In-beam γ-ray spectroscopy with GRETINA at NSCL

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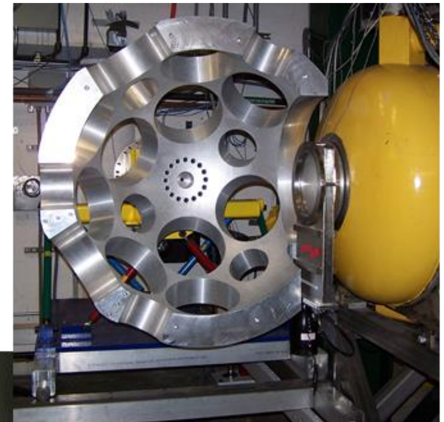
Outline

April 23, 2012 – truck from LBNL at NSCL loading dock



- In-beam γ-ray spectroscopy
- GRETINA at NSCL
- Selected science examples
  - –Nuclear structure physics (*N=40*)
  - –Nuclear astrophysics (proton-rich)
- Summary and outlook

June 2013 – last science run (the 24th experiment)

In-beam γ-ray spectroscopy with fast beams

γ-ray spectrometers

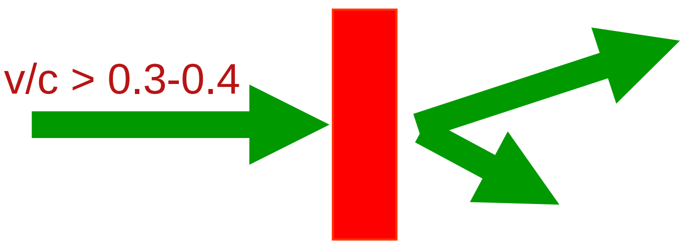
SeGA,CAESAR,Grape,DALI2,RISING, …

New generation: GRETINA and AGATA

Driver provides stable “primary beam”

Fragment separator selects species of interest

A1900, FRS, BigRIPS, ALPHA/LISE



Spectrographs or detectors to the ID reaction residue of interest

S800, CATE/Aladin, zero-deg./TOF spectrometer, SPEG

Nuclear structure

Single-particle properties
- Knockout
- HI-induced pickup
- Light-ion transfer

Collective phenomena
- Excited-state lifetime measurements
- Coulomb-excitation
- Inelastic proton scattering

Nuclear astrophysics

Level schemes
- Coincidence spectroscopy

Weak interactions
- B(GT) values from charge-exchange reactions

In-beam γ-ray spectroscopy at ARIS

Needed for all these measurements: Emission angle of the γ-ray to Doppler-reconstruct the transition energies into the rest frame of the projectile

High energy resolution after Doppler reconstruction and opportunities at a stable-beam facility

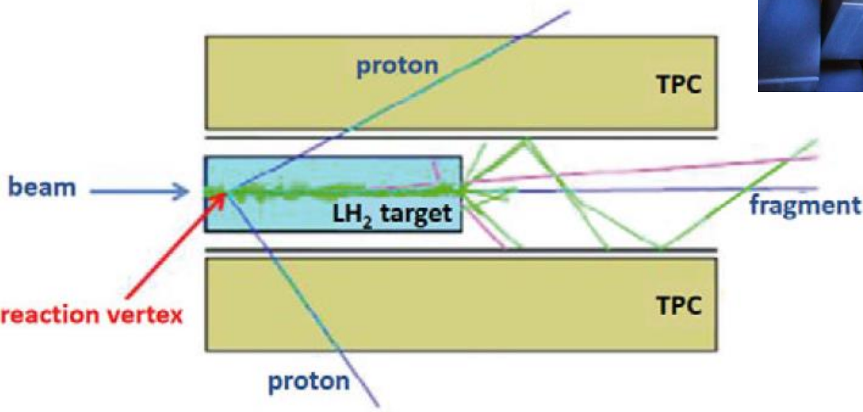
AGATA@LNL – D. Mengoni (Plenary 9)

High detection efficiency and high beam intensities

SUNFLOWER – N. Aoi (Plenary 9)

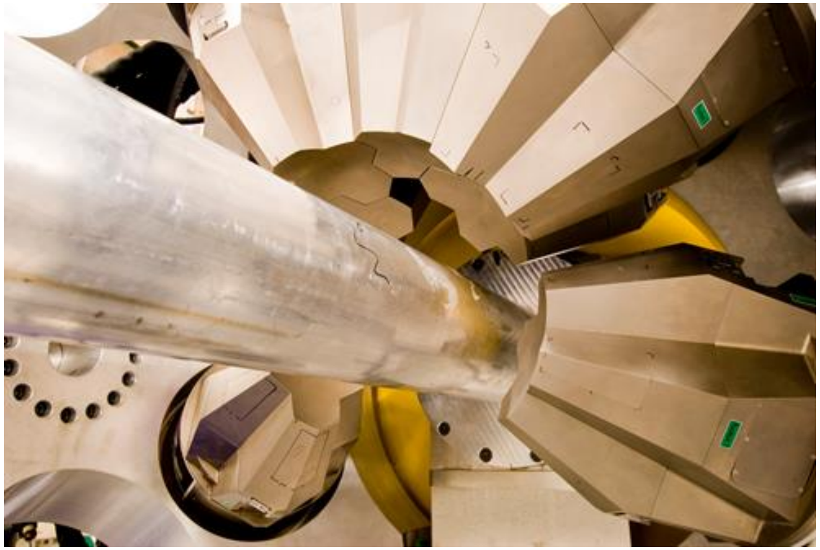
Increased luminosity, determination of the interaction point for improved energy resolution after Doppler reconstruction

MINOS – A. Obertelli (Plenary 8)

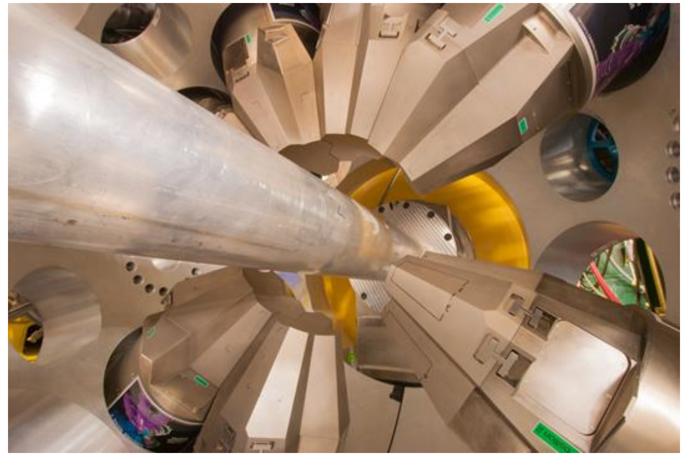


The different configurations of the GRETINA campaign

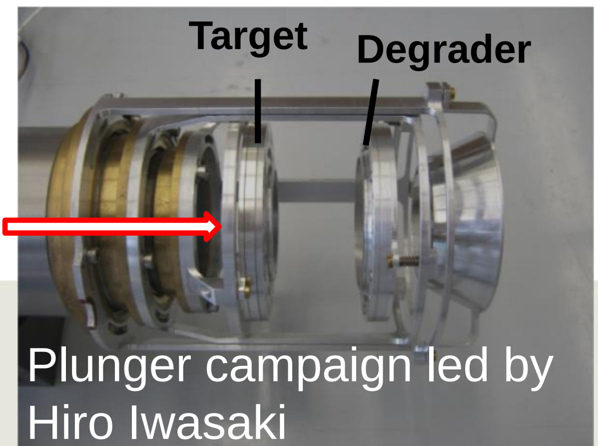
"Standard configuration":
4 detectors under forward angles and 3 at 90 degree

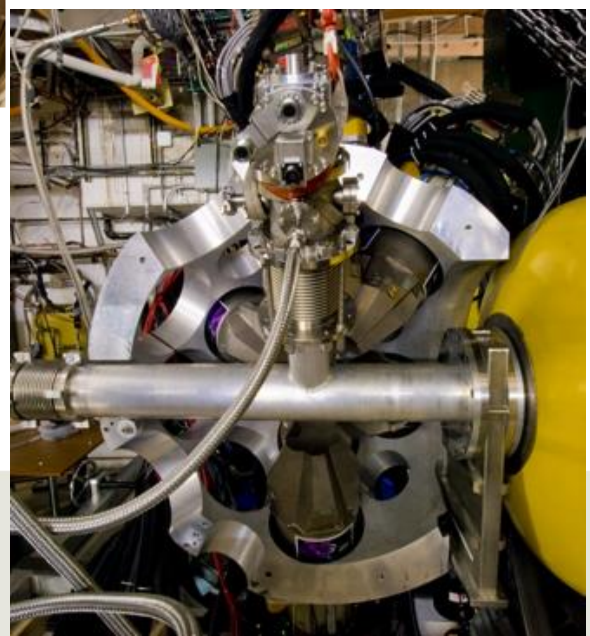


All detectors under 90 degree



Plunger lifetime measurements





All detectors in one hemisphere and LH_2 target in

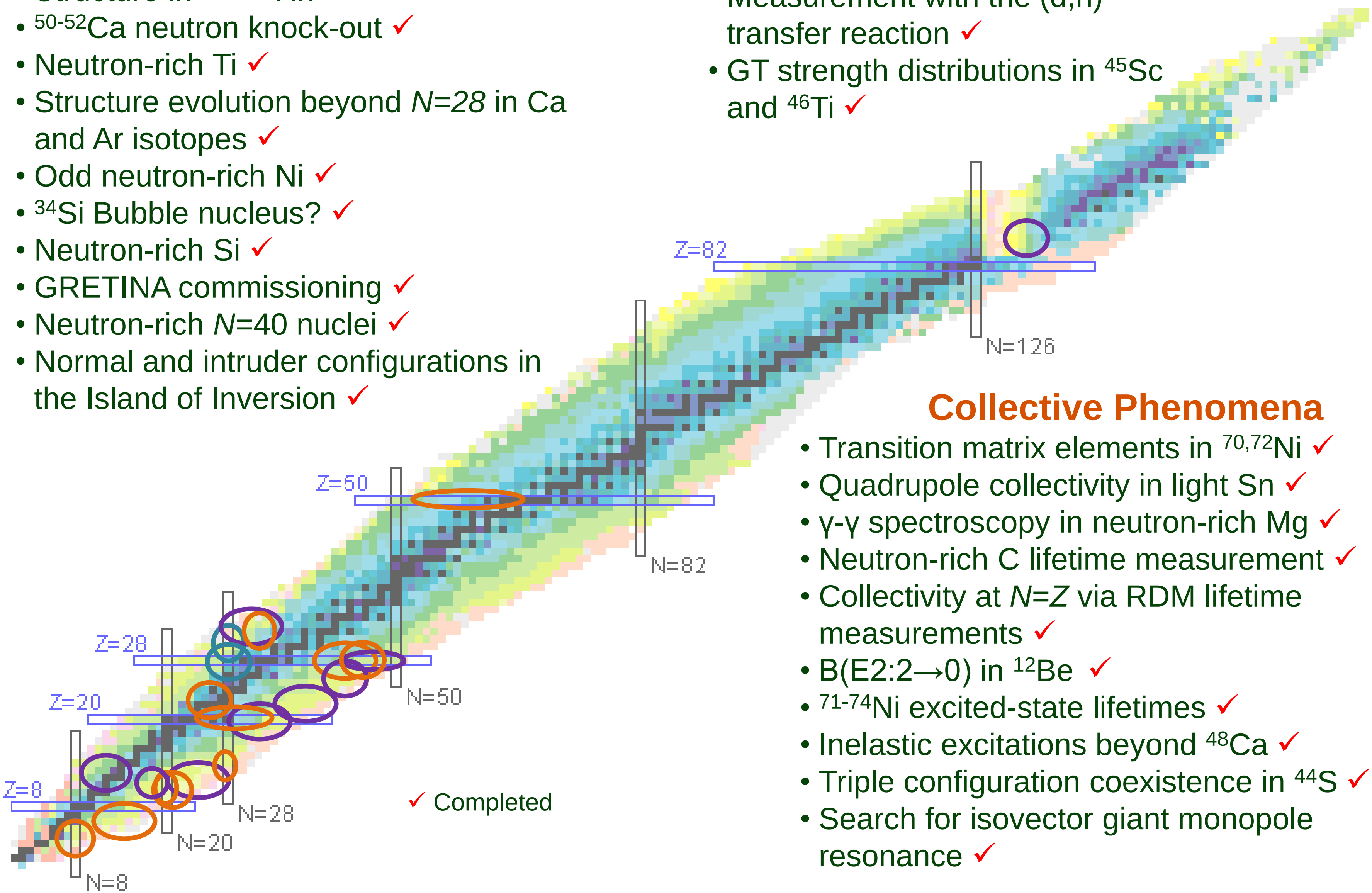
GRETINA at NSCL: beams from *Z=4* to *Z=92* – A campaign of 24 experiments

Nuclear Shell Evolution

- *N=Z* Mirror Spectroscopy ✓
- Structure in ^{221,223}Rn ✓
- $^{50\text{-}52}$Ca neutron knock-out ✓
- Neutron-rich Ti ✓
- Structure evolution beyond *N=28* in Ca and Ar isotopes ✓
- Odd neutron-rich Ni ✓
- ^{34}Si Bubble nucleus? ✓
- Neutron-rich Si ✓
- GRETINA commissioning ✓
- Neutron-rich *N*=40 nuclei ✓
- Normal and intruder configurations in the Island of Inversion ✓

Nuclear Astrophysics

- Excitation energies in ^{58}Zn ✓
- Measurement with the (d,n) transfer reaction ✓
- GT strength distributions in ^{45}Sc and ^{46}Ti ✓

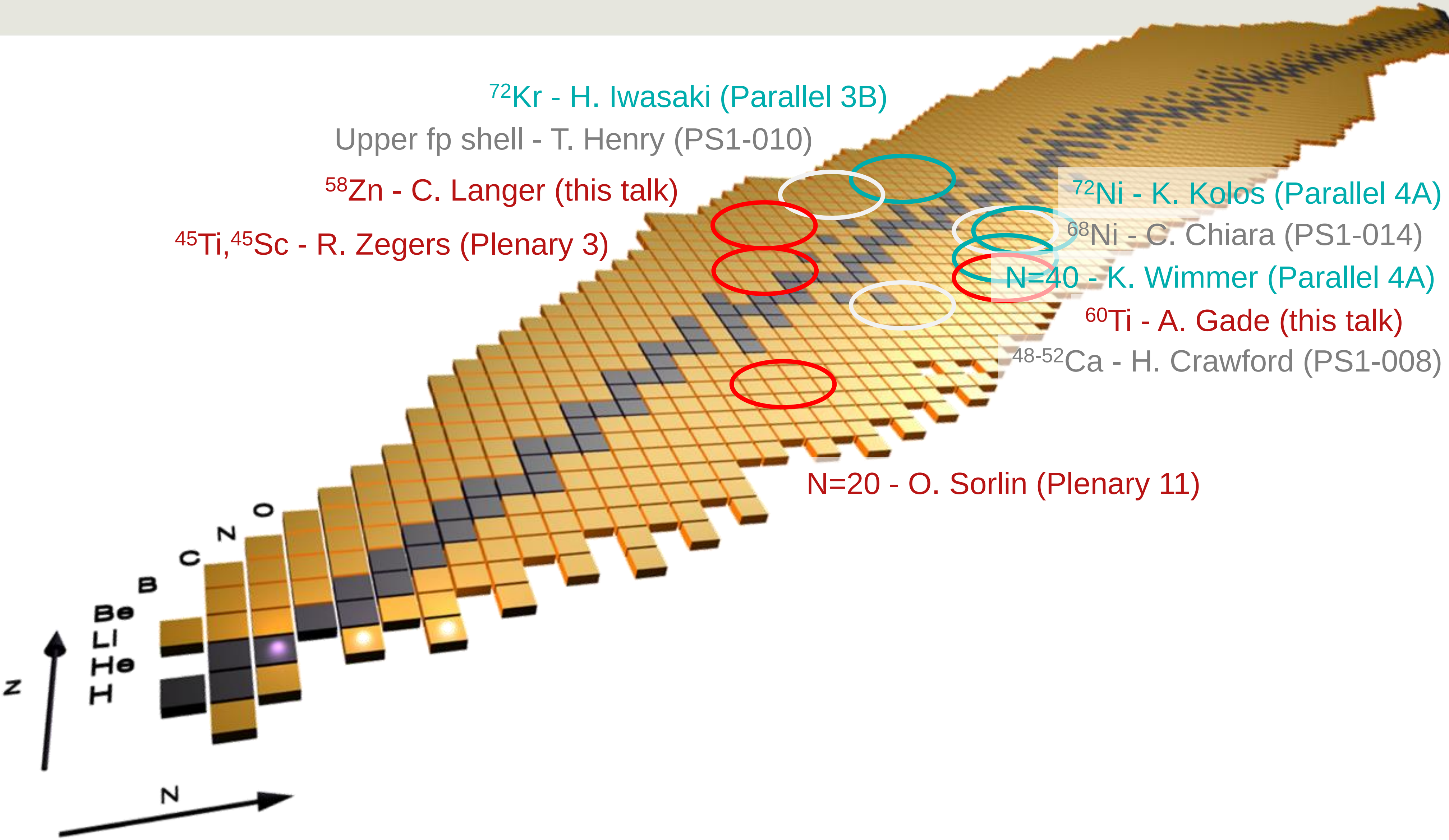


✓ Completed

Collective Phenomena

- Transition matrix elements in ^{70,72}Ni ✓
- Quadrupole collectivity in light Sn ✓
- γ-γ spectroscopy in neutron-rich Mg ✓
- Neutron-rich C lifetime measurement ✓
- Collectivity at *N=Z* via RDM lifetime measurements ✓
- B(E2:2→0) in ^{12}Be ✓
- $^{71\text{-}74}$Ni excited-state lifetimes ✓
- Inelastic excitations beyond ^{48}Ca ✓
- Triple configuration coexistence in ^{44}S ✓
- Search for isovector giant monopole resonance ✓

GRETINA science in talks at ARIS 2014

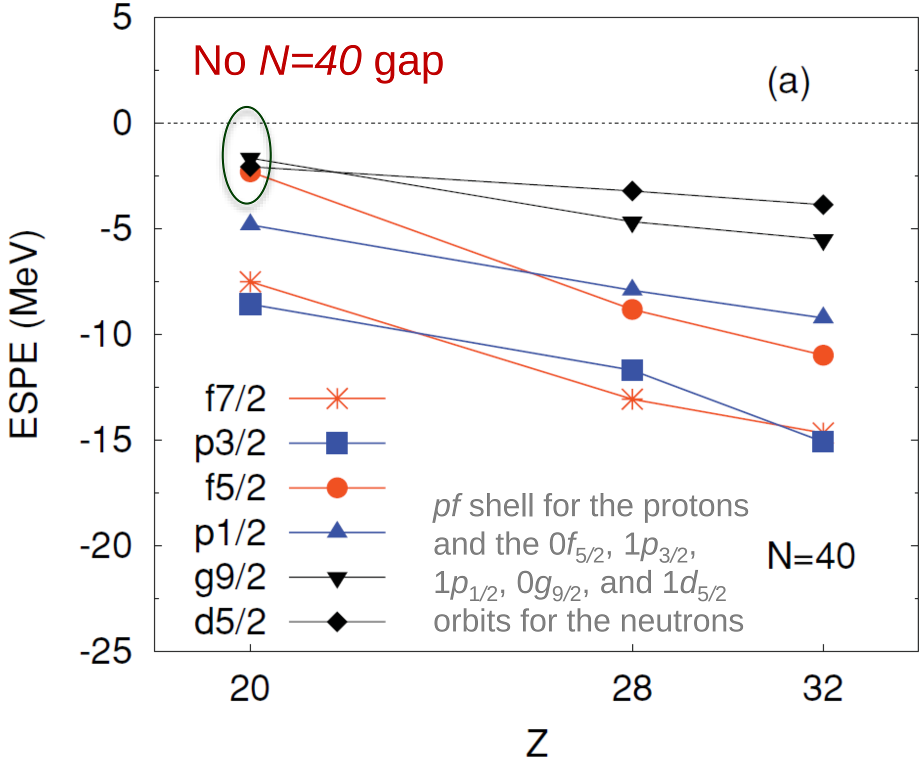


Nuclear chart courtesy of Thomas Duguet

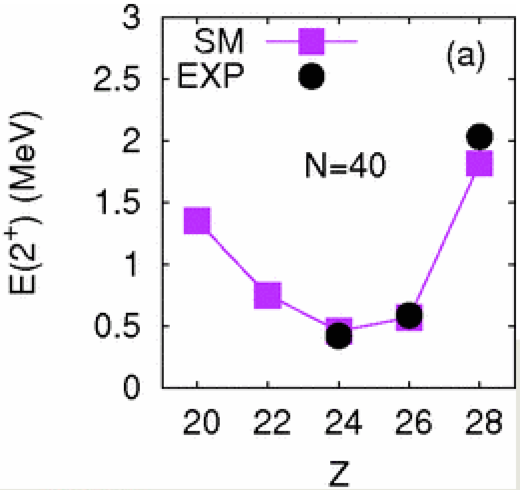
GRETINA surrounding the target position of the S800 spectrograph

Shell evolution around *N=40* – nuclear structure towards ^{60}Ca

LNPS effective interaction



- Effective shell model interaction with the largest model space available predict $f_{5/2}$, $d_{5/2}$, $g_{9/2}$ degenerate – essentially no *N=40* gap at all
- The 12 CSkP Skyrme functionals by B. A. Brown [PRL 111, 232502 (2013)] give an *N=40* shell gap between 3-4 MeV and this would change the particle-hole content of the wave functions in this region
- Experimental information is needed

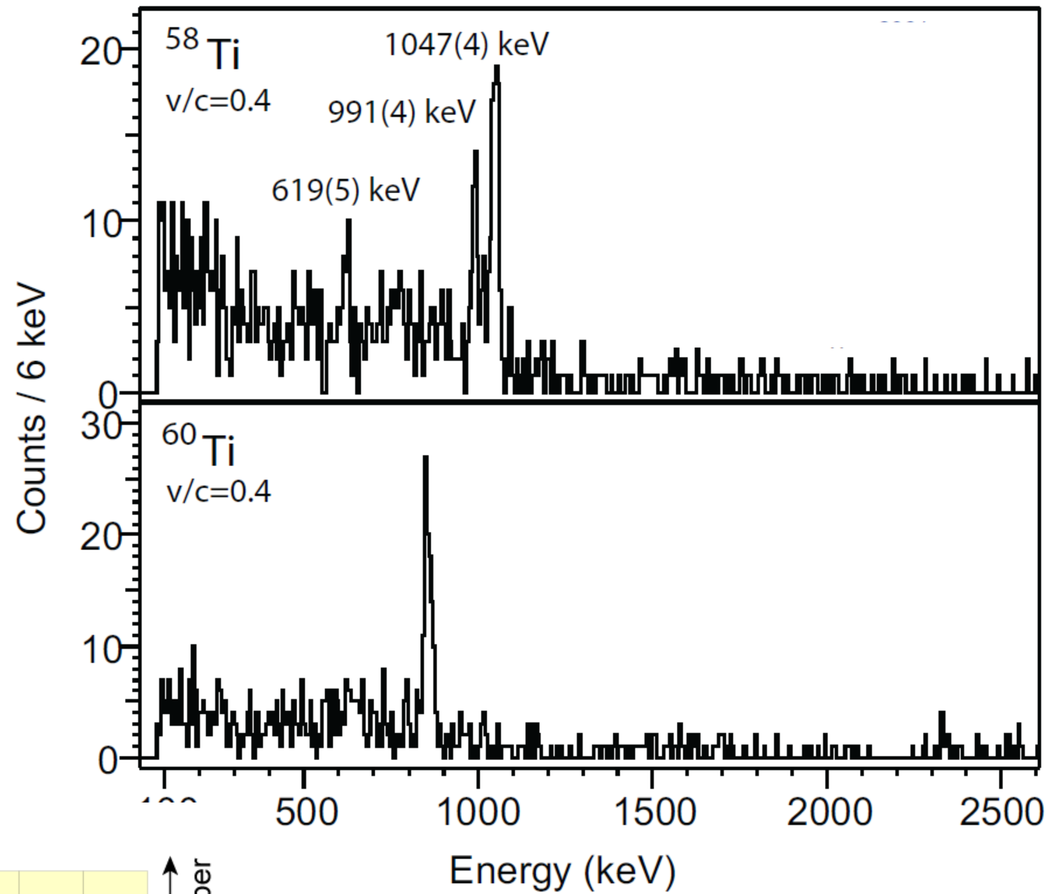


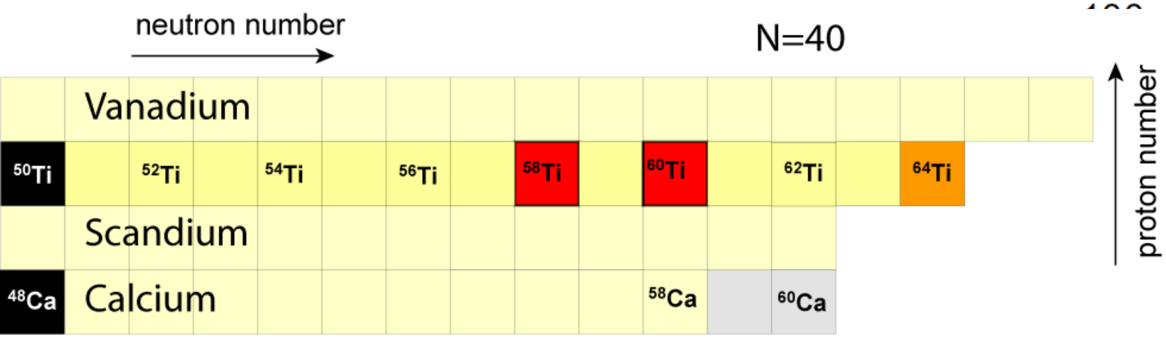
Nucleus	$\nu g_{9/2}$	$\nu d_{5/2}$	0p0h	2p2h	4p4h	6p6h	E_{corr}
^{68}Ni	0.98	0.10	55.5	35.5	8.5	0.5	−9.03
^{66}Fe	3.17	0.46	1	19	72	8	−23.96
^{64}Cr	3.41	0.76	0	9	73	18	−24.83
^{62}Ti	3.17	1.09	1	14	63	22	−19.62
^{60}Ca	2.55	1.52	1	18	59	22	−12.09

S. Lenzi *et al.*, PRC 82, 054301 (2010)

Shell evolution around *N=40* in neutron-rich Ti isotopes: $^{9}Be(^{61}V,^{60}Ti+\gamma)X$

- The structure of neutron-rich Ti-Ni isotopes is subject to shell evolution largely driven by the monopole parts of the *pn* tensor force
- Excited states are often one of the first benchmarks. Only one excited state was known in ^{58}Ti, nothing in ^{60}Ti.
- Excited states in $^{58,60}Ti$ were populated in nucleon removal reactions and will provide first benchmarks towards *N=40* in the Ti isotopes



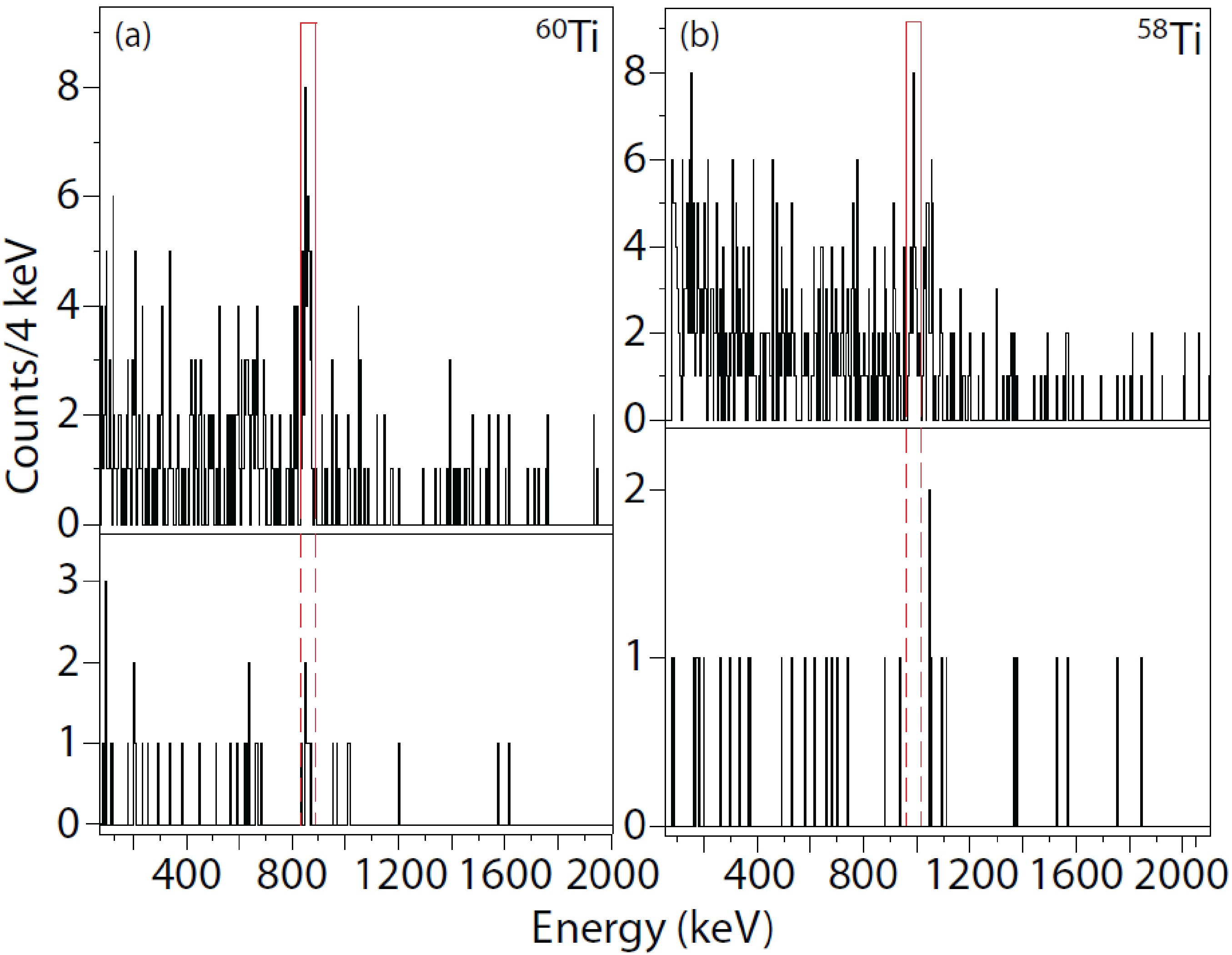


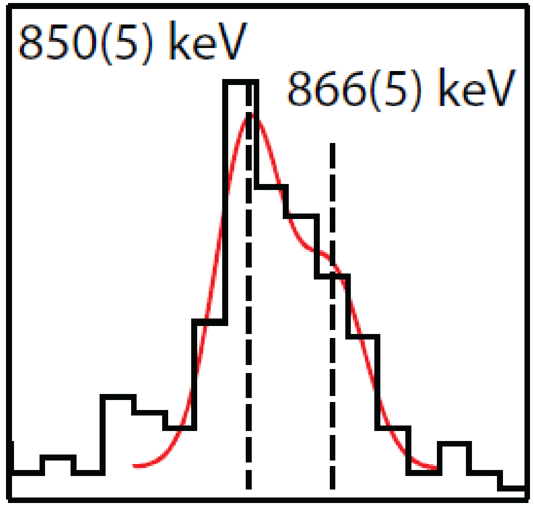
^{50}Ti and ^{48}Ca are the last stable titanium and calcium isotope

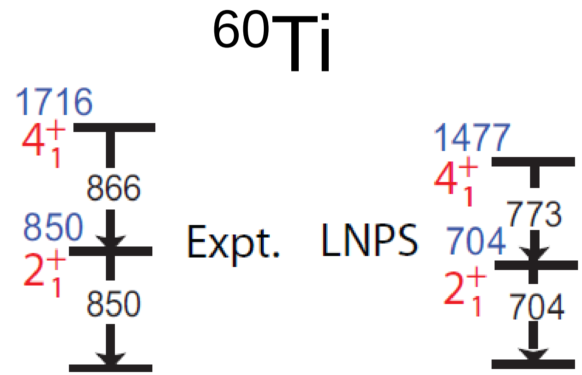
^{64}Ti and ^{58}Ca are the last titanium and calcium isotopes known to exist

A. Gade *et al.,* PRL 112, 112503 (2014)

Looks like a doublet, smells like a doublet …



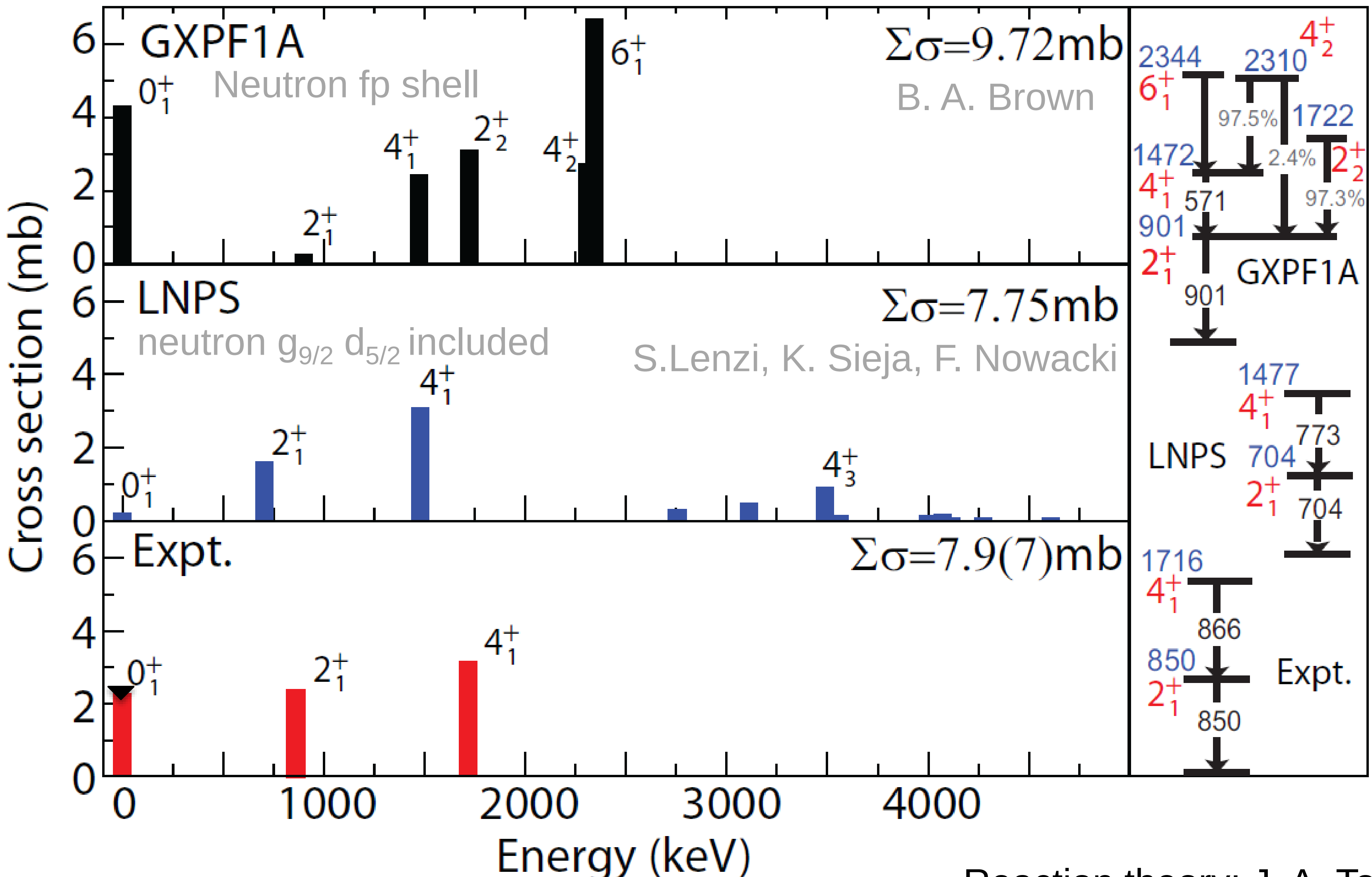




National Science Foundation
Michigan State University

A. Gade, R. V. F. Janssens *et al.*,
PRL 112, 112503 (2014)

Probing the wave function with direct reactions

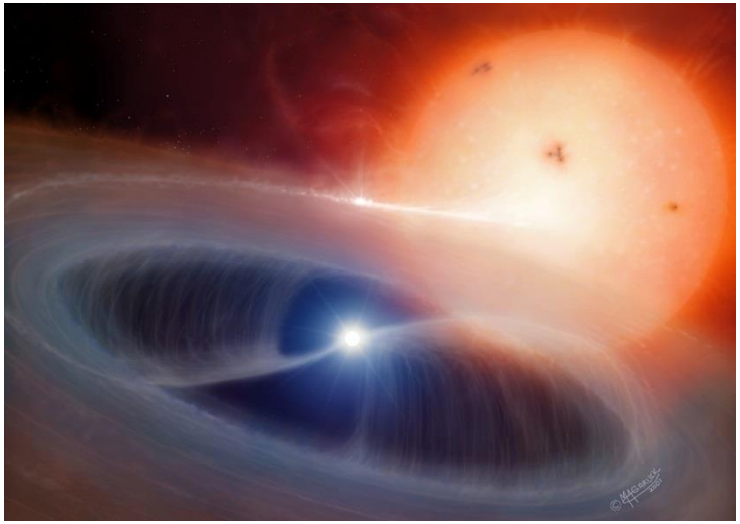


Reaction theory: J. A. Tostevin

A. Gade, R. V. F. Janssens *et al.*,
PRL 112, 112503 (2014)

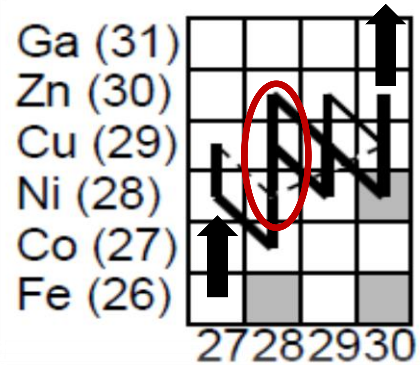
rp process reaction flow through ^{56}Ni: Importance of excited states in ^{58}Zn

Type I X-ray burst – the *rp* process



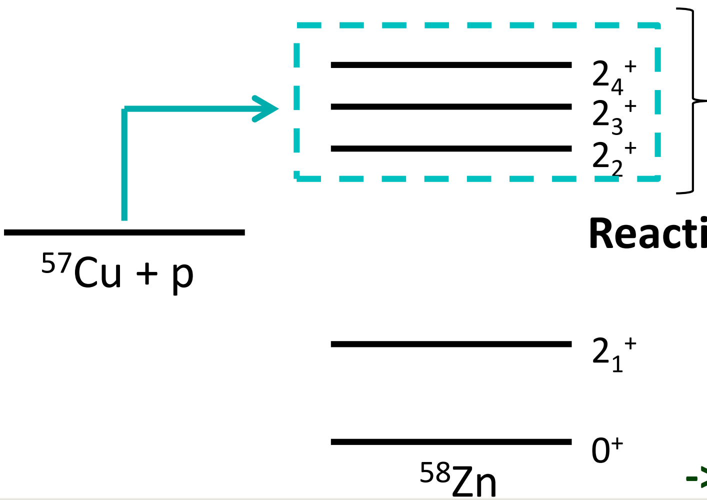
What are the most important reactions?

^{57}Cu(p,γ)^{58}Zn among TOP 20 reactions



Nuclear reaction flow powers X-ray bursts through important waiting point ^{56}Ni

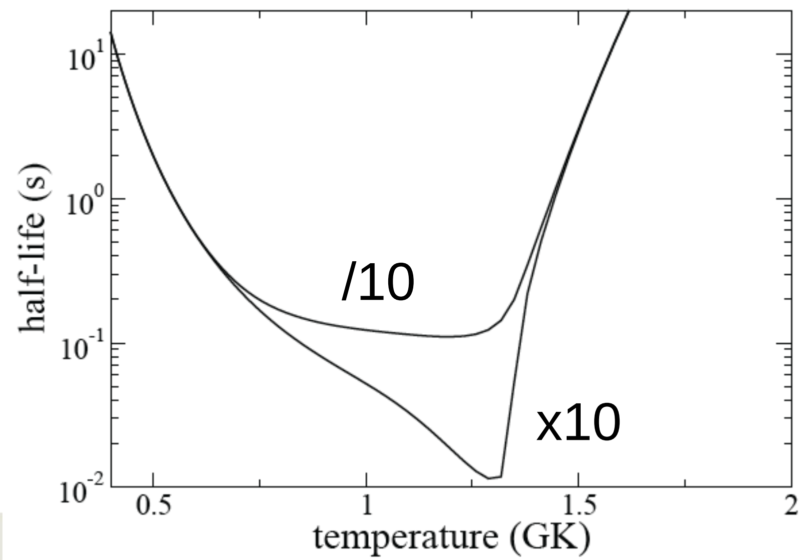
Variations of ^{57}Cu(p,γ)^{58}Zn affect the eff. lifetime of ^{56}Ni



Gamow window (E_0 ~ 1.15 ± 0.73 MeV)

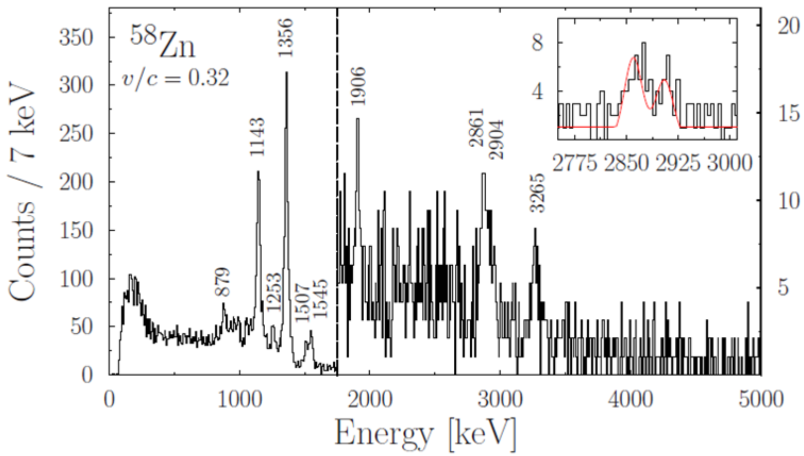
Reaction rate dominated by 2^+ resonances

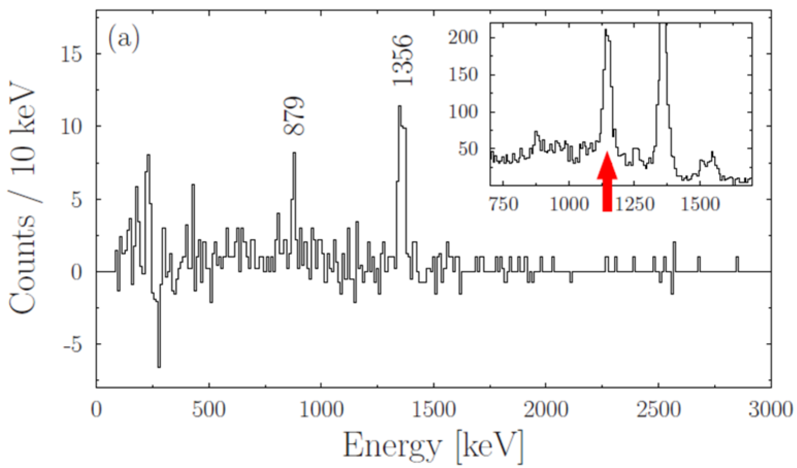
So far: no states measured in ^{58}Zn -> only from theory

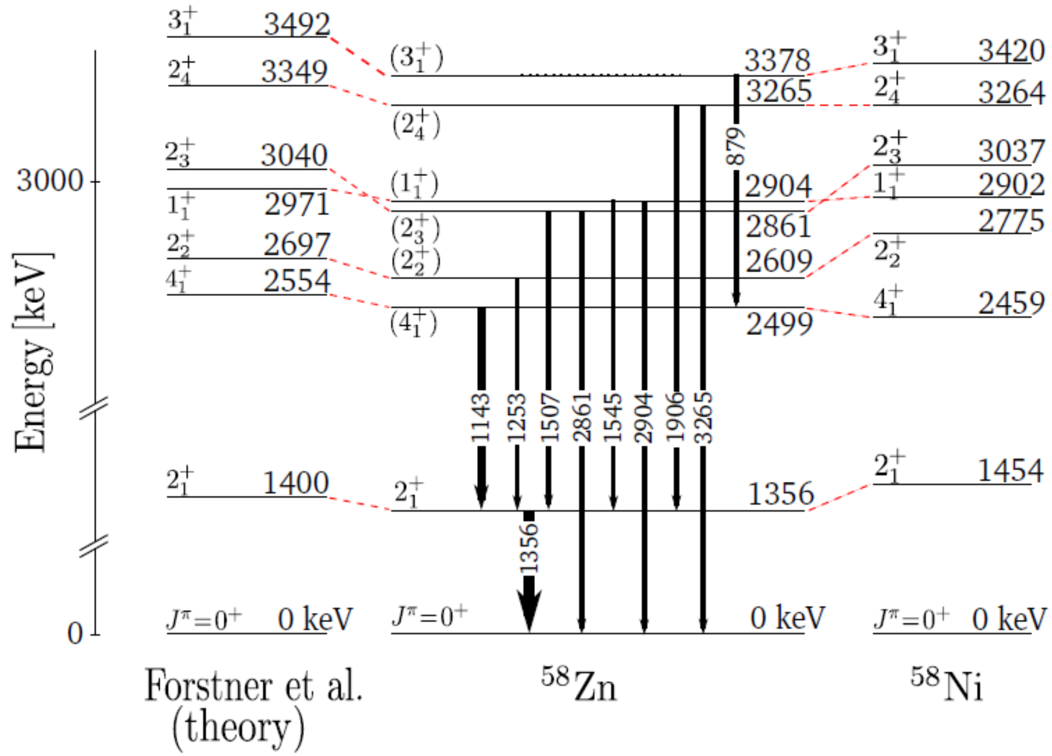


C. Langer, F. Montes *et al.*, PRL, accepted

Spectroscopy of neutron-deficient ^{58}Zn in $d(^{57}Cu,^{58}Zn+\gamma)$ at 75 MeV/u

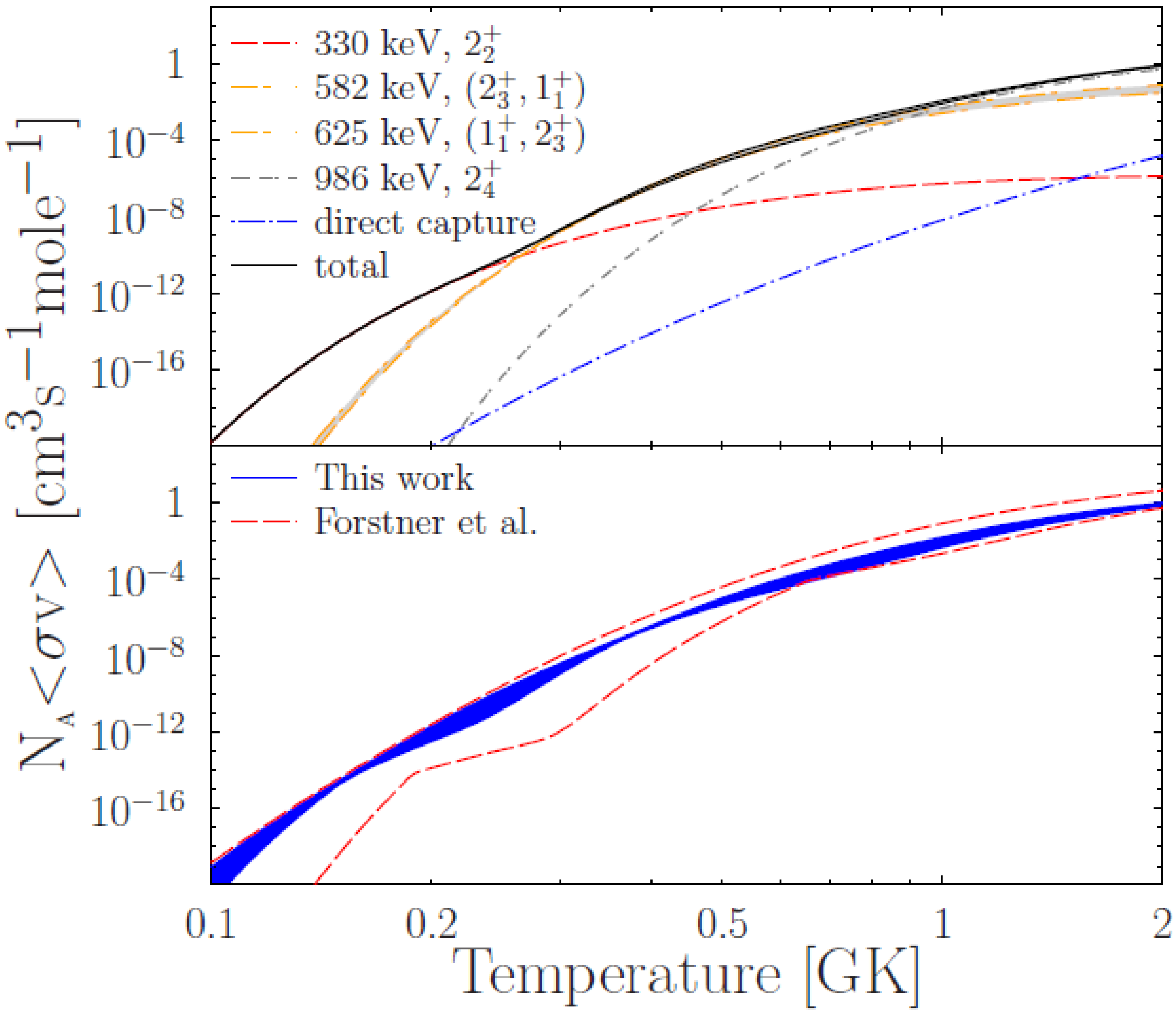






C. Langer, F. Montes *et al.*, PRL, accepted

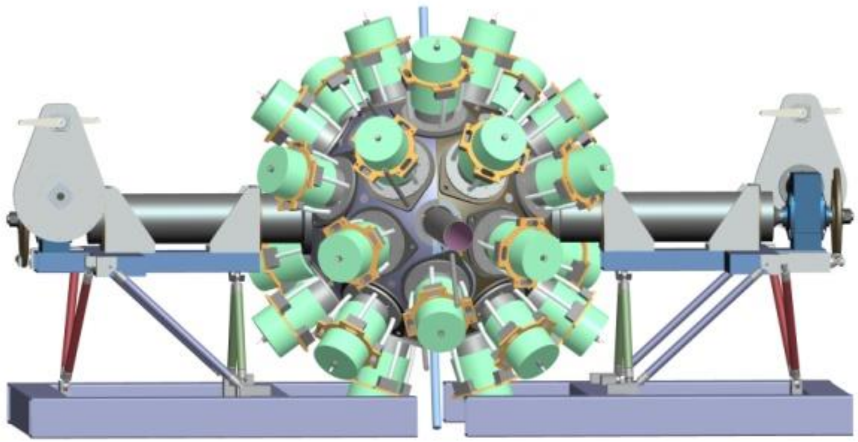
Uncertainty of reaction rate reduced from 4 orders of magnitude to factor of 10



C. Langer, F. Montes *et al.*, PRL, accepted

Outlook – The future is bright

- In-beam γ-ray spectroscopy is prospering around the world with great opportunities afforded by advanced arrays, clever targets and powerful accelerators
- GRETINA at NSCL was a great success and the second science campaign at ATLAS/ANL just started
  - First GRETINA@NSCL science results are out (see publications and talks/posters during this week)
- GRETINA will return to NSCL for a second fast beam campaign in 2015 after the ANL campaign is completed (likely with more detectors!)



Partners in crime …

- ^{58}Zn science slides contributed by Chris Langer and Fernando Montes *et al.* (MSU)

@

Acknowledgement *(for setting up and keeping GRETINA going at NSCL)* :
LBNL: I.Y. Lee, A.O. Macchiavelli, C.M. Campbell, H. Crawford, M. Cromaz, C. Lionberger, A. Wiens
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