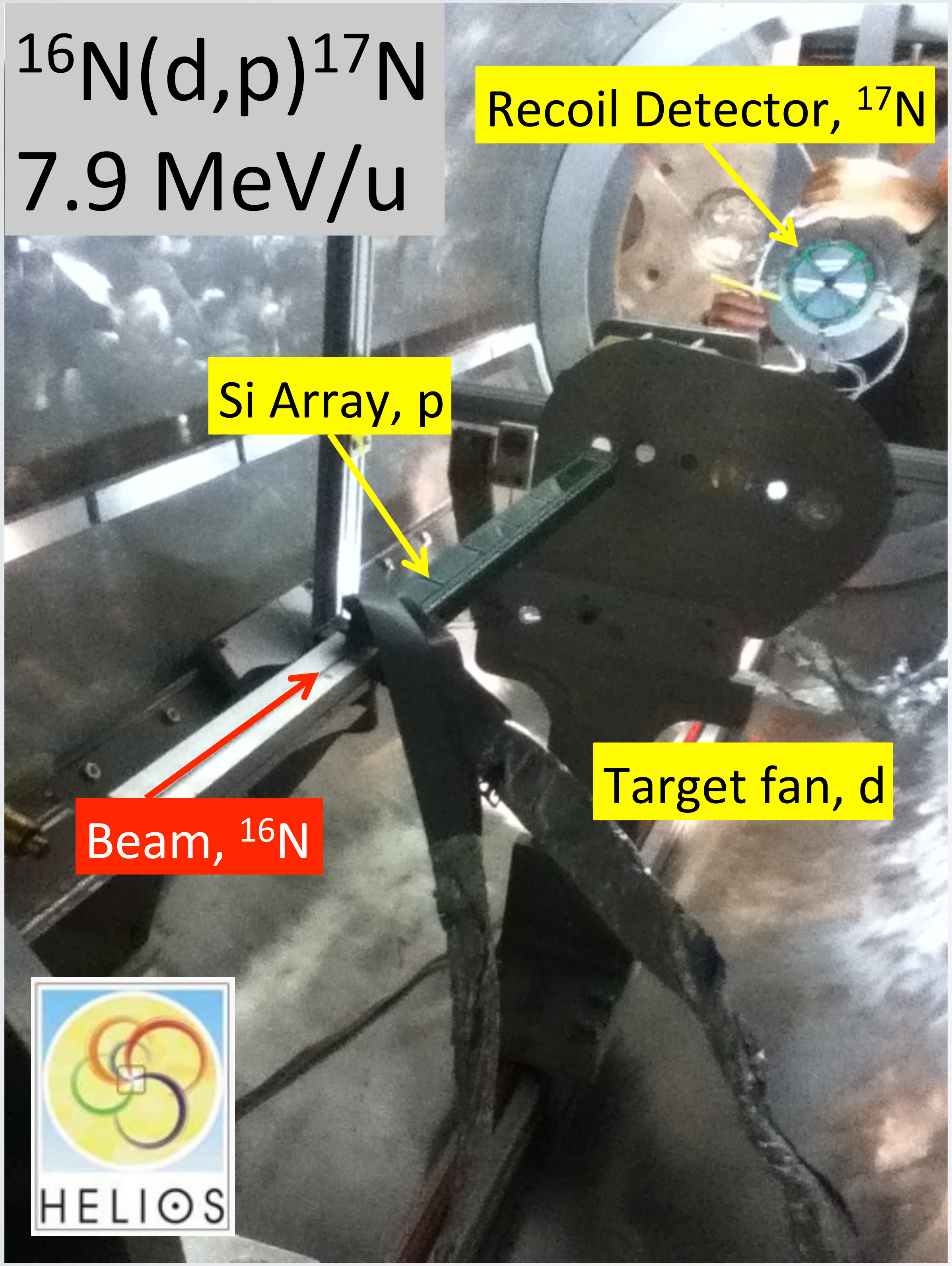


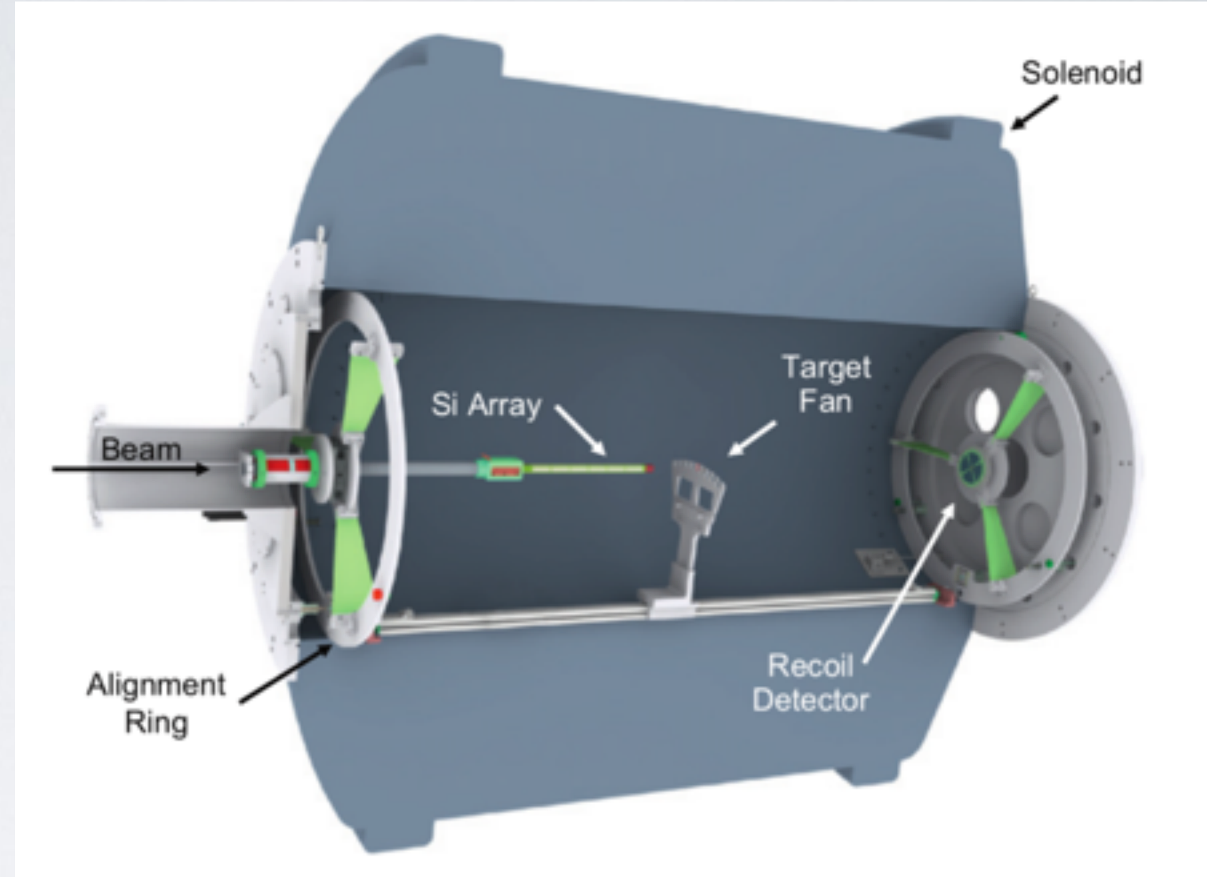
direct neutron capture

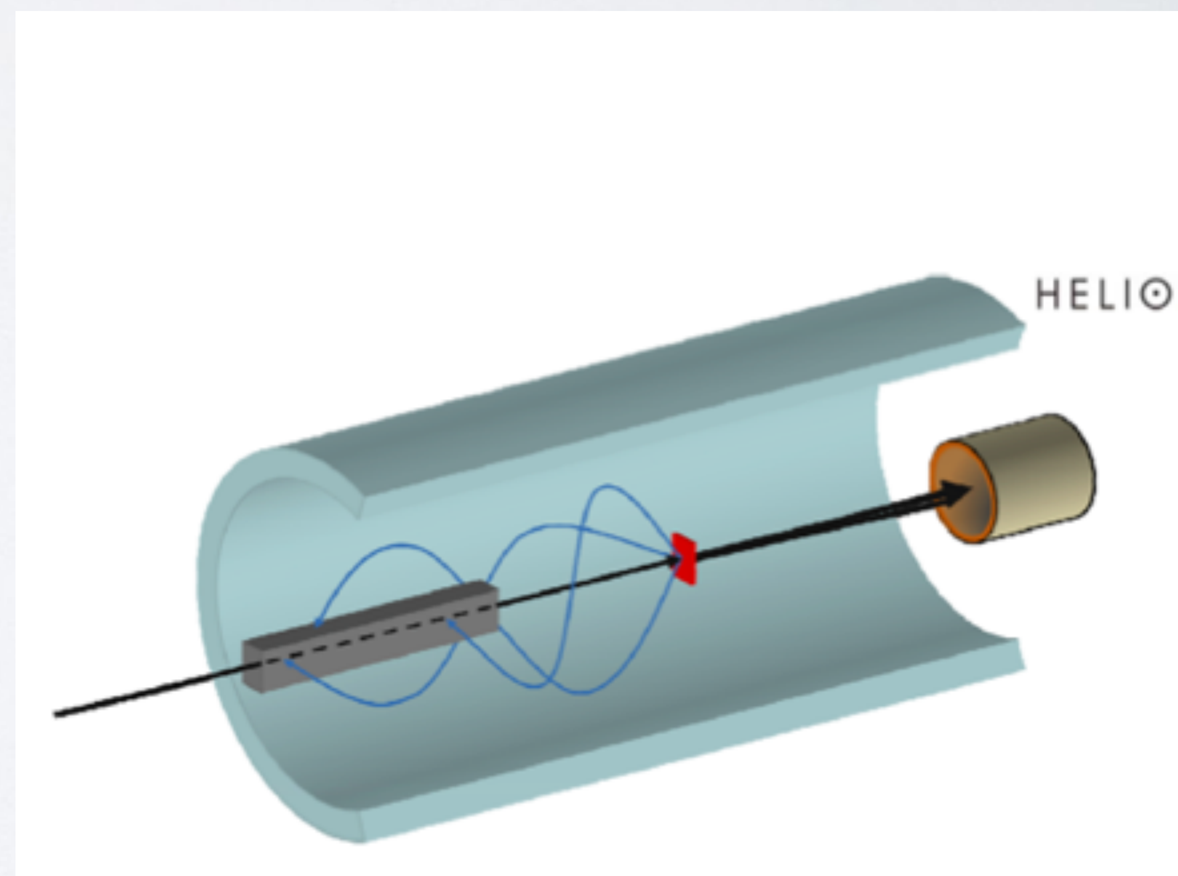
decay of resonances

THE HELIOS SPECTROMETER

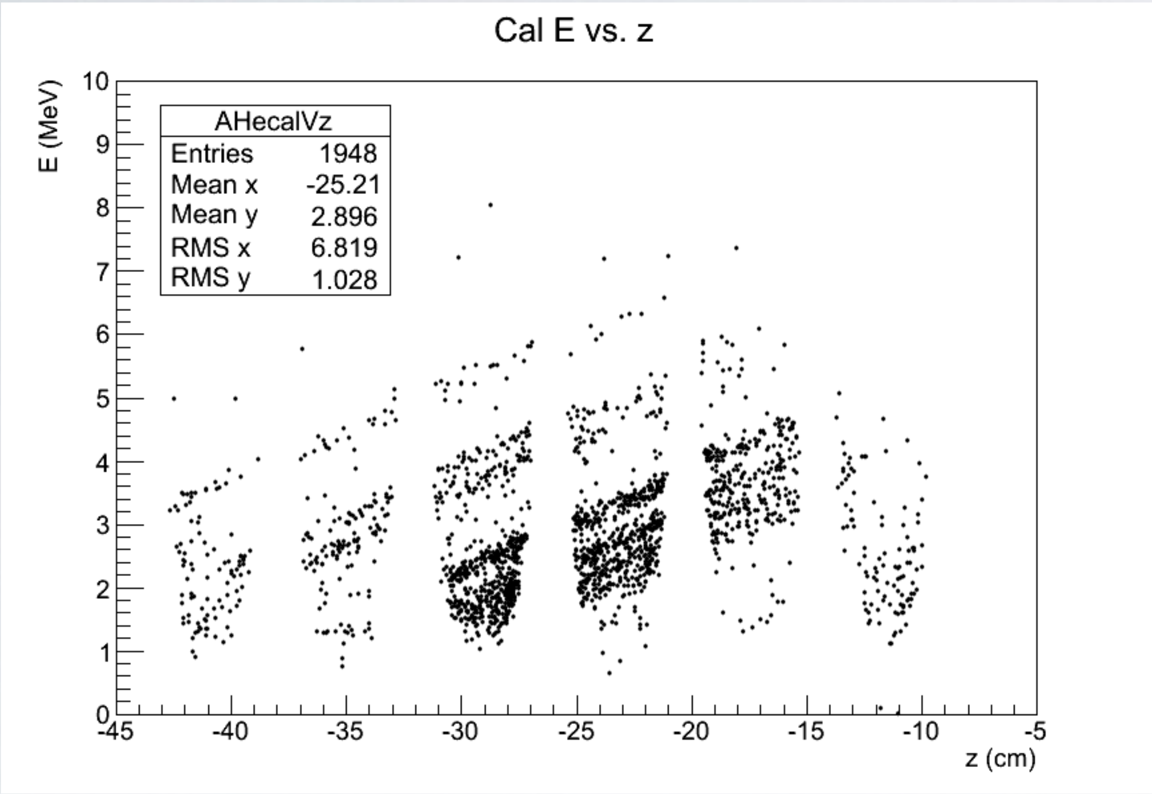
ARGONNE NATIONAL LABORATORY

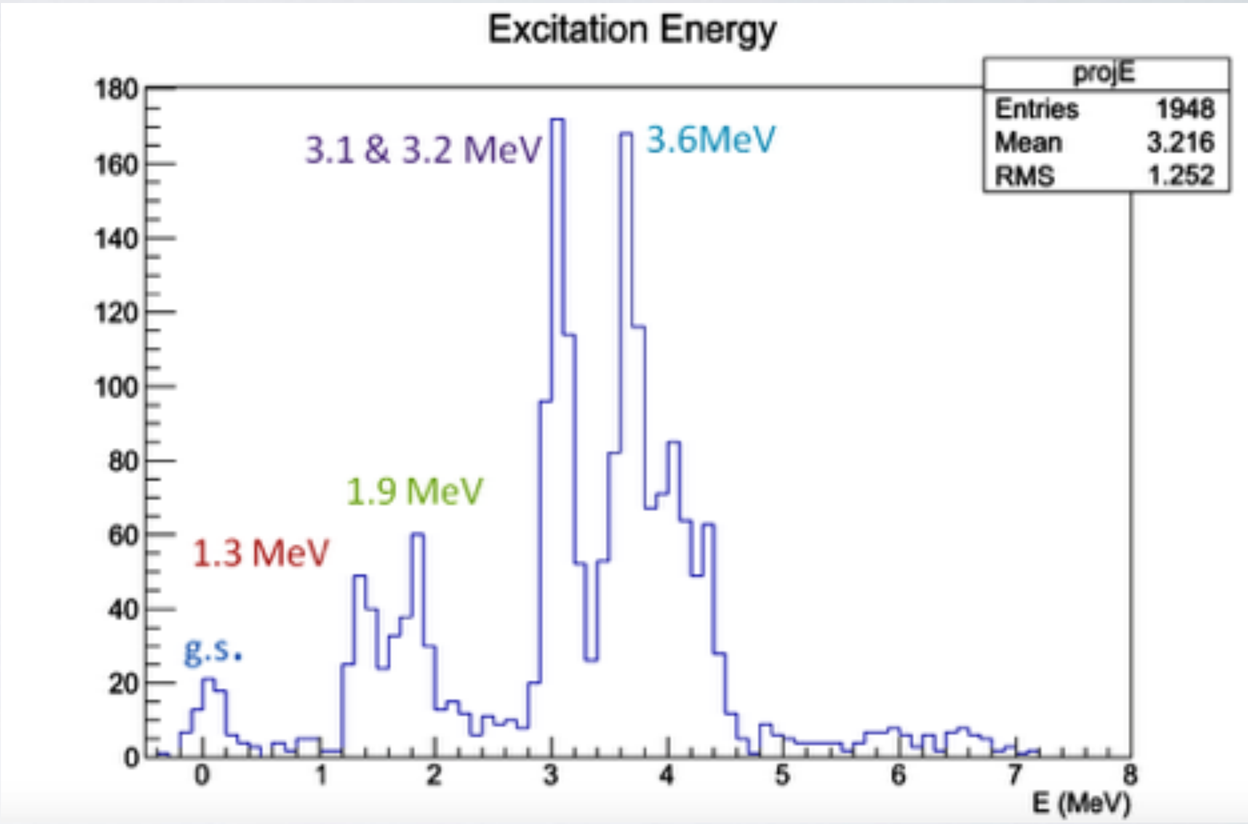


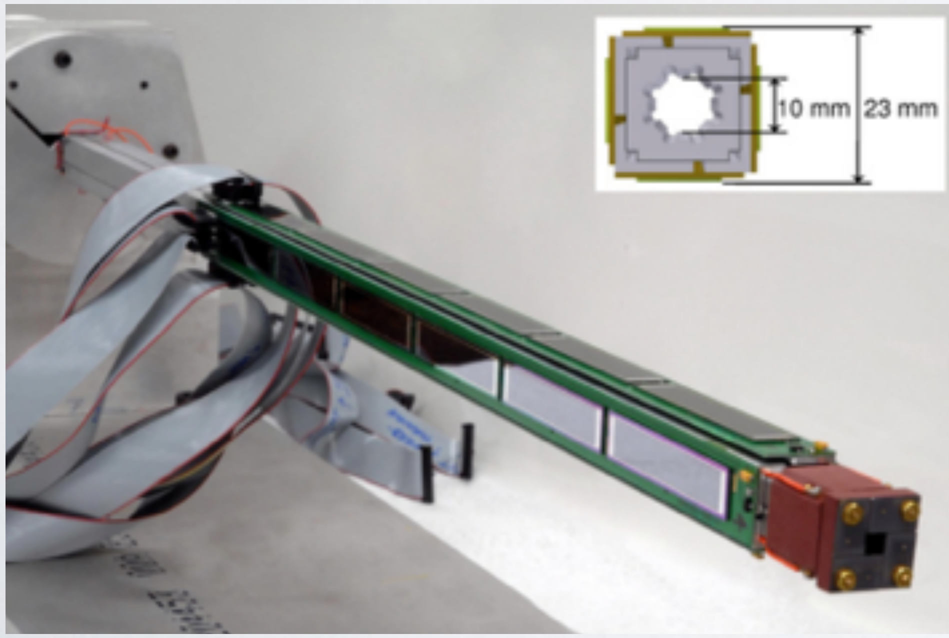


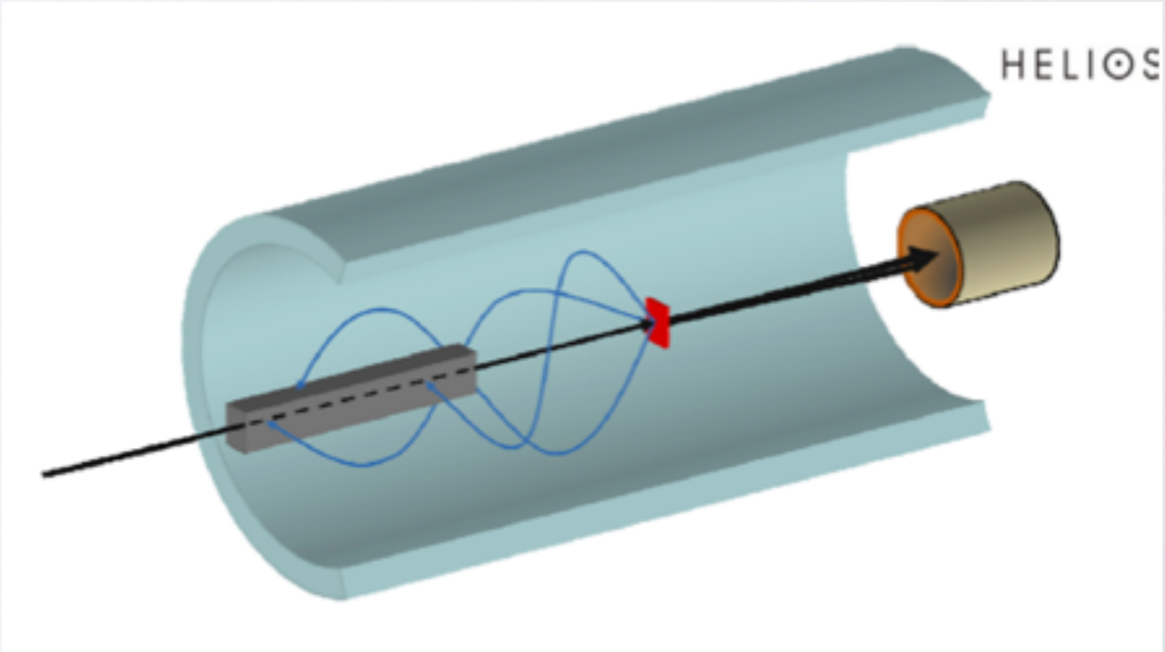


PRELIMINARY DATA









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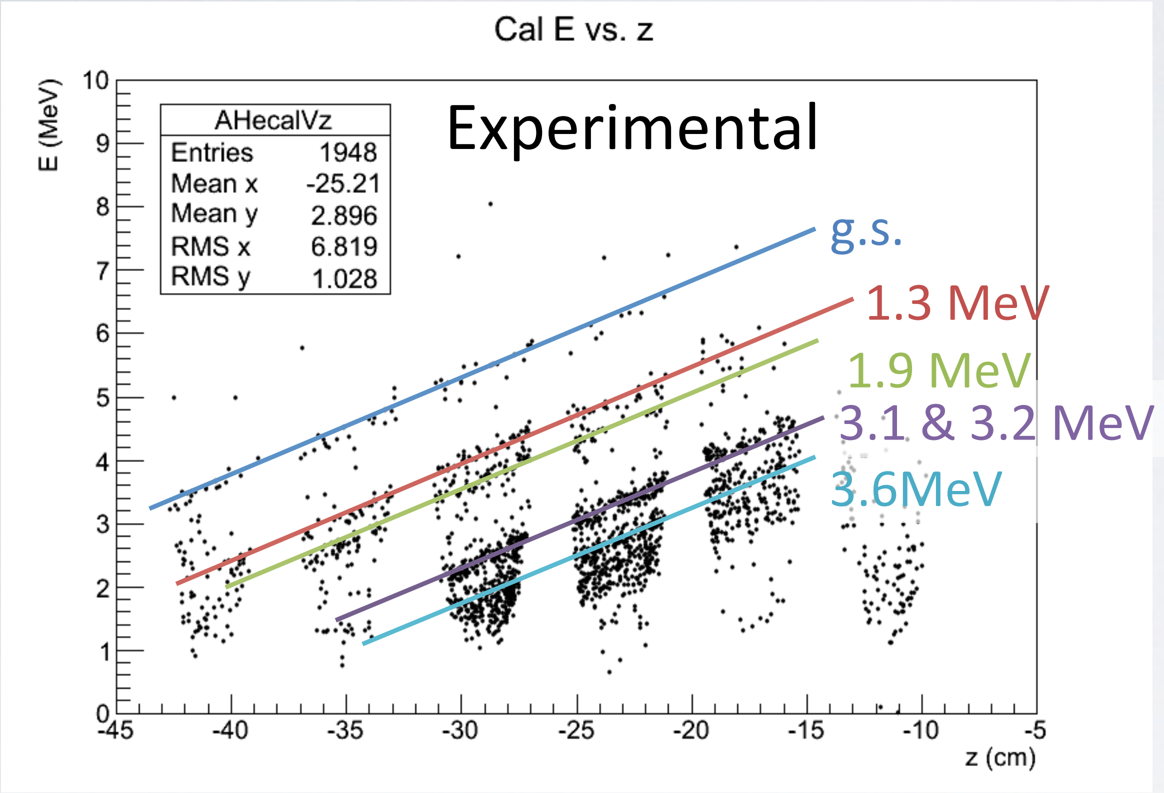

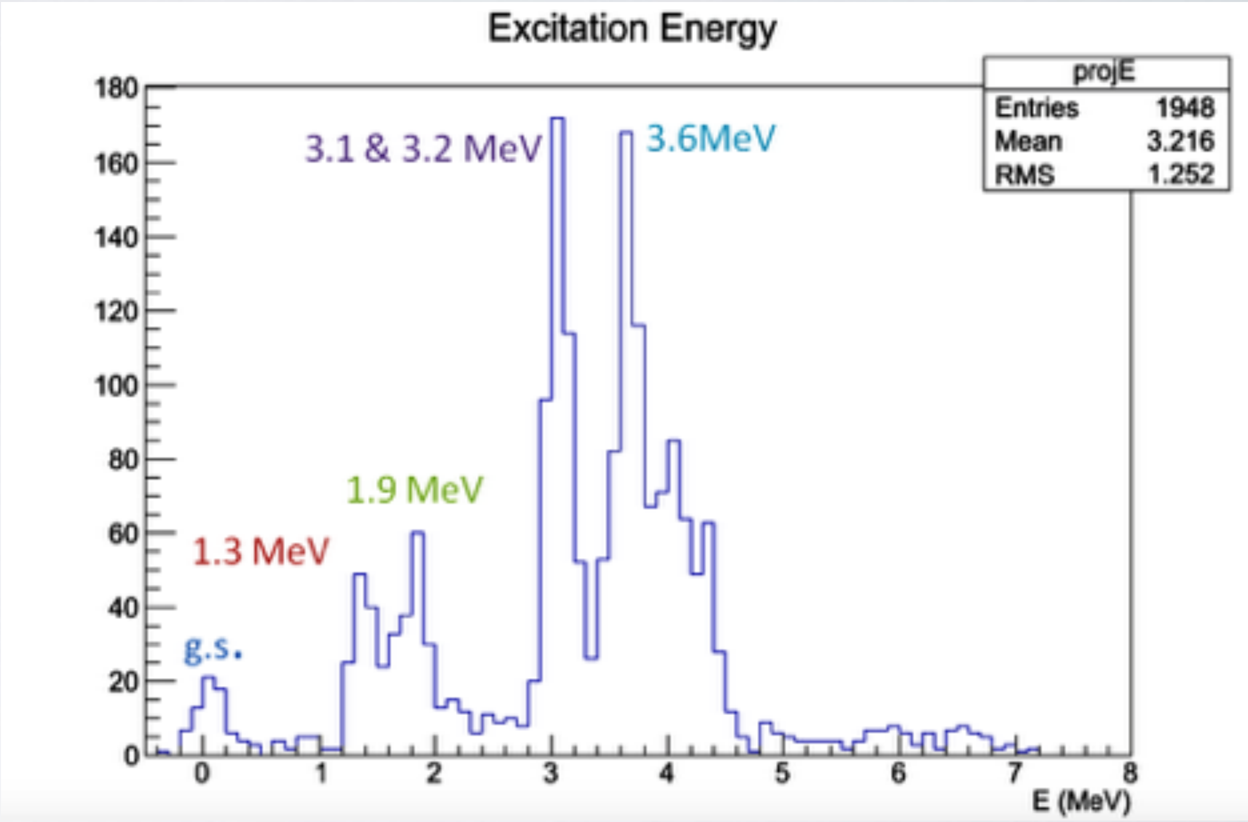

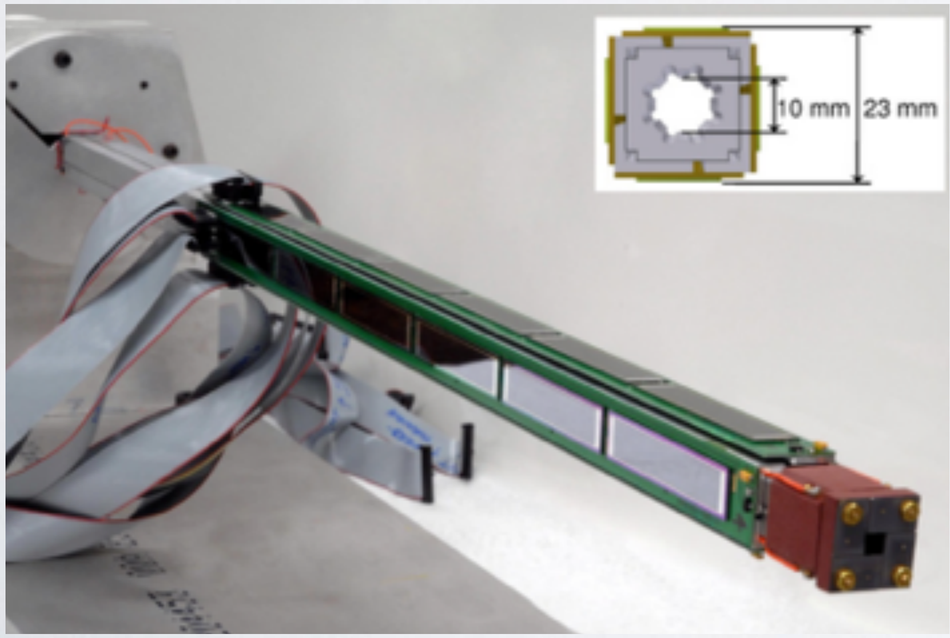

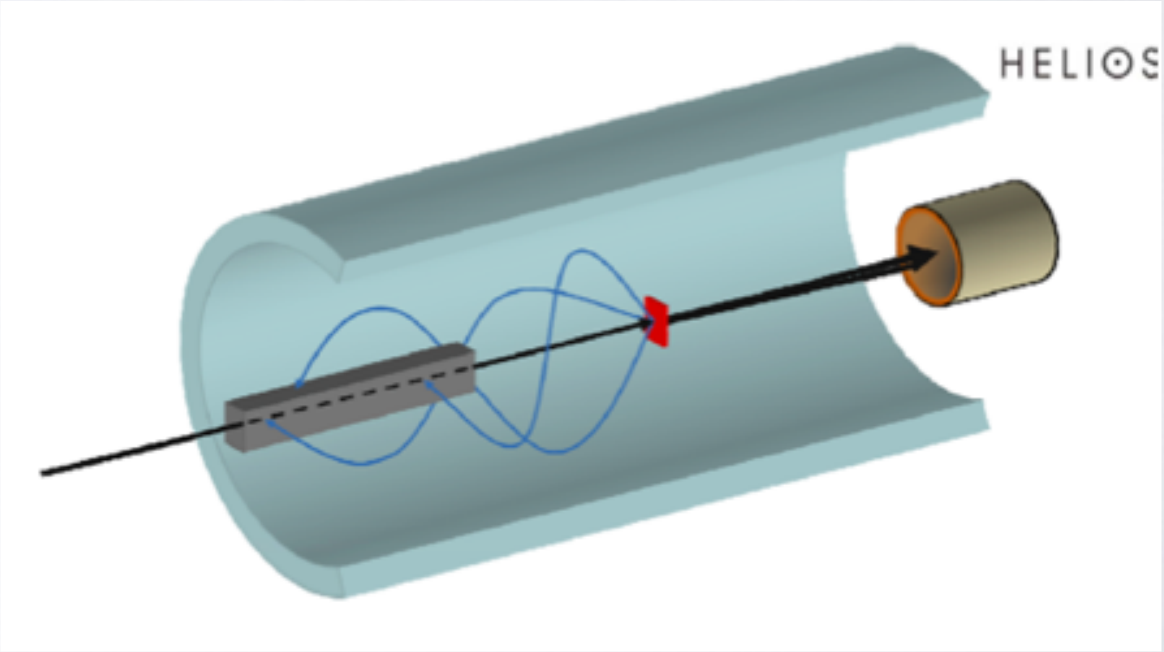

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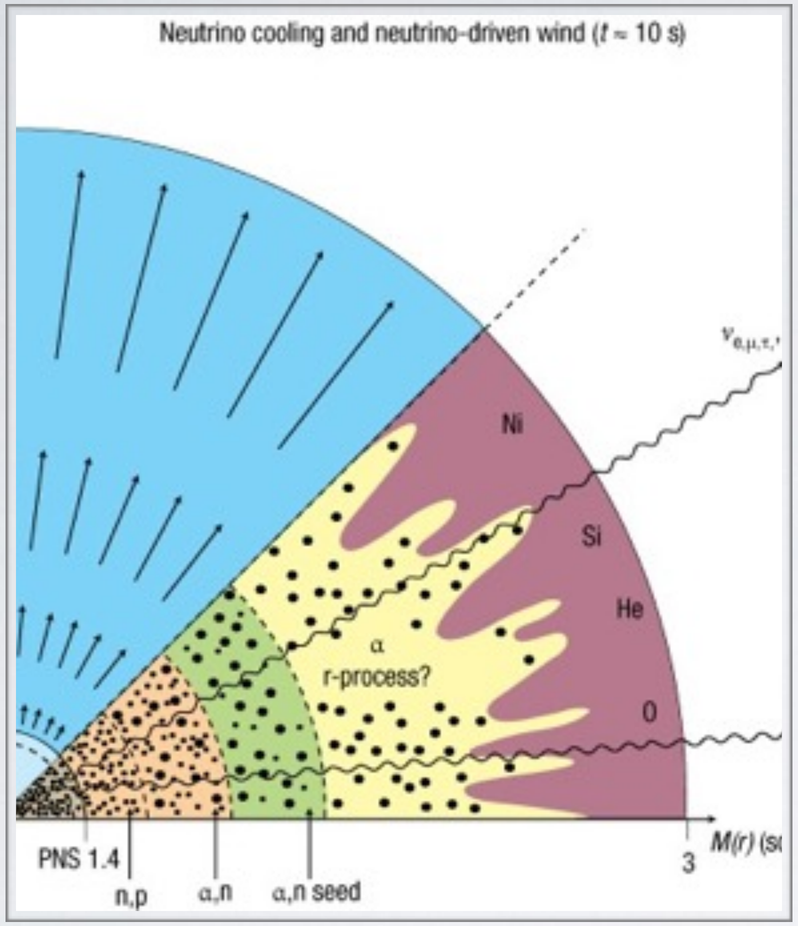

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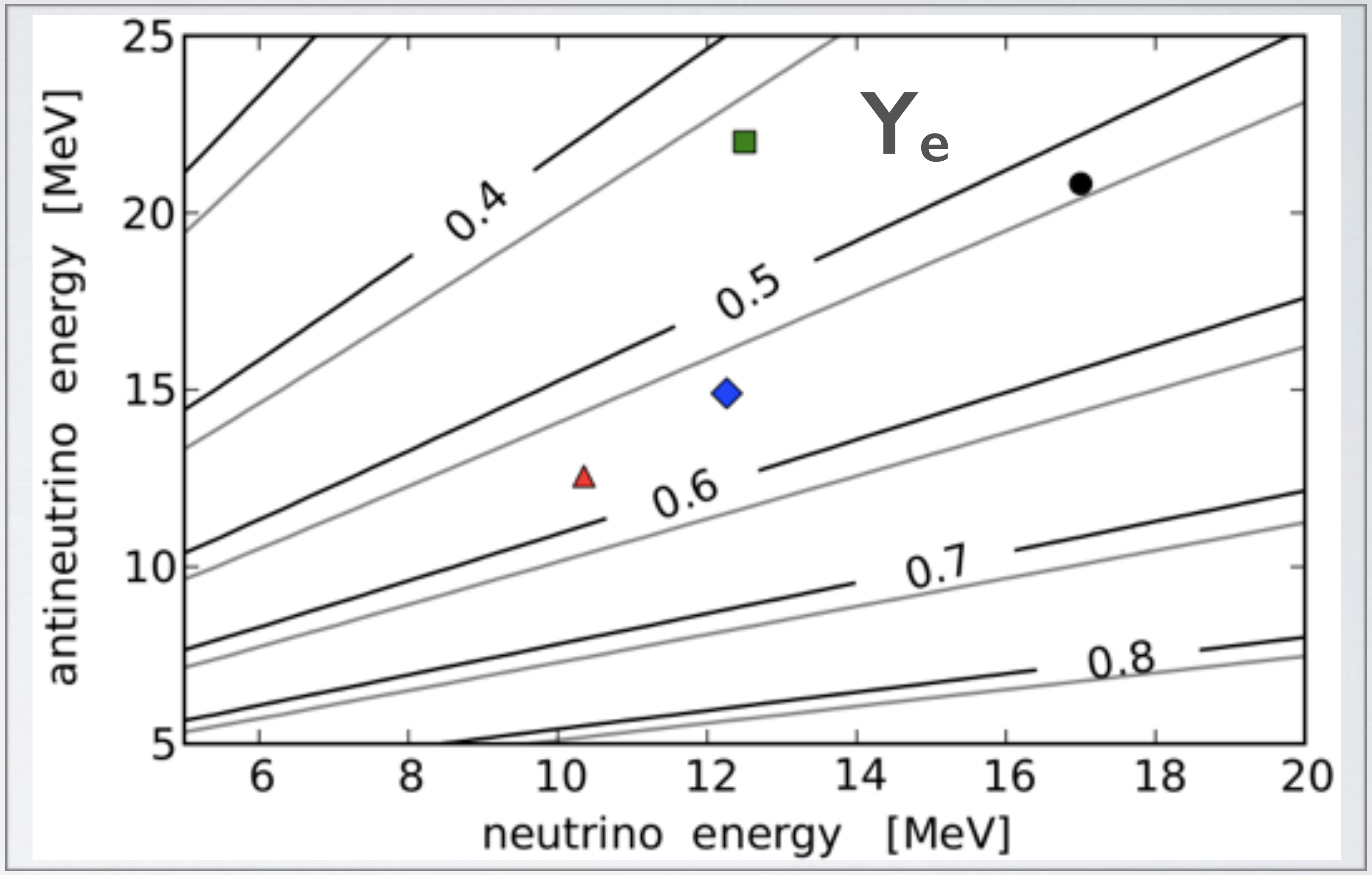

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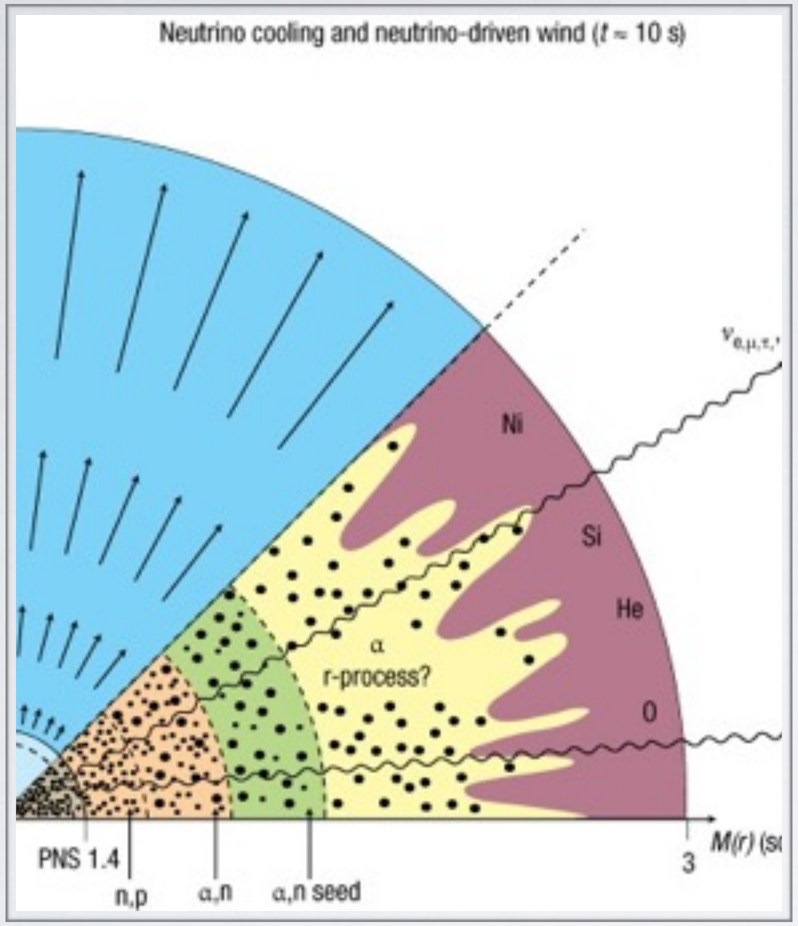

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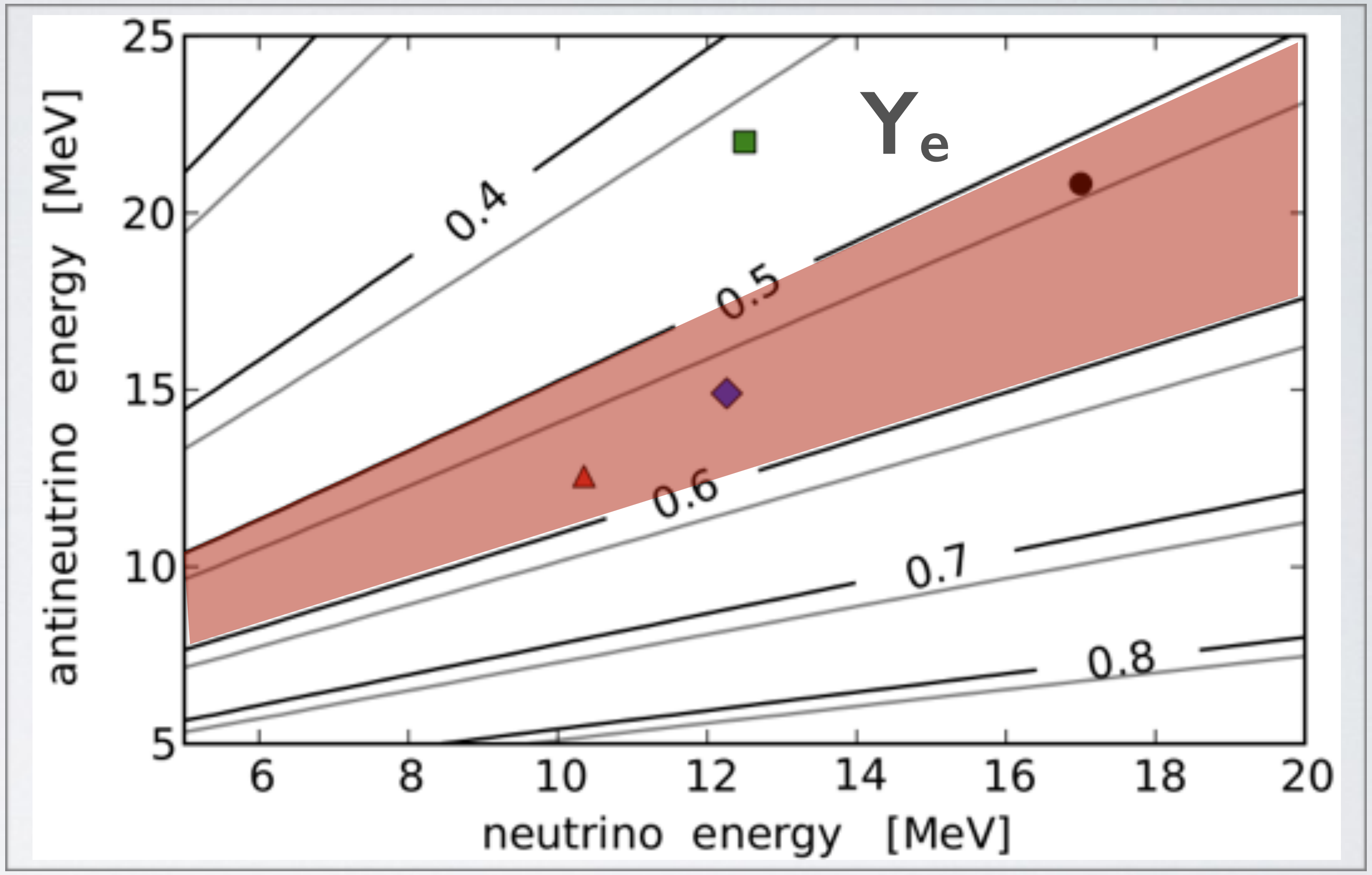

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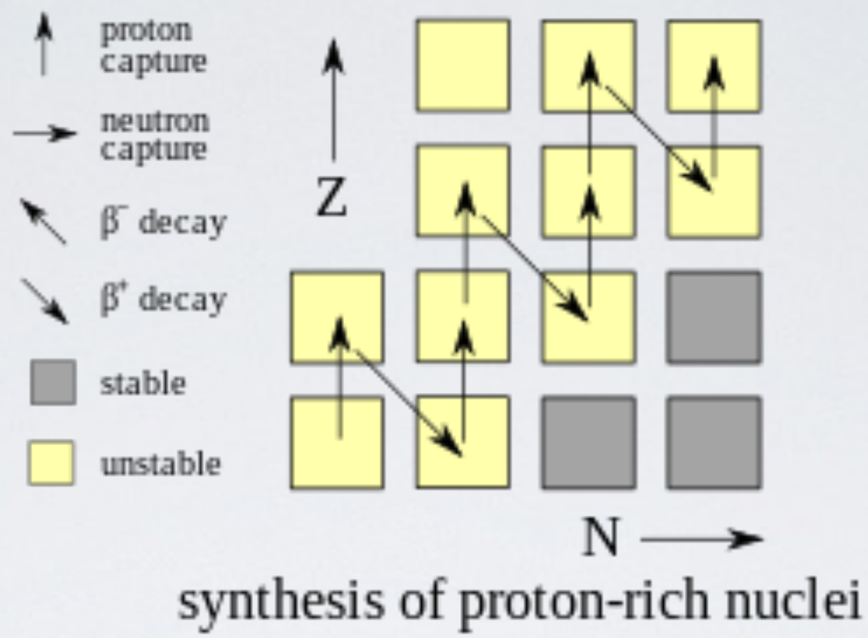

Slows down at ^{64}Ge (long beta-decay half life)

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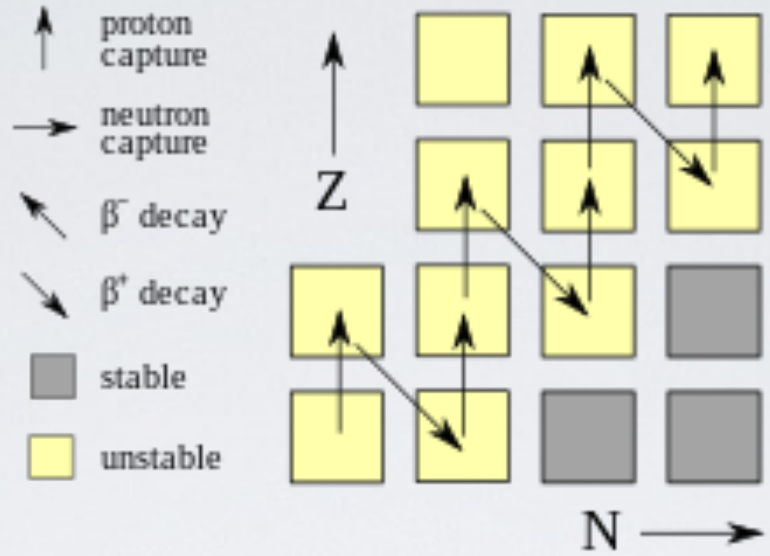

synthesis of proton-rich nuclei

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$$\overline{\nu}_{\mathrm{e}} + \mathrm{p} \rightarrow \mathrm{n} + \mathrm{e}^{+}$$

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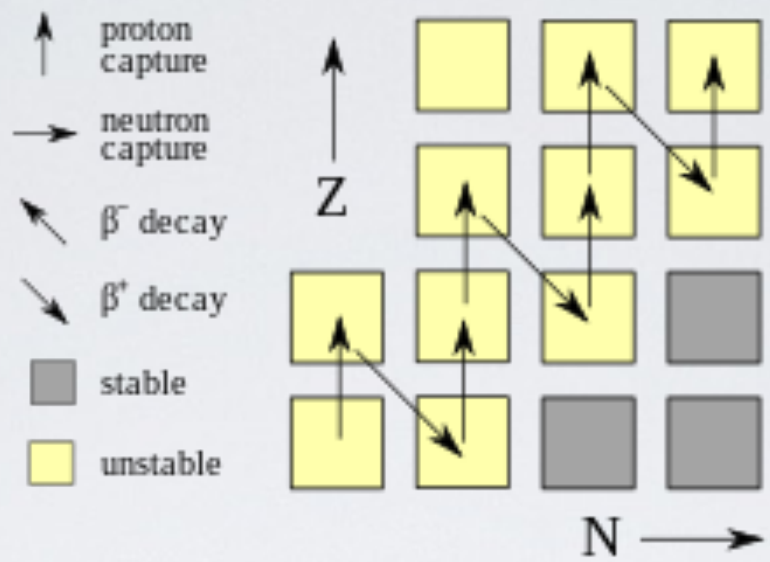

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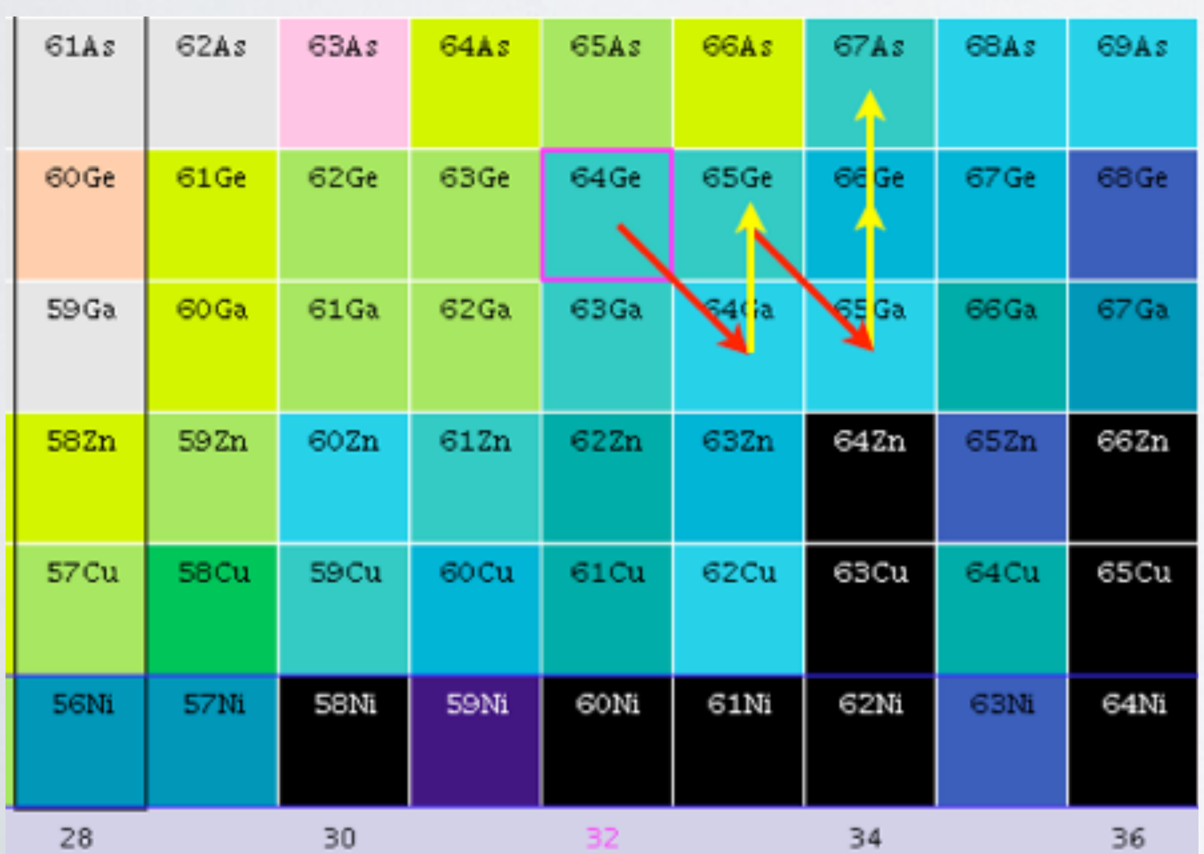

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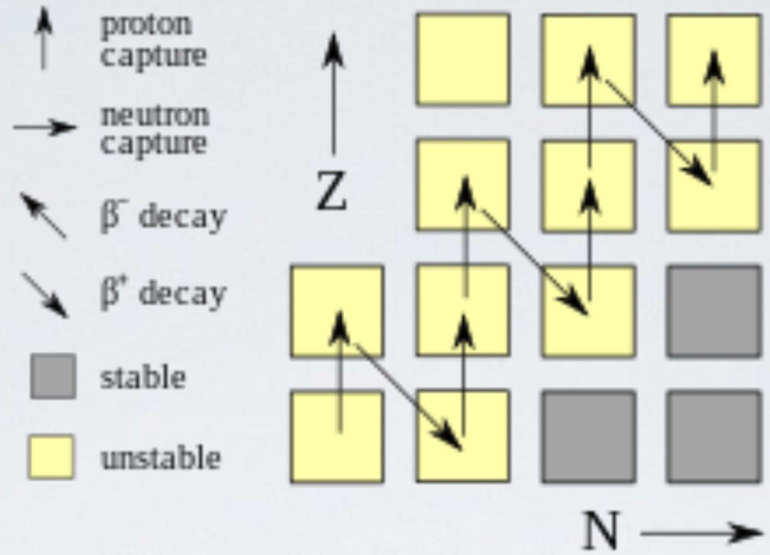

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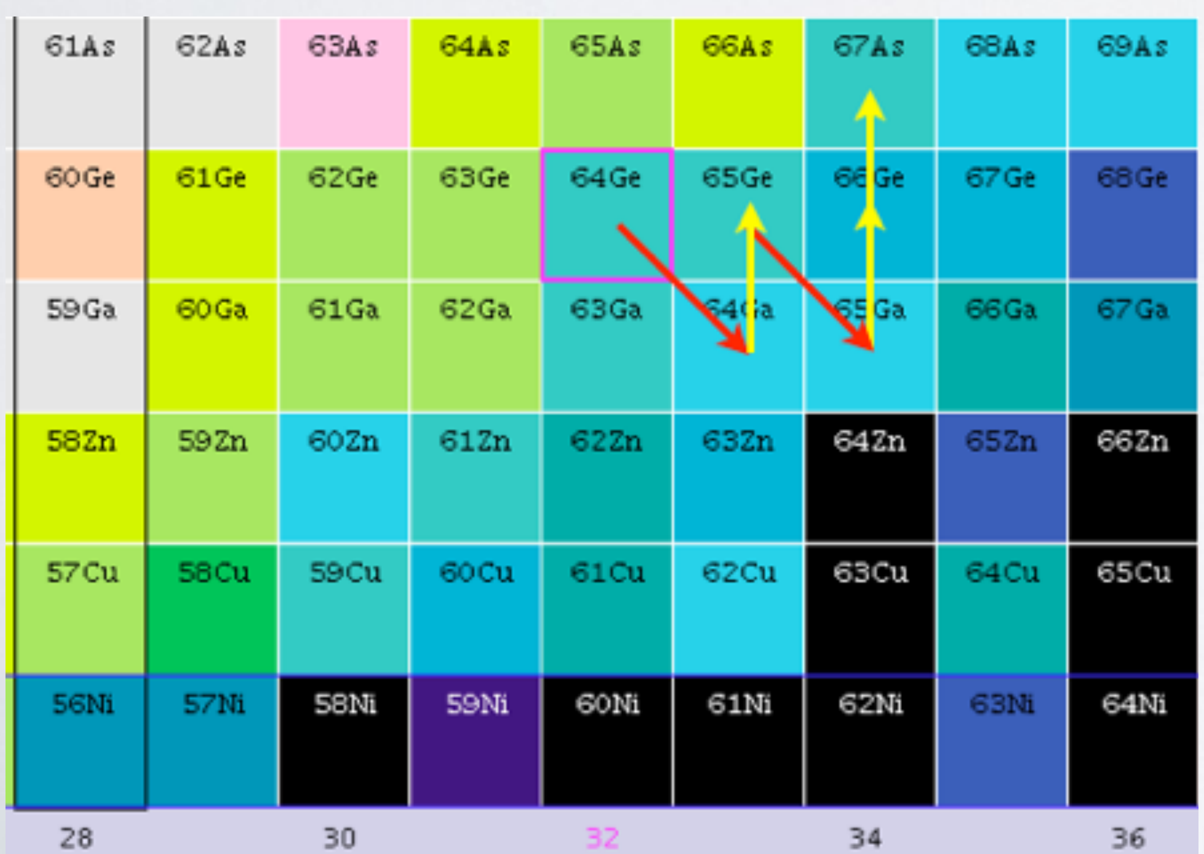
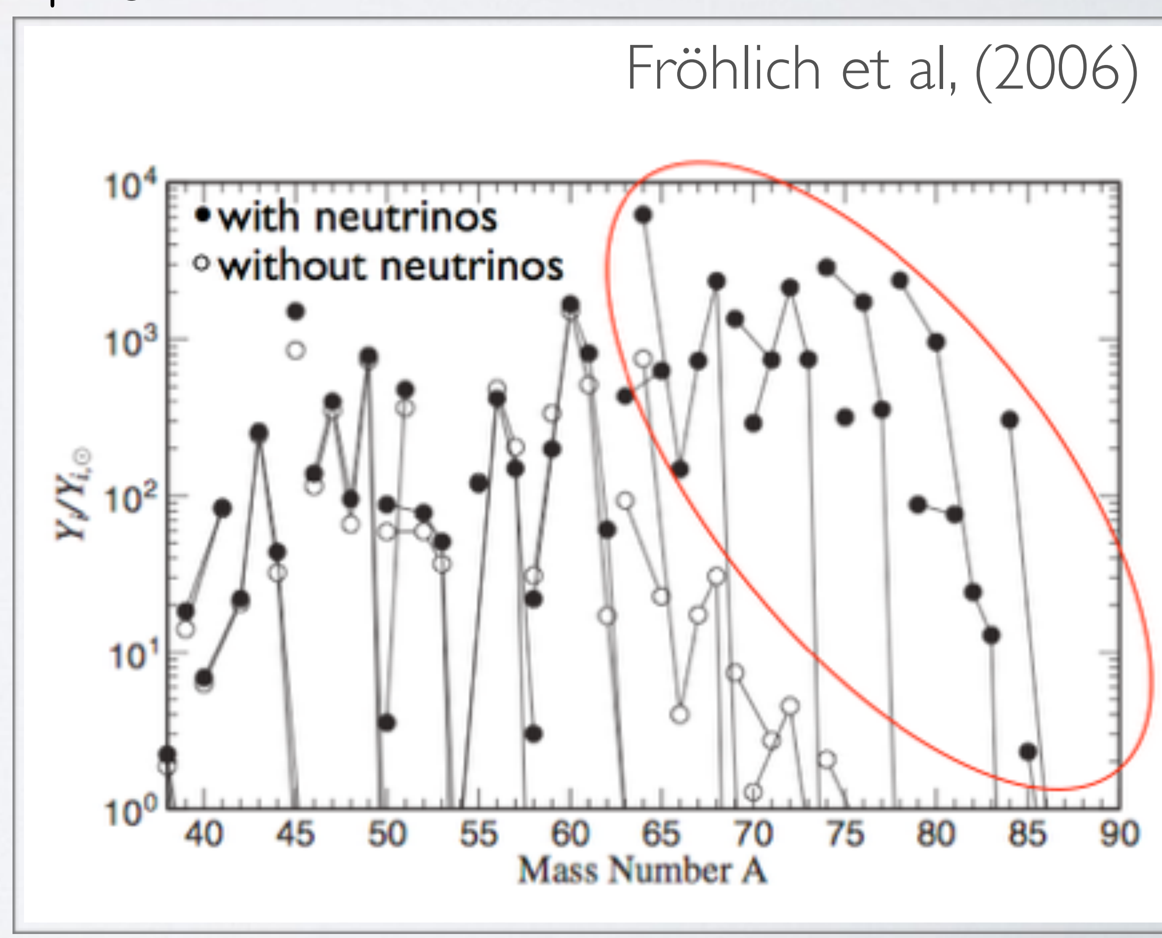
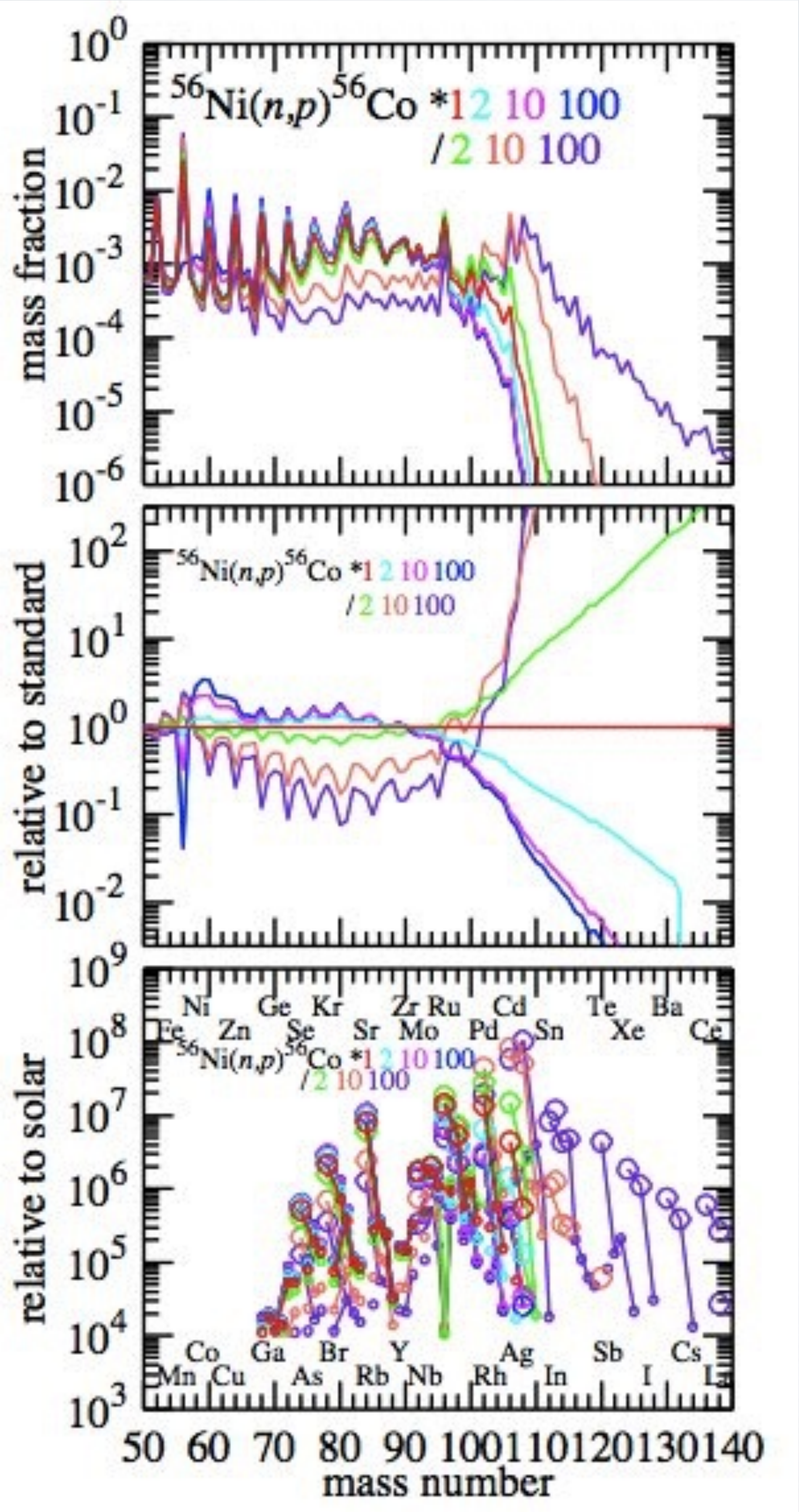




EFFECT OF NUCLEAR PHYSICS INPUT ON NUCLEOSYNTHESIS

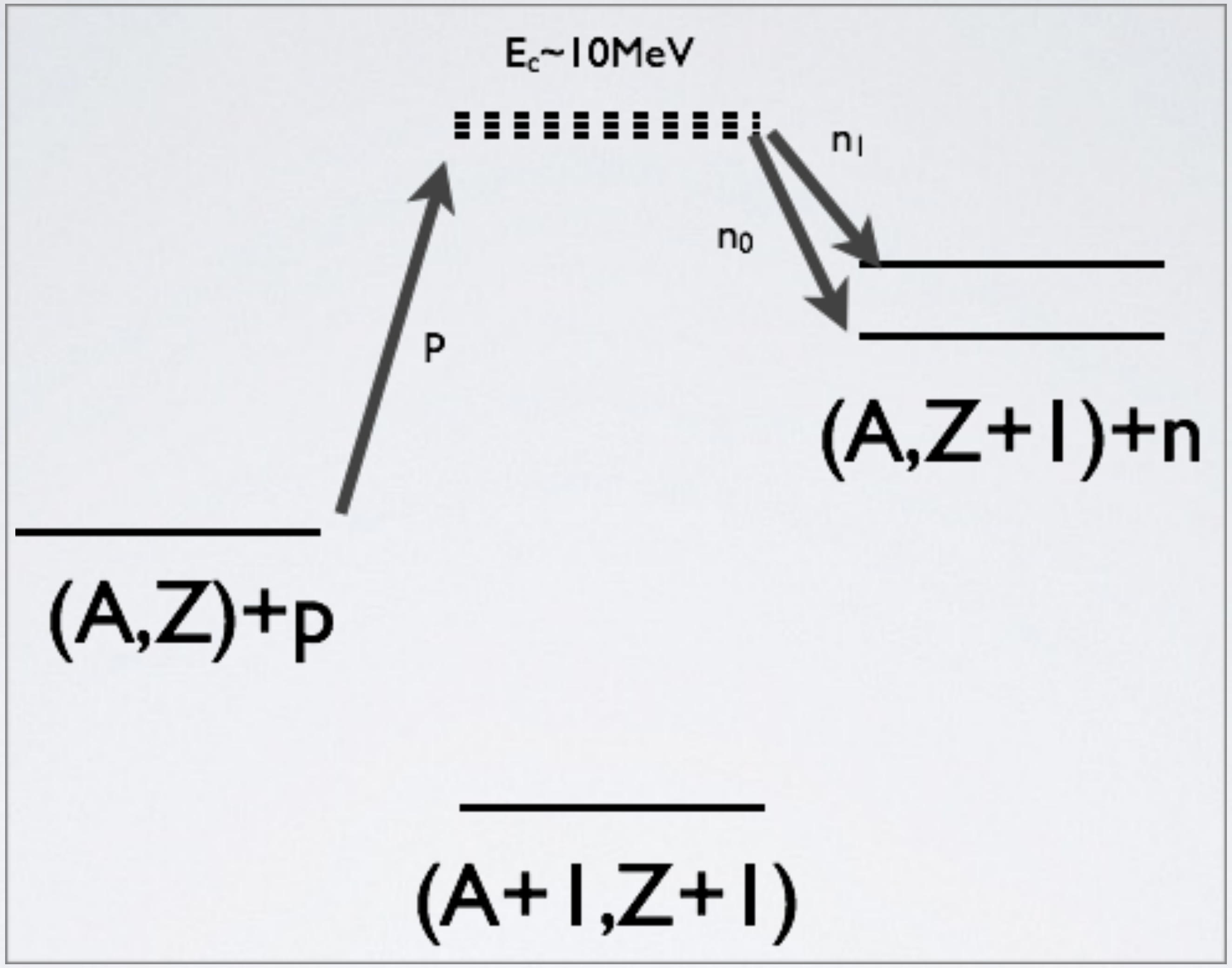


Wanajo et al 2011

- $0 < E_n < 1$ MeV $1.5\text{GK} < T < 3\text{GK}$
- compound nucleus process
- (most) important reaction rate: ^{56}Ni(n,p)
- proton rich, unstable nuclei
- no experimental data

How can we constrain the key reaction rates?

Indirect way: If we cannot do (n,p) then perhaps (p,n)?



Can we constrain the relevant p, n widths for ^{56}Ni(n,p)^{56}Co?

"Investigation of the role of the νp process in the synthesis of heavy elements through the reaction ^{56}Co(p,n)^{56}Ni in inverse kinematics at ReA3"

G. Perdikakis et al, Proposal 14061 to NSCL PAC 38, April 2014 (approved)

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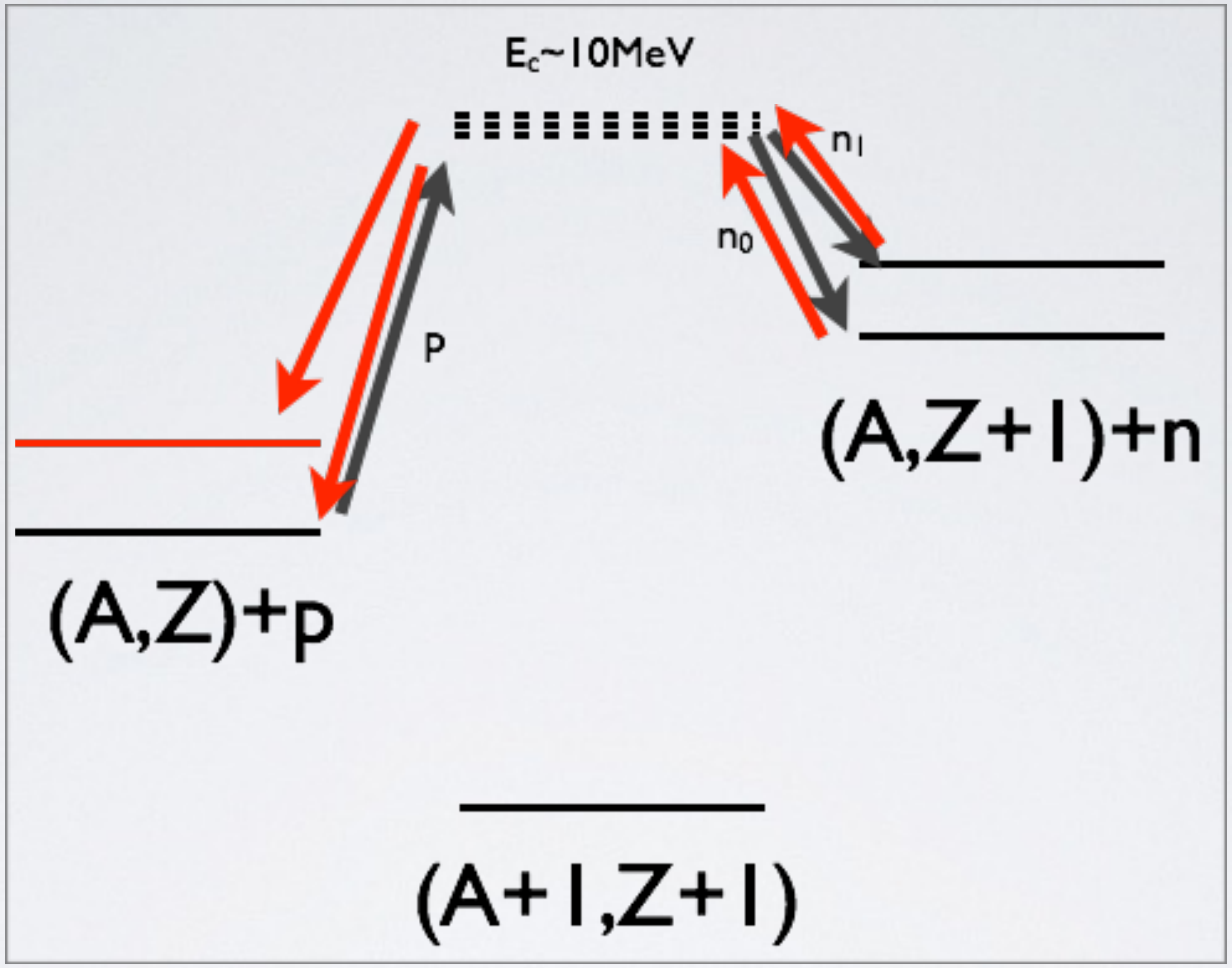

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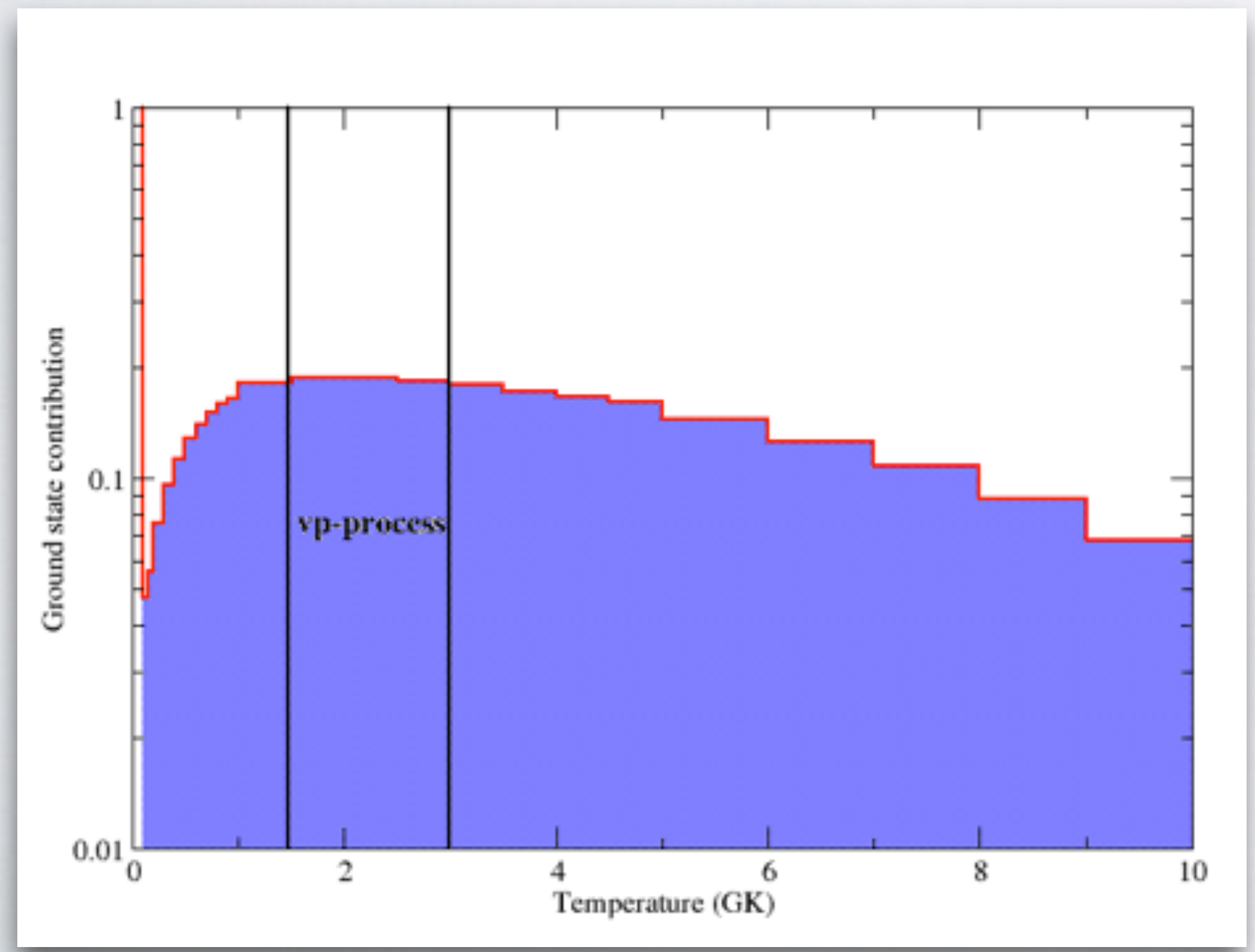
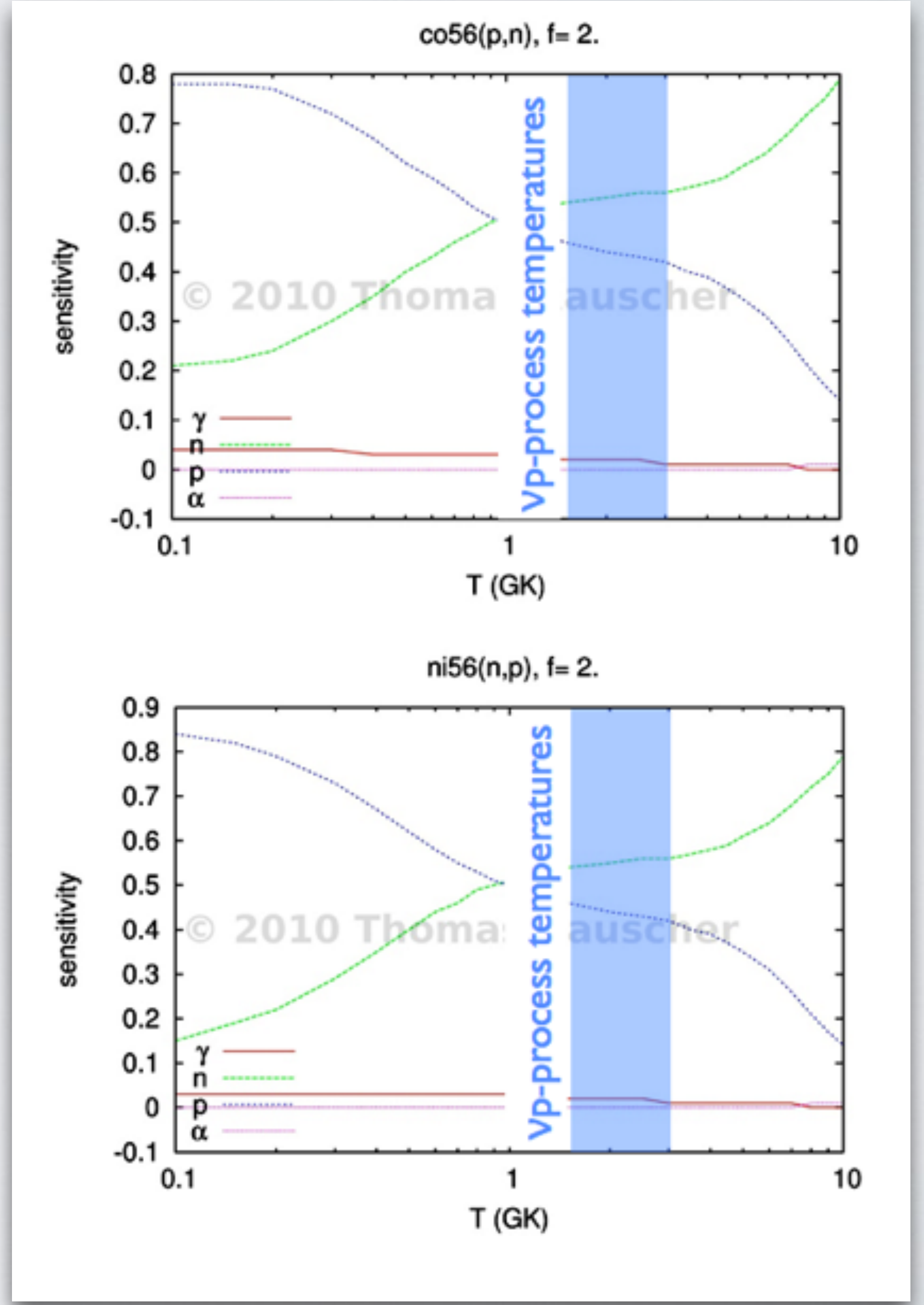
SENSITIVITY OF INVERSE REACTION

Are we constraining the same p, n widths?

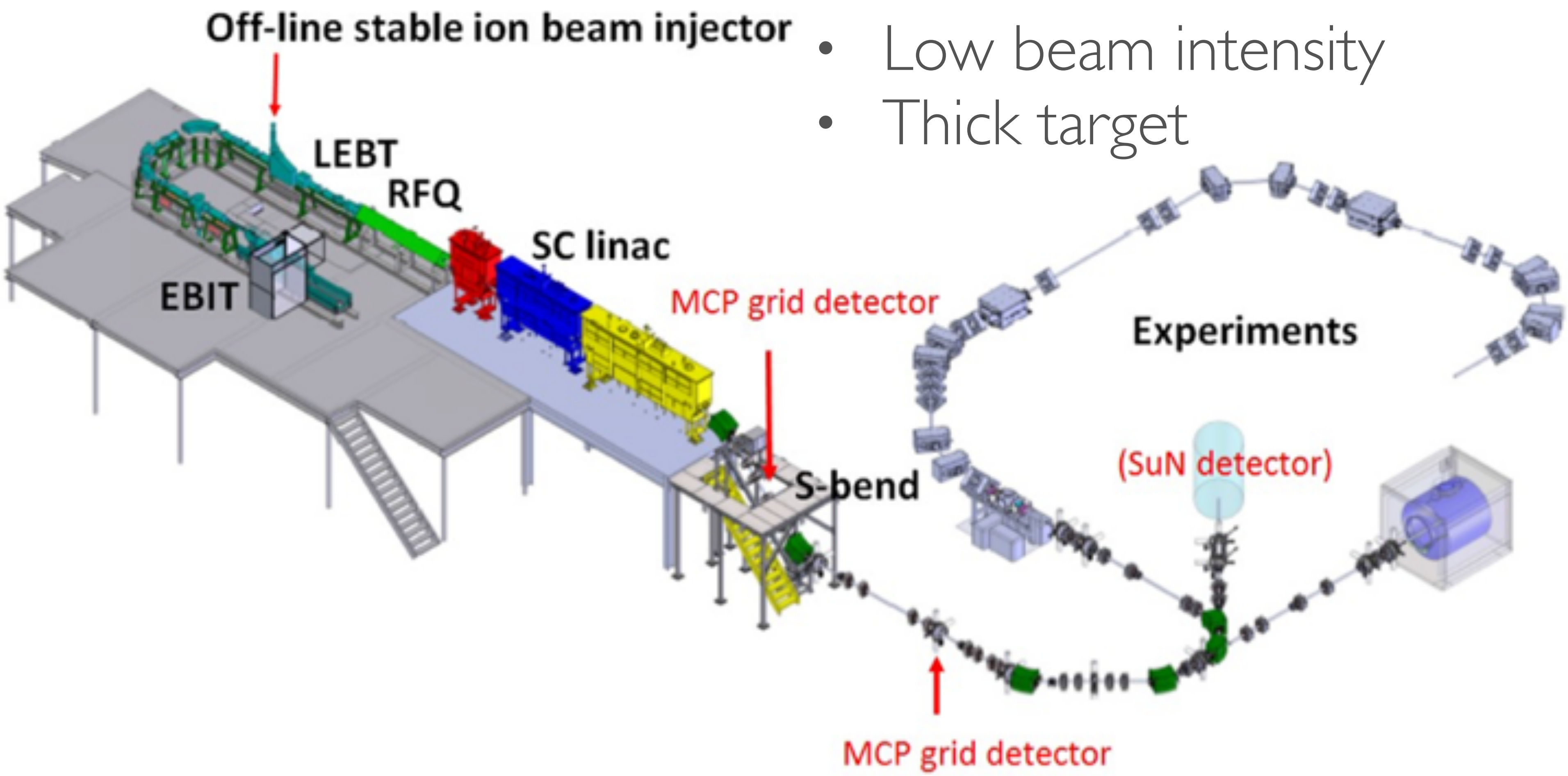
Is our sensitivity to each width the same in the lab?





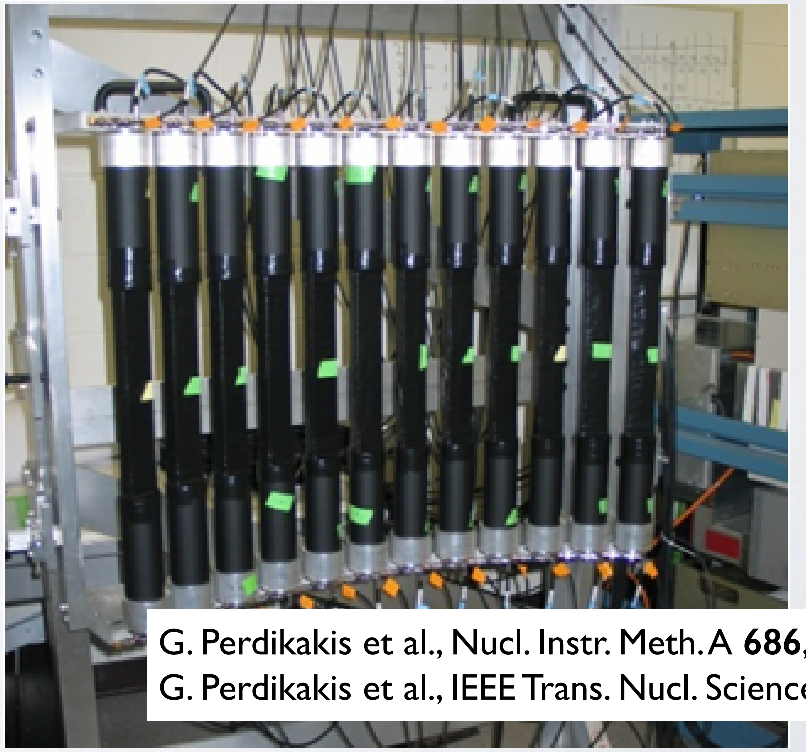
ReA 3

- E_{beam}~ 5MeV/u
- E_n = 0 - 1 MeV
- Inverse kinematics
- Low beam intensity
- Thick target



LENDA

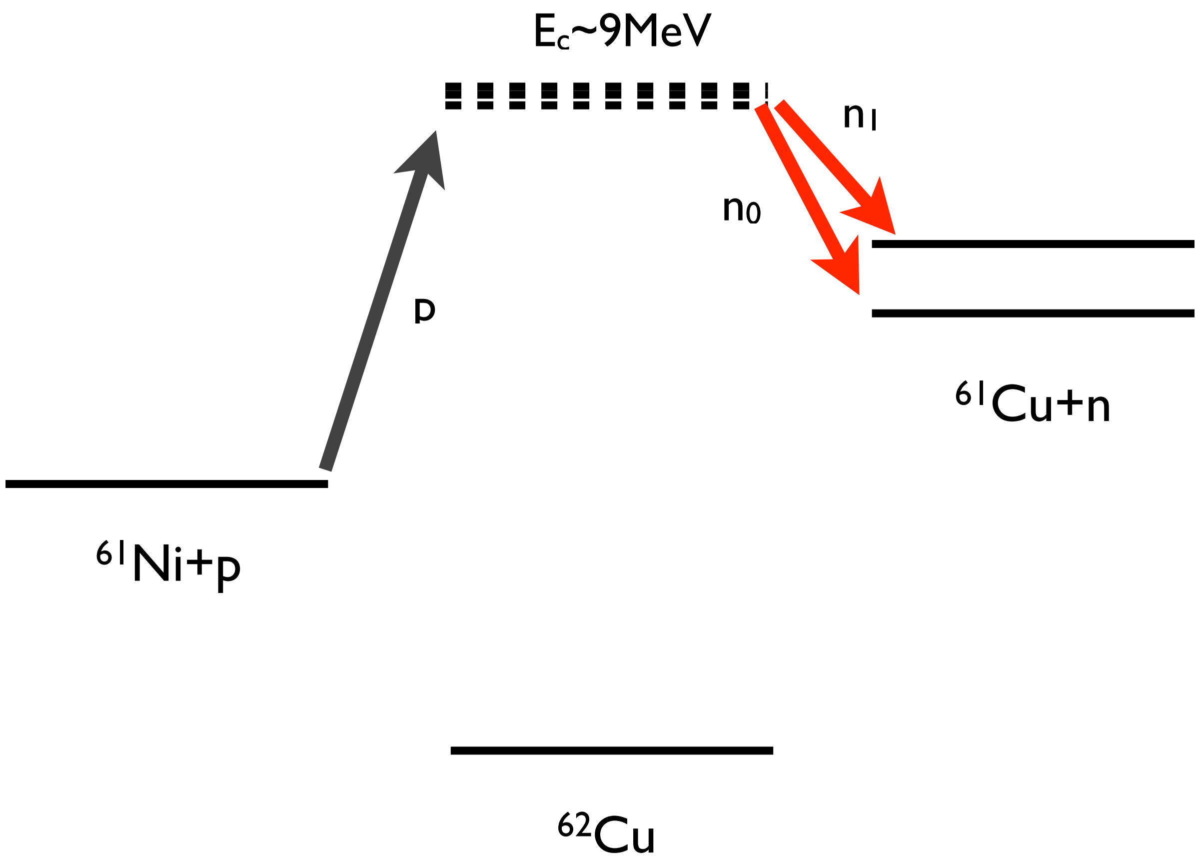
- 24 plastic scintillator bars
- timing resolution ~ 400ps
- Angle resolution 2° @ 1m
- Coverage: 45° lab angle
- Efficiency > 20% below 4 MeV
- En ≥ 130 keV



G. Perdikakis et al., Nucl. Instr. Meth. A **686**, (2012), 117
G. Perdikakis et al., IEEE Trans. Nucl. Science **56**, (2009), 1174

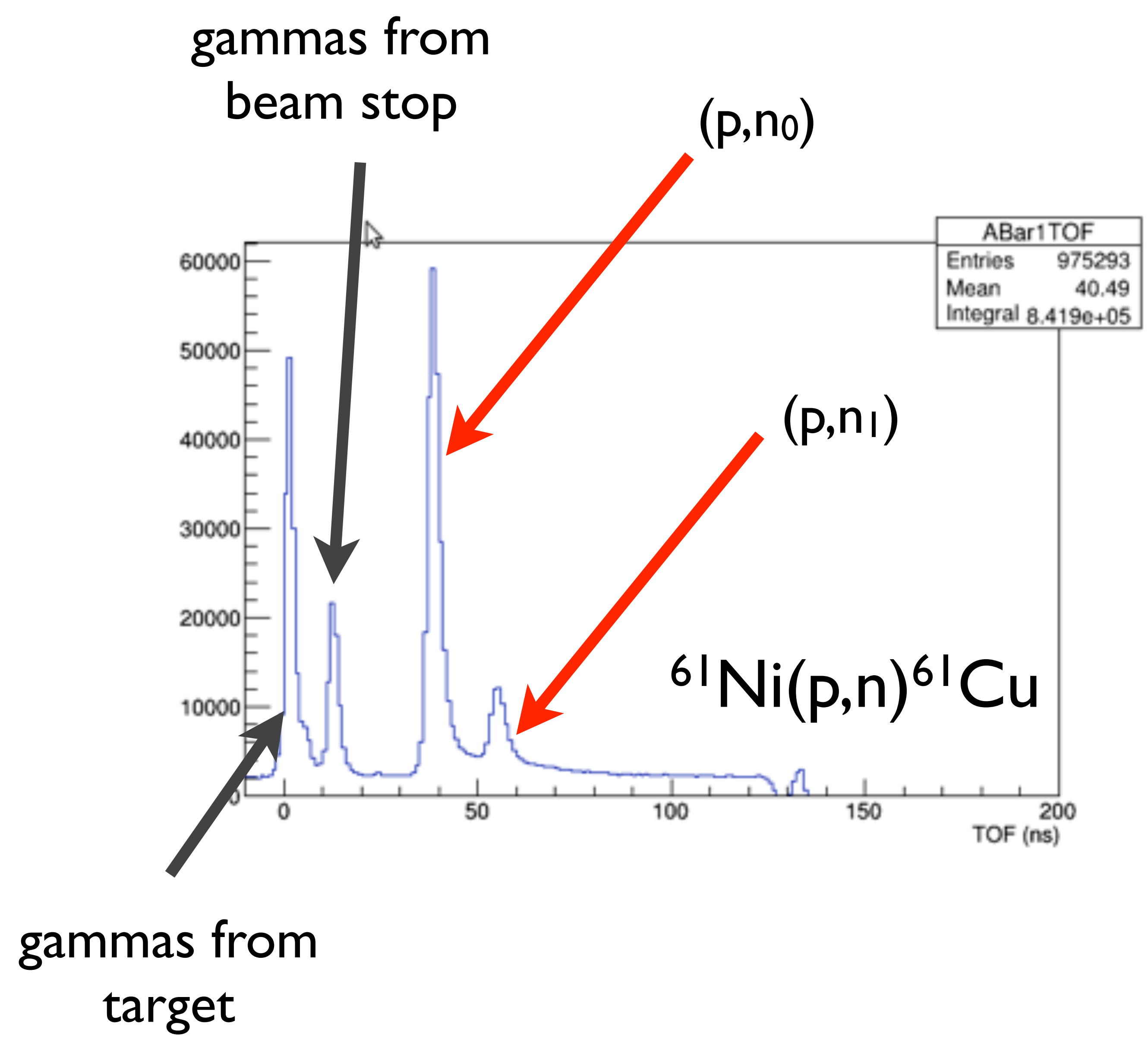
(p,n) reactions to study νp-process in core-collapse supernovae

First test at University of Notre Dame
(Regular Kinematics)

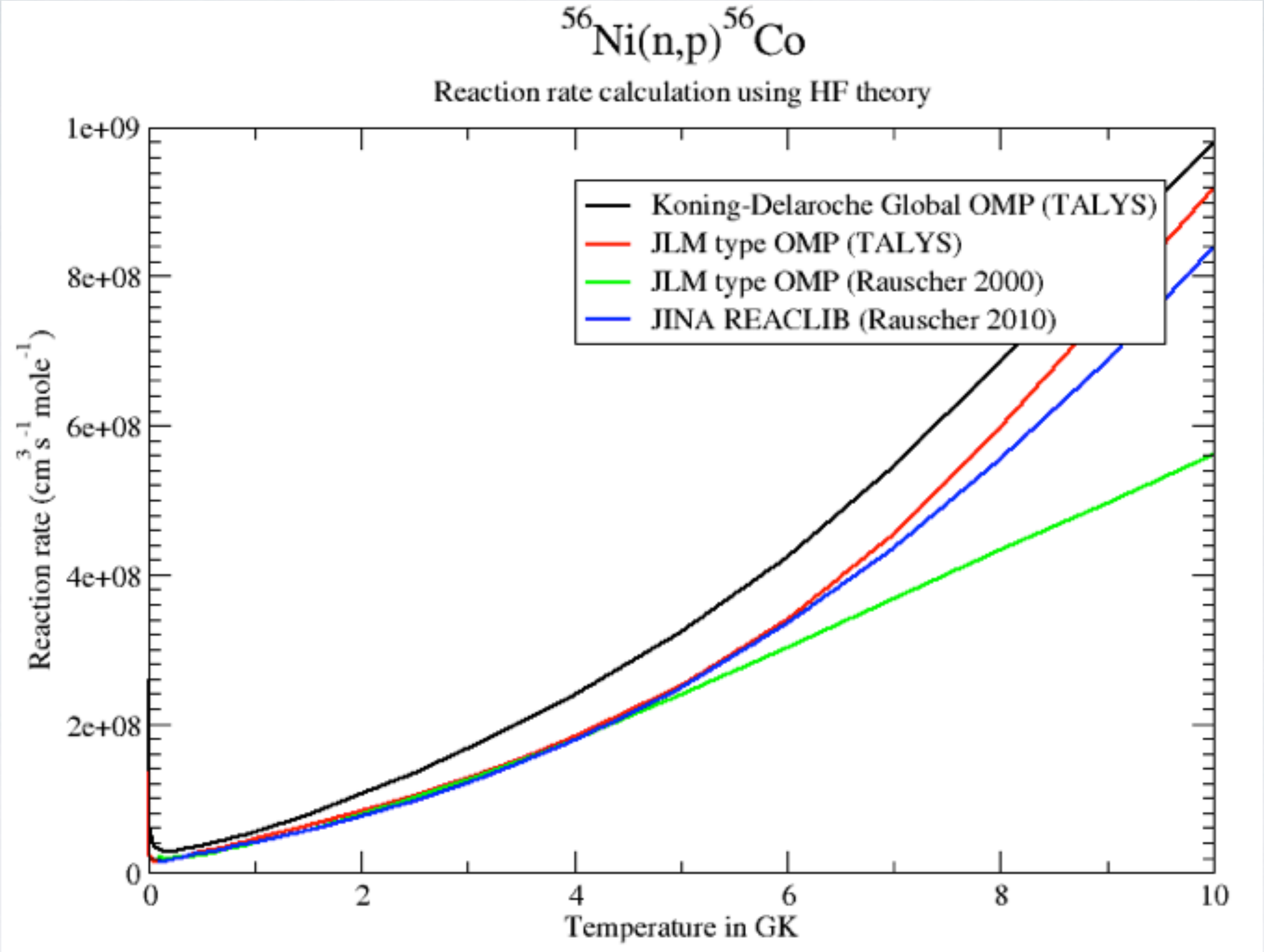


Low beam energies 2 - 6 MeV/u
Compound nucleus mechanism

Challenging!
Spectroscopy of neutrons with energies between 0-1 MeV



- Neutron energy by TOF @ 50cm
- Bunched beam (spacing 200ns)
- 2-3 ns FWHM timing resolution
- $E_n \geq 130$ keV
- No particle tagging



40% rate variation between rate calculations
Factor ~10 variation in νp-process yield for A>120

SUMMARY

- Reaction studies of core collapse supernovae nucleosynthesis scenarios under way or in preparation
- Experiment to constrain experimentally the main nuclear uncertainty of νp-process nucleosynthesis approved and in preparation (collaboration with C. Frohlich)
- New project to study the effect of nuclear uncertainties to the r-process path (collaboration with R. Surman)

SUMMARY

Things commonly overlooked
in HF calculations:

- parity distribution
- spin distribution
- pairing effects
- code implementation

M. Beard et al, PRC 90, 034619, (2014)

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