The GRETINA science campaign at NSCL and FRIB update

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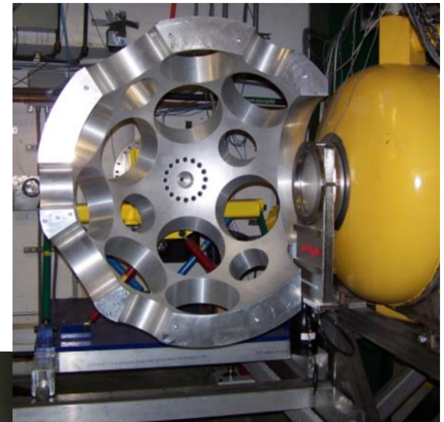
NSCL and Michigan State University

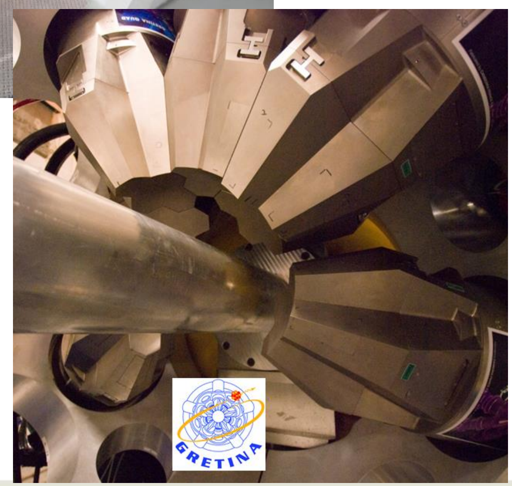
Outline

- GRETINA at NSCL
- Selected science examples
  - Nuclear astrophysics
  - Benchmarking weak-interaction strength
  - Nuclear structure physics (N=40)
- FRIB status
- Summary and outlook

GRETINA’s time line at NSCL

- April 23, 2012 – truck from LBNL at NSCL loading dock
- Week of April 30, 2012 – first detectors in the frame
- May/June – benchmarking of GRETINA with sources, GRETINA DAQ improvements, combining S800 and GRETINA DAQs
- June 23 – first beam in the setup for DAQ commissioning
- July 9, 2012 – PAC-approved commissioning run
- July 23, 2012 – first run of science campaign
- June 17, 2013 – start of last science run (23 experiments later …)





GRETINA surrounding the target position of the S800 spectrograph

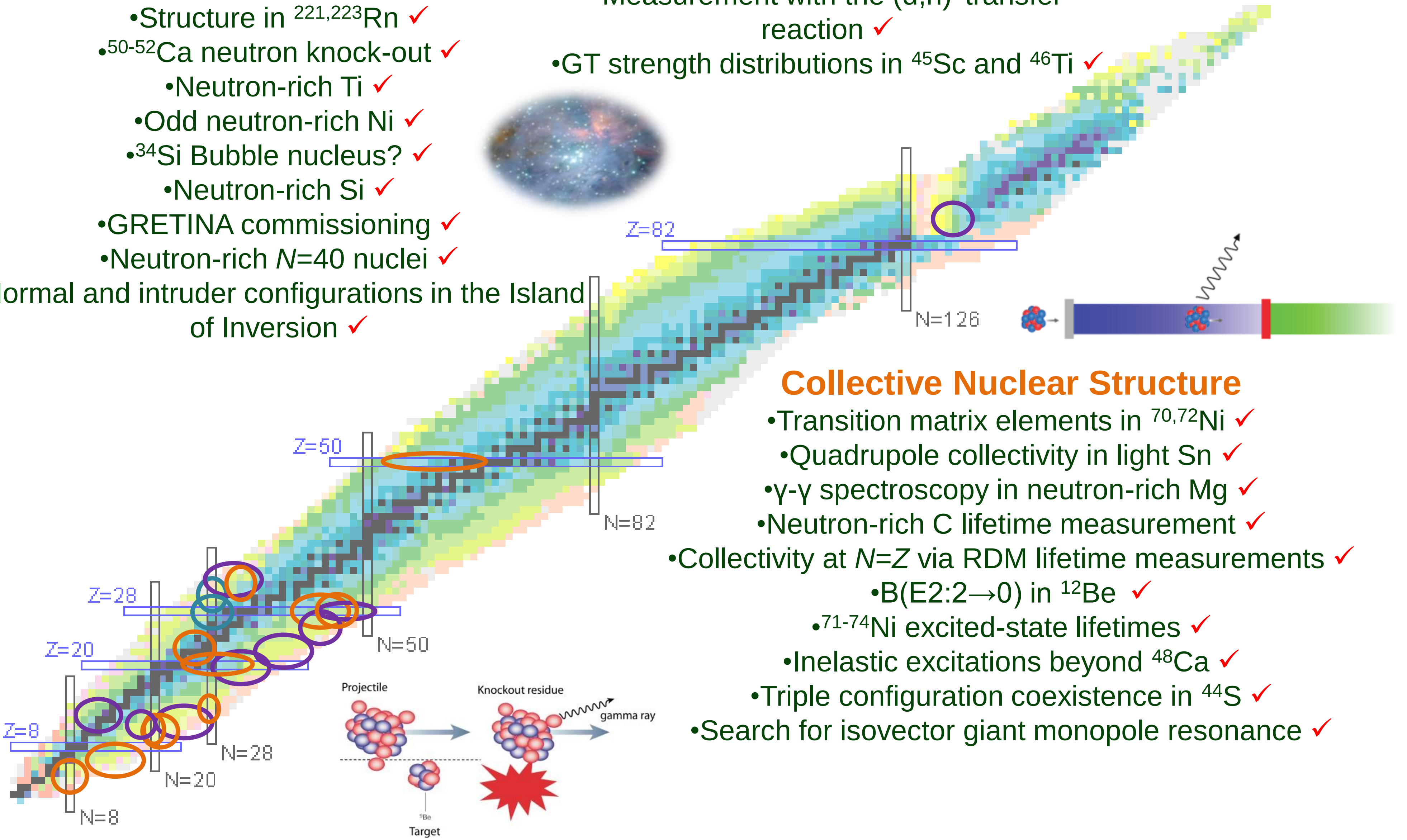
With beams from Be (Z=4) to U (Z=92)

Nuclear Shell Evolution

- •*N*=*Z* Mirror Spectroscopy ✓
- •Structure in ^{221,223}Rn ✓
- •$^{50\text{-}52}$Ca neutron knock-out ✓
- •Neutron-rich Ti ✓
- •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 ✓



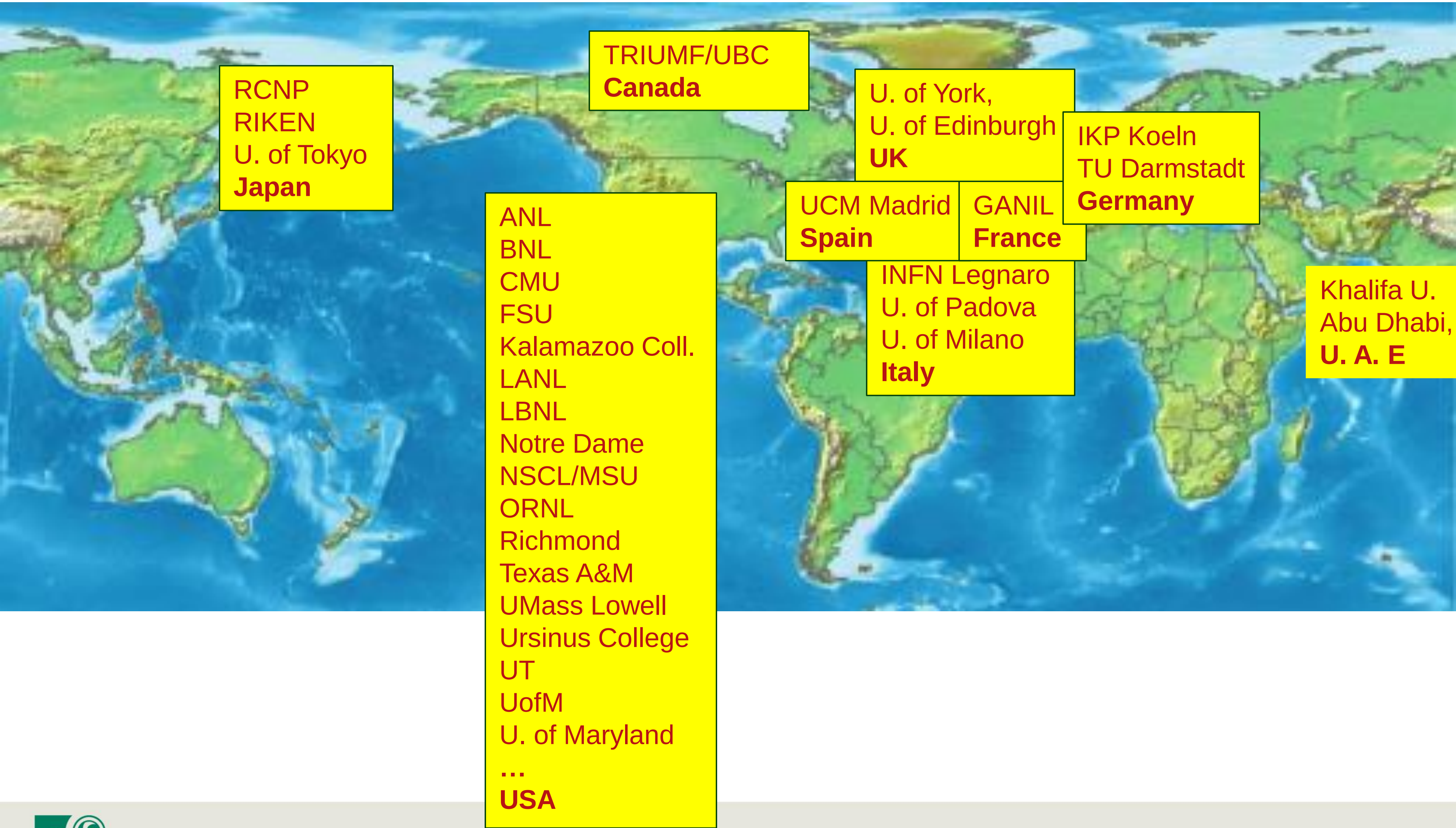
Collective Nuclear Structure

- •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 ✓

✓ Completed in 2012/2013

Slide adapted from H. L. Crawford

GRETINA at NSCL attracted researchers from all over the world

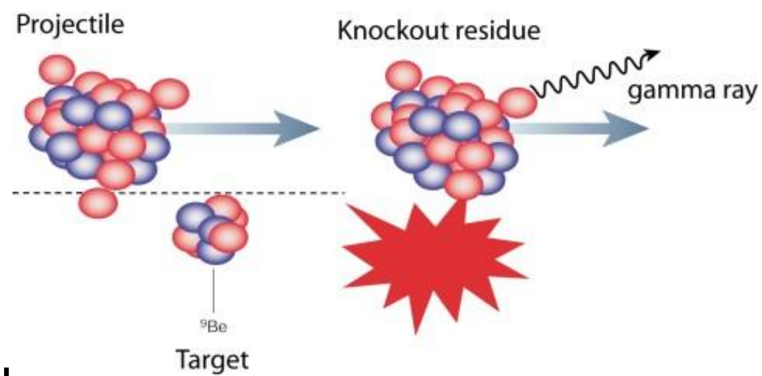


… from Kalamazoo to Abu Dhabi

Broad spectrum of science opportunities and experimental techniques - Structure

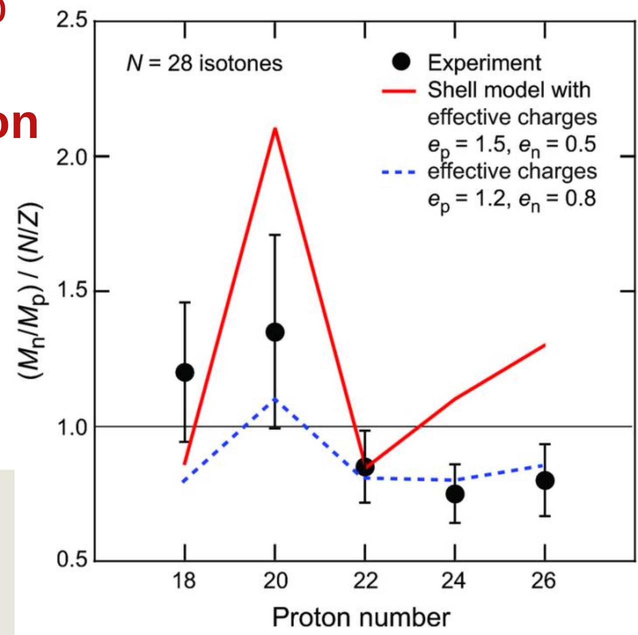
Nuclear Structure Physics

- Complementary degrees of freedom are accessible
  - Single-particle properties
    - » Nucleon knockout
    - » Transfer reactions
  - Collective degrees of freedom
    - » Excited-state lifetime measurements
    - » Inelastic scattering
  - …

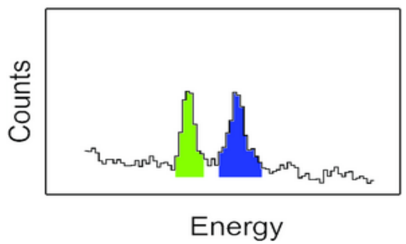


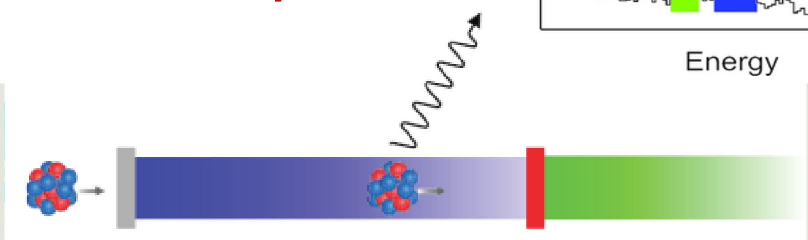
Direct reactions:
- nucleon-removing reactions (knockout)
- Nucleon-adding transfer reactions (light-ion and heavy-ion induced)

Disentangle proton and neutron contributions to collectivity with **inelastic proton scattering**



Precision excited-state lifetime measurements with the **plunger technique** or **Doppler-shift line-shape**



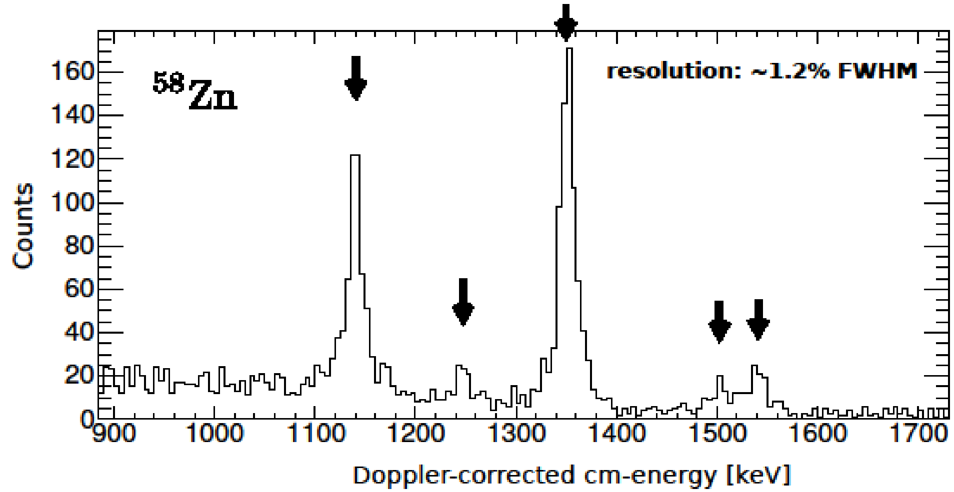


Broad spectrum of science opportunities and experimental techniques - Astro

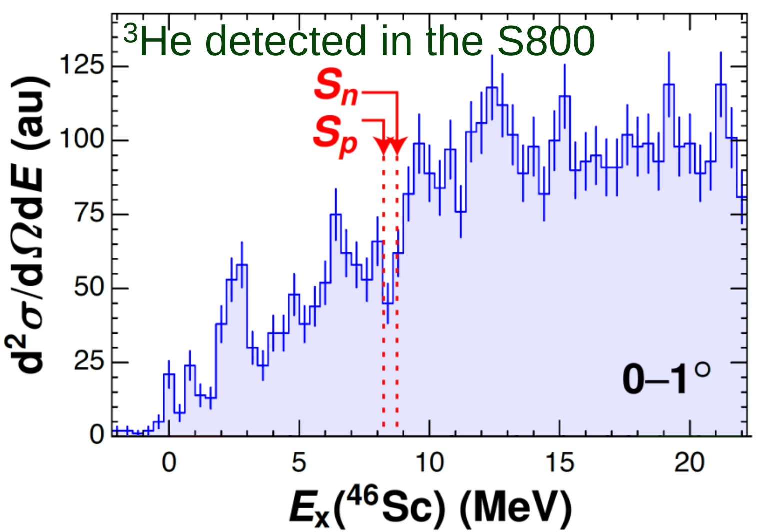
Nuclear Astrophysics

- Various quantities/observables are accessible
  - Energies of states of astrophysical relevance (e.g. rp process)
    - » Any reaction that populates the states on interest
  - Spectroscopic factors or ANCs to restrict Γ_p for relevant excited states which set the (p,γ) rate for some states of astrophysical relevance
    - » (d,n+γ) transfer reactions
  - Weak-interaction strength to probe input for EC rates
    - » Charge-exchange [(t,^{3}He), (p,n), (^{7}Li,^{7}Be), …]
  - …

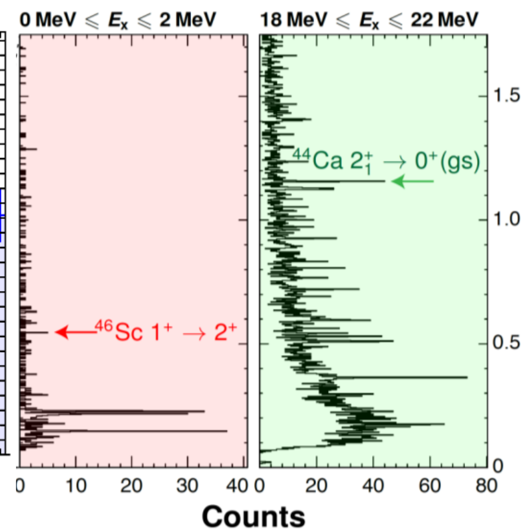
Measuring energies of astro-relevant excited states



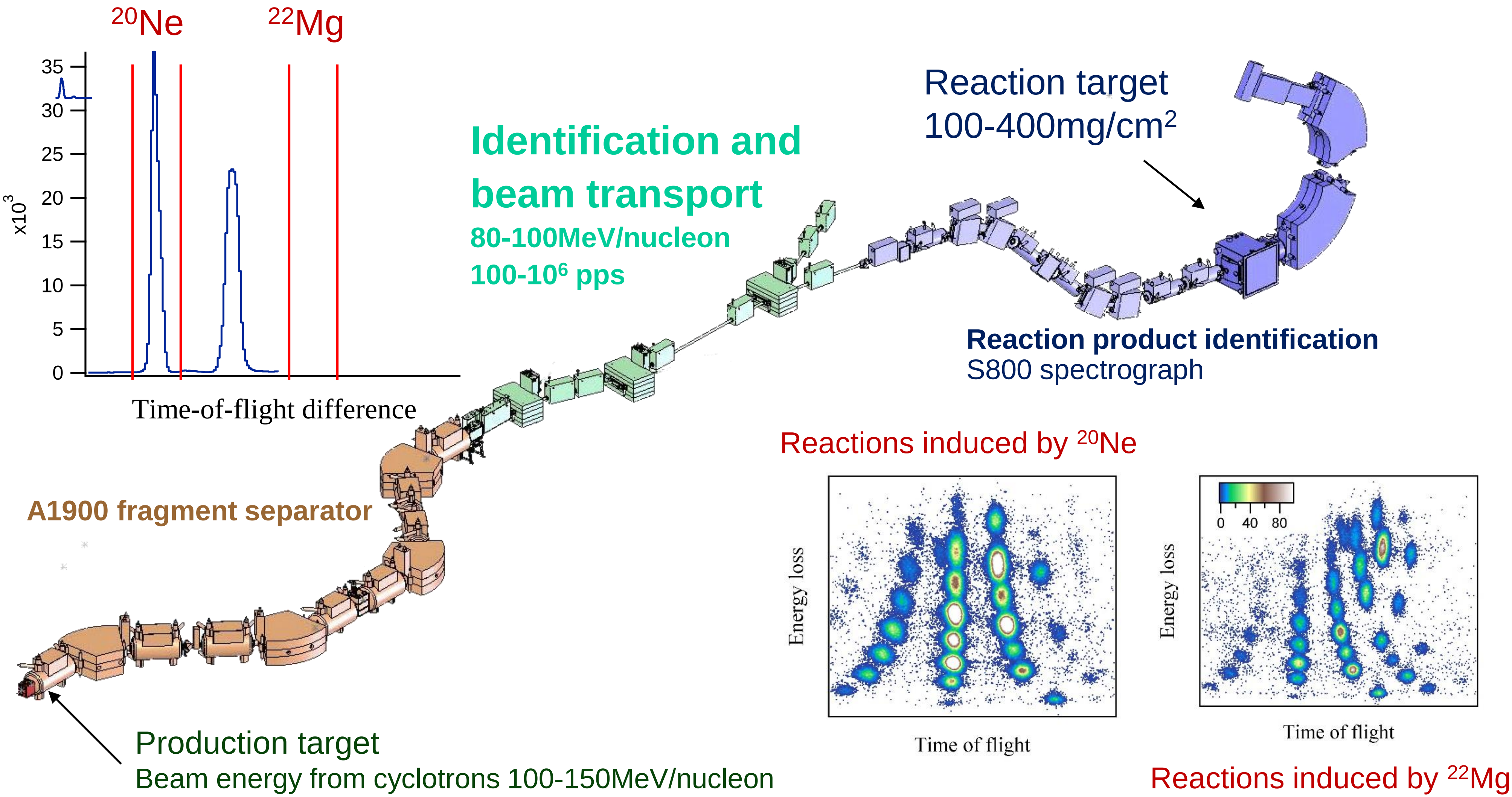
Gamow-Teller strength from charge-exchange



γ-rays of ^{46}Sc and decay daughters

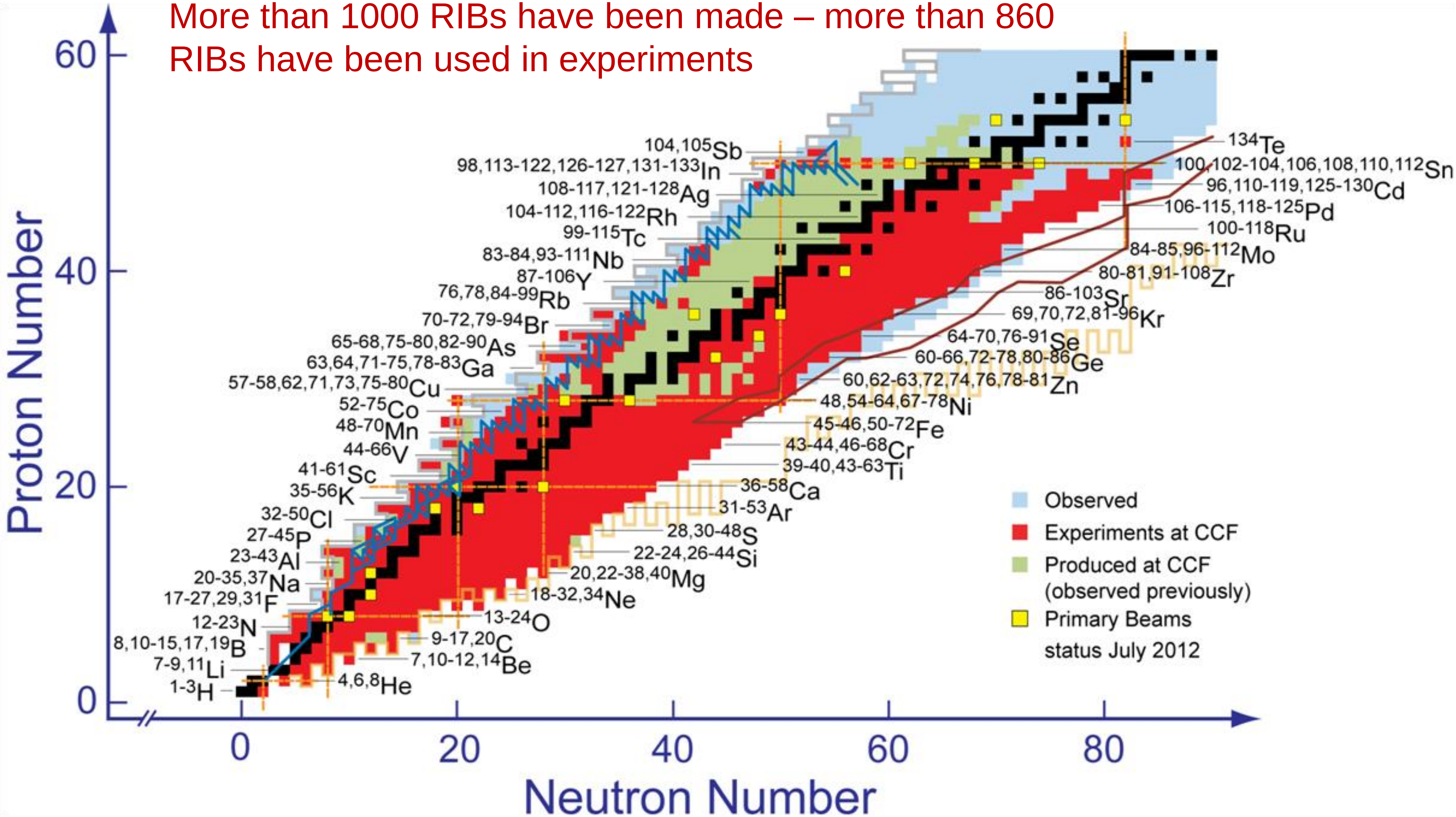


Fast-beam experiments at NSCL



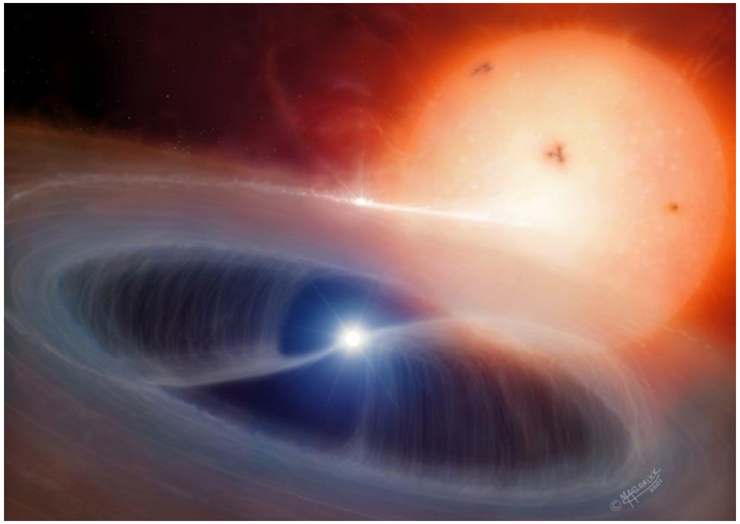
Beams produced and used for experiments with the CCF

More than 1000 RIBs have been made – more than 860 RIBs have been used in experiments



Spectroscopy of proton-rich ^{58}Zn

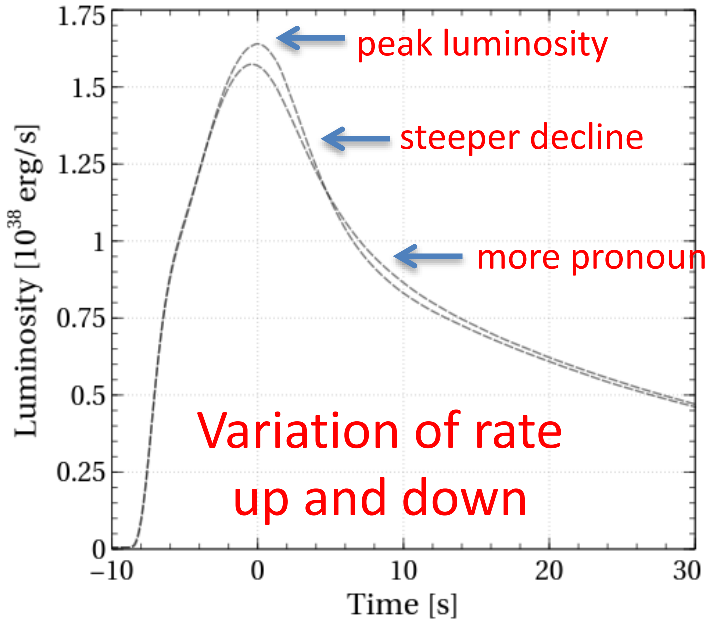
Type I X-ray burst – the rp process

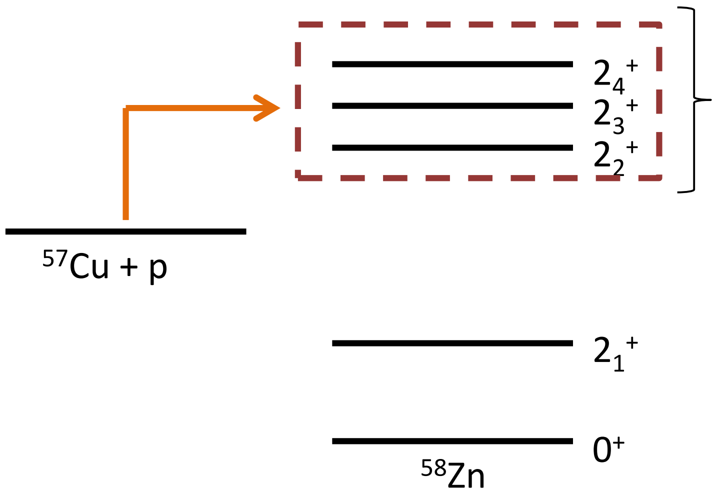


What are the most important reactions?

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

induced light curve uncertainties





Gamow window (E_0 ~ 1.15 ± 0.73 MeV)

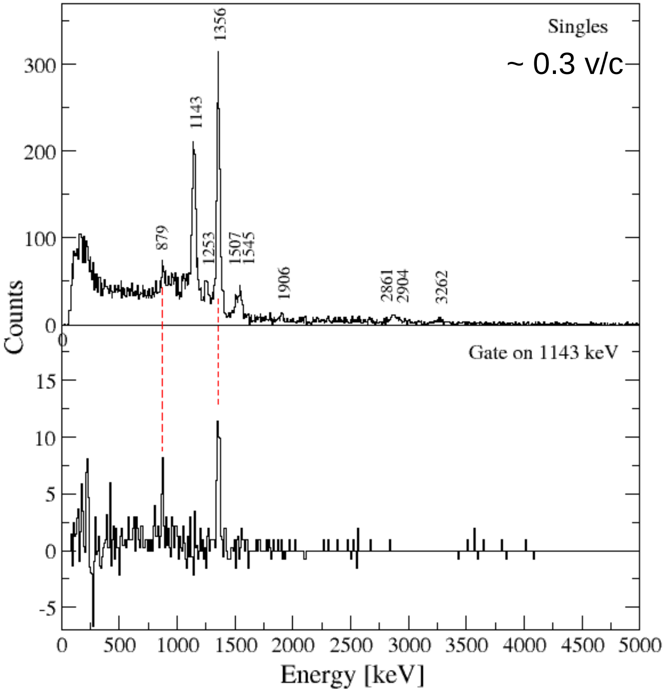
So far: no states measured in ^{58}Zn

-> only from theory with big uncertainties!

Reaction rate dominated by 2^+ resonances

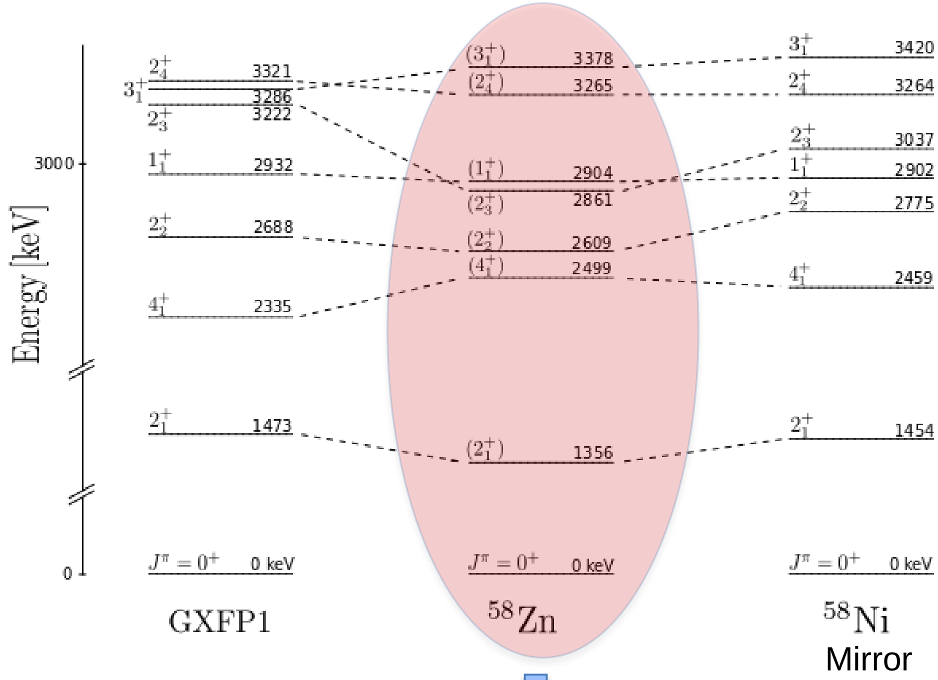
C. Langer, F. Montes, et al. (2013)

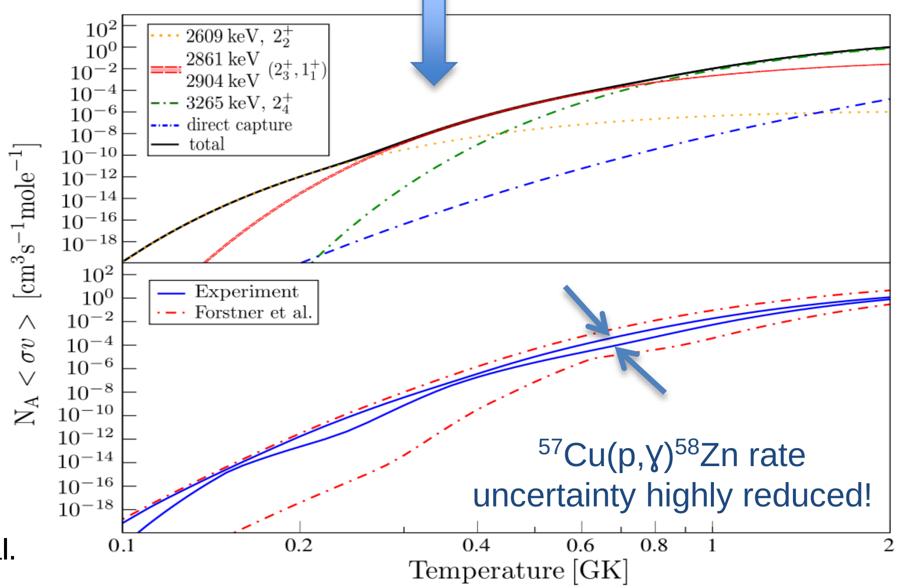
Spectroscopy of proton-rich ^{58}Zn



using γγ's, mirror

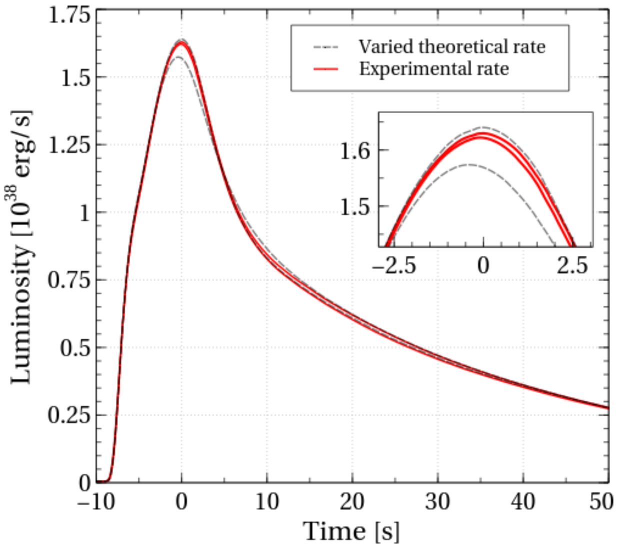
+ shell-model





light curve modeled with

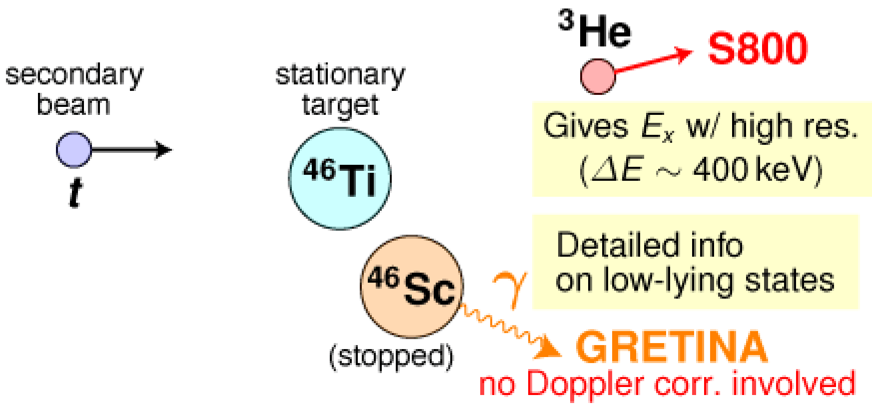
1D hydro KEPLER code

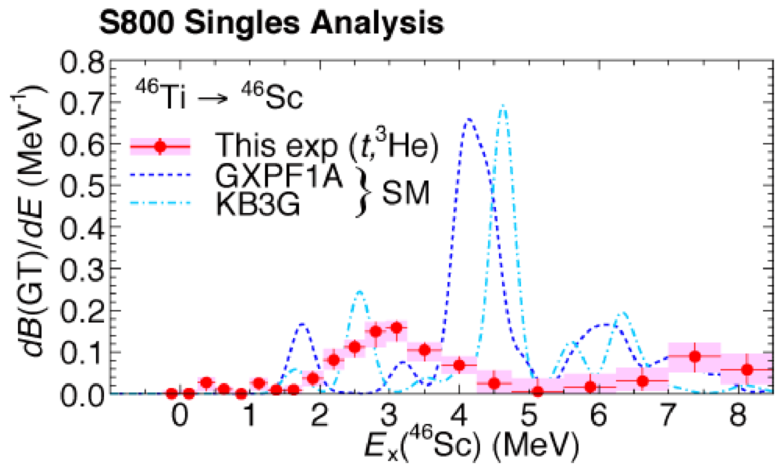


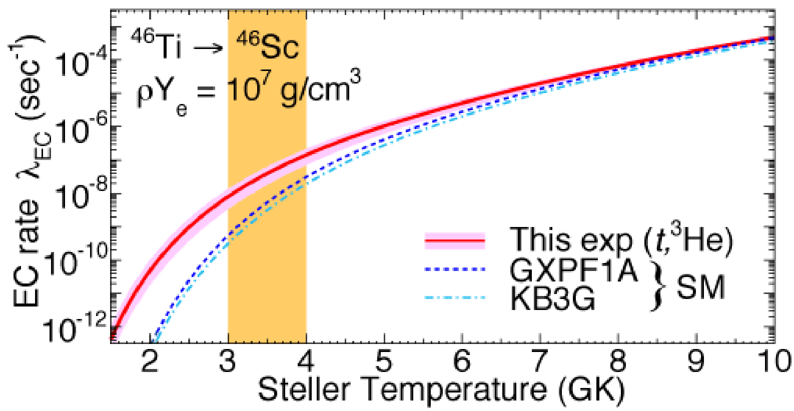
C. Langer, F. Montes, et al. tbp (2013)

Benchmarking nuclear Hamiltonians for the description of weak interactions strength –
Gamow-Teller strength distribution in ^{46}Ti

- *B*(GT) in *pf*-shell
  - Electron capture rates of astrophysical importance: Supernova evolution
  - Lightest *pf*-shell nuclei: Shell model's deficiency is possible (Mixing of *pf* & *sd* shells)
  - Needs detailed knowledge of the lowest-lying GT transition: Important for EC rates
- Experiment: Charge-Exchange reaction
  - ^{46}Ti(t,^{3}He)^{46}Sc measurement
    - » High resolution, wide E_x range
    - » Multipole decomposition analysis: Extract GT based on angular distribution
  - Measured γ's from stopped ^{46}Sc residue







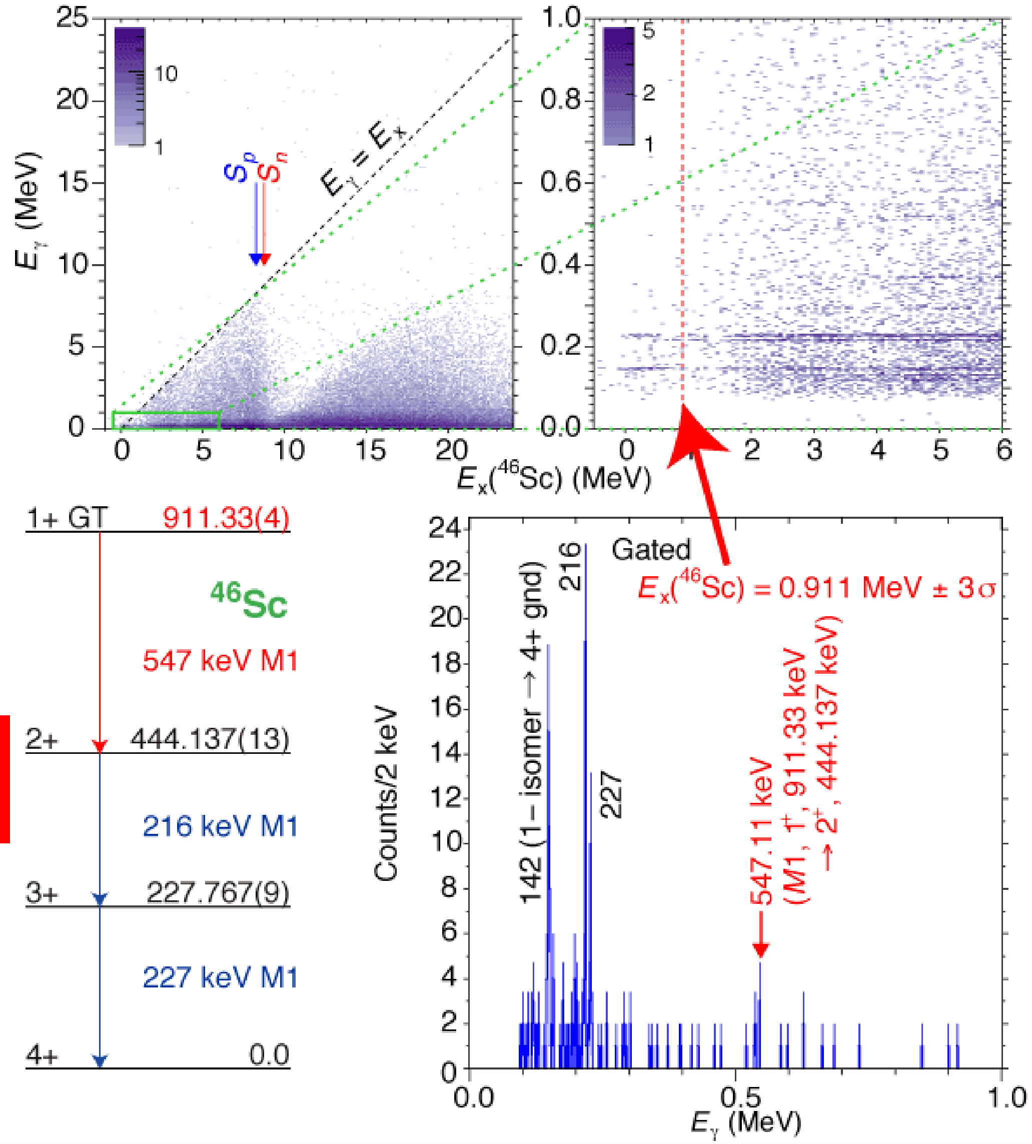
Gamow-Teller strength distribution in ^{46}Ti

- Analysis of γ rays
  - Coincidence with ^{3}He
    - » $E_\gamma = E_x$ line
    - » S_p & S_n particle decays
  - High S800 resolution
    - » Clean E_x selection possible
  - B(GT) for lowest-lying GT states
    - » Lowest known 1^+ GT: 911 keV
    - » De-excitation γ: 547 keV (NNDC)
    - » B(GT) = 0.0088(50)

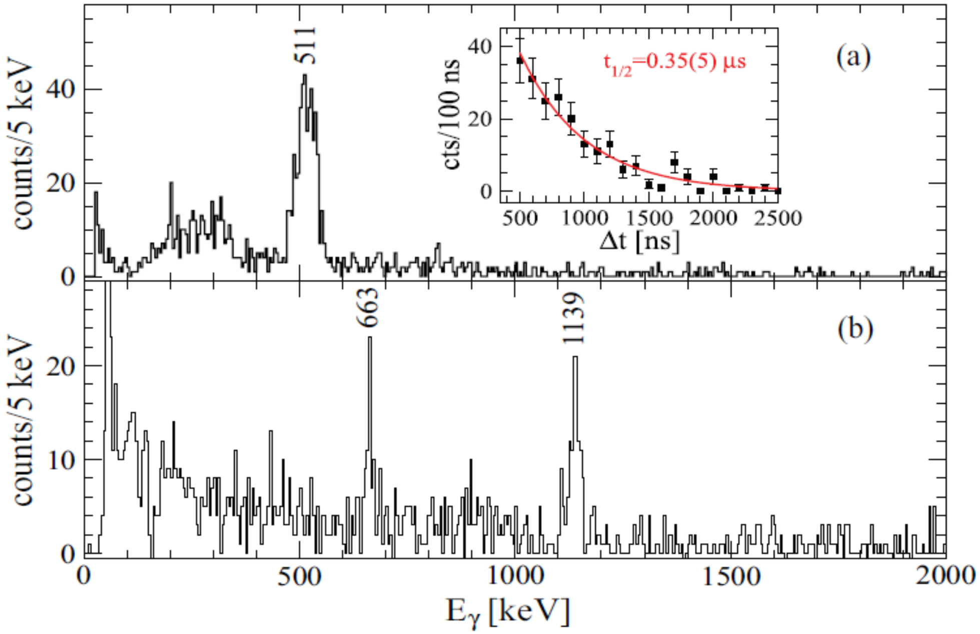
      (Consistent with singles analysis)

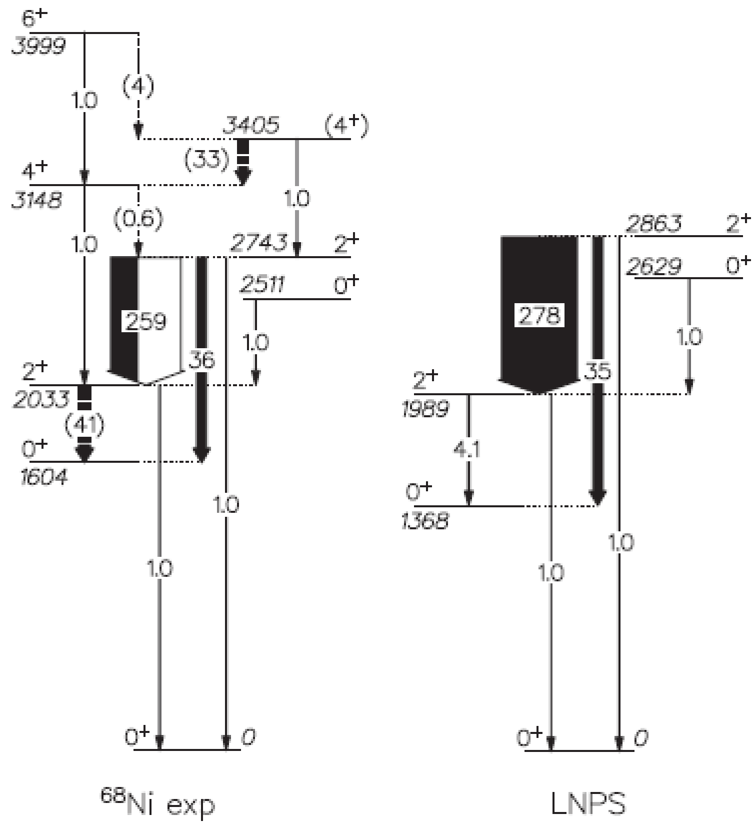
High-resolution CE spectroscopy	High-resolution γ-ray spectroscopy
B(GT) distrib. up to up to high-lying states	Detailed knowledge of low-lying states

Accurate EC rates made available



Single-particle structure of neutron-rich N=40 nuclei



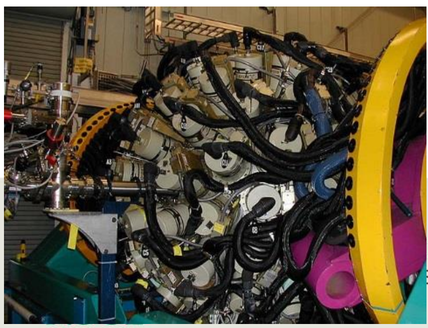


Comparisons with SM calculations reveal the importance of mixing to account for the observed decay patterns. The 2_1^+ and 0_2^+ states appear to have similar structure, and the 2_2^+ and 0_3^+ states may as well. Thus, the present data appear to support the shape-coexistence picture of Refs. [10,13].

PHYSICAL REVIEW C **88**, 041302(R) (2013)

Configuration mixing and relative transition rates between low-spin states in ^{68}Ni

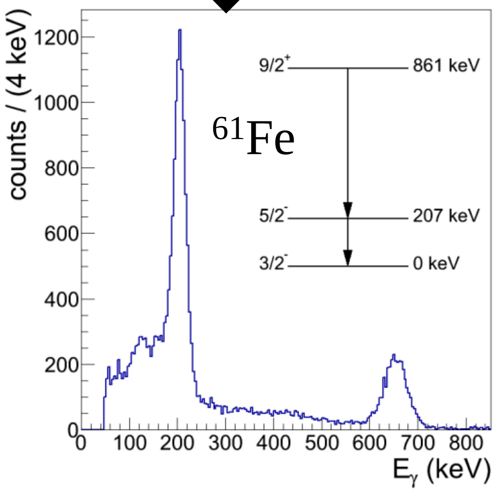
F. Recchia,[1,*] C. J. Chiara,[2,3] R. V. F. Janssens,[3] D. Weisshaar,[1] A. Gade,[1,4] W. B. Walters,[2] M. Albers,[3] M. Alcorta,[3] V. M. Bader,[1,4] T. Baugher,[1,4] D. Bazin,[1] J. S. Berryman,[1] P. F. Bertone,[3,†] B. A. Brown,[1,4] C. M. Campbell,[5] M. P. Carpenter,[3] J. Chen,[6] H. L. Crawford,[5] H. M. David,[3,7] D. T. Doherty,[3,7] C. R. Hoffman,[3] F. G. Kondev,[6] A. Korichi,[3,8] C. Langer,[1] N. Larson,[1,9] T. Lauritsen,[3] S. N. Liddick,[1,9] E. Lunderberg,[1,4] A. O. Macchiavelli,[5] S. Noji,[1] C. Prokop,[1,9] A. M. Rogers,[3,‡] D. Seweryniak,[3] S. R. Stroberg,[1,4] S. Suchyta,[1,9] S. Williams,[1] K. Wimmer,[1,10] and S. Zhu[3]

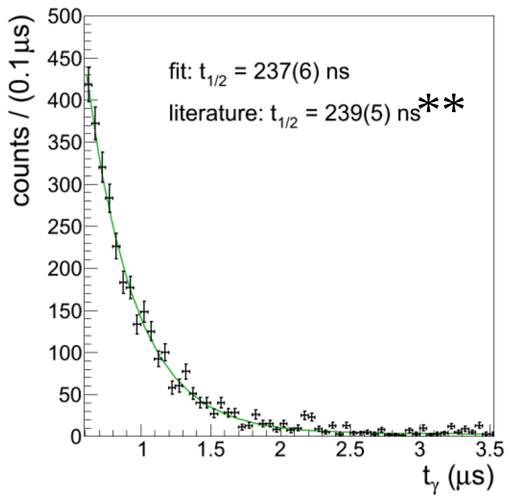


Single-particle structure of neutron-rich N=40 nuclei

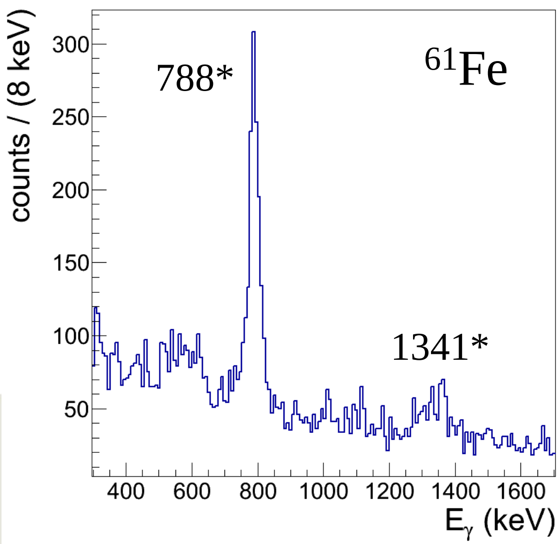
Challenge: Many isomeric states in this region
→ Implementation of isomer tagging in S800

Delayed γ-ray coincidence in hodoscope

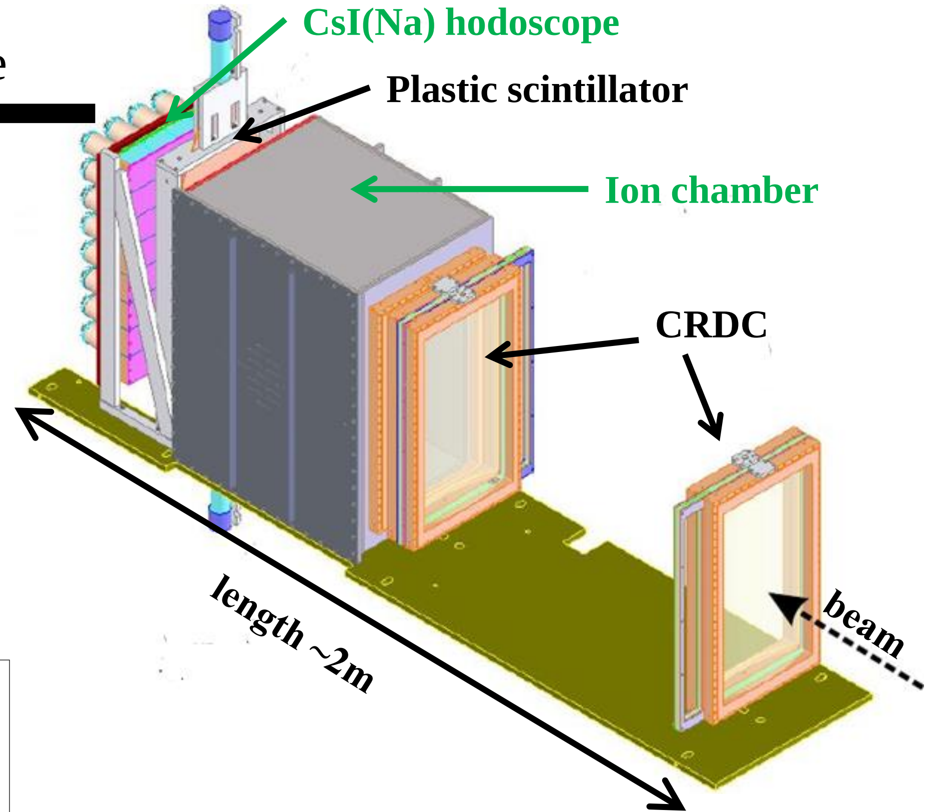




Correlated with prompt γ ray in GRETINA



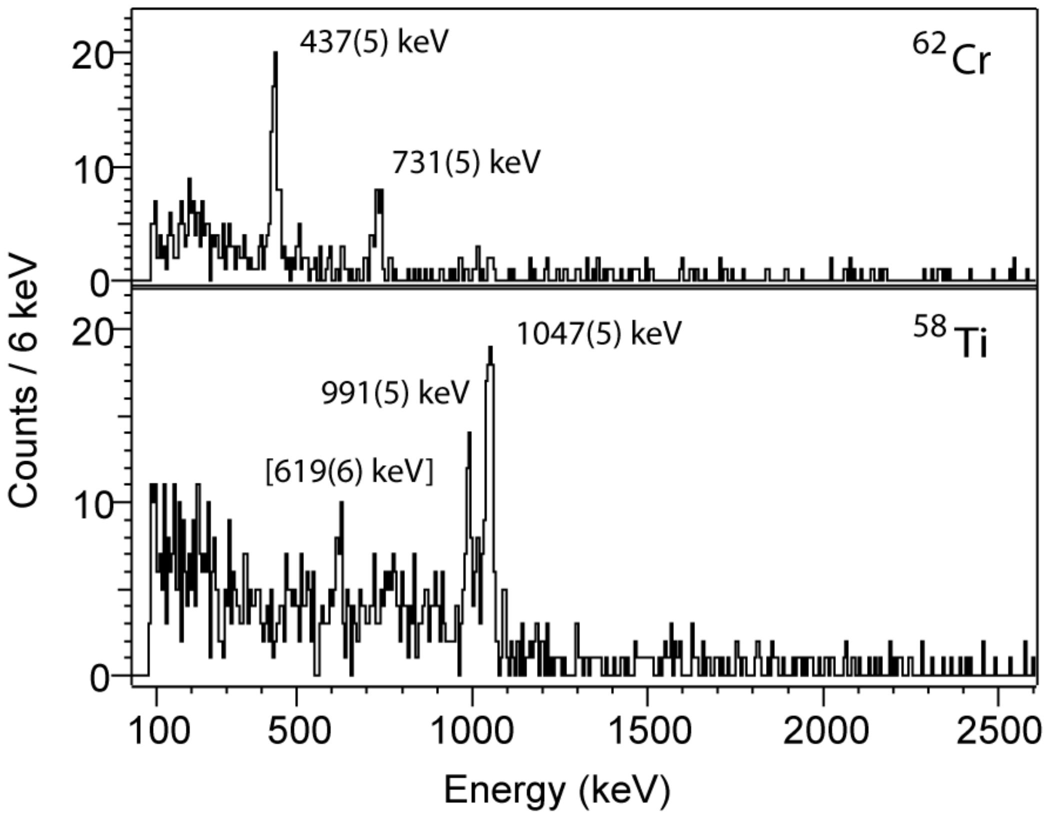
S800 Focal Plane Detectors



(**) I. Mateae al., PRL 93 (2004) 142503

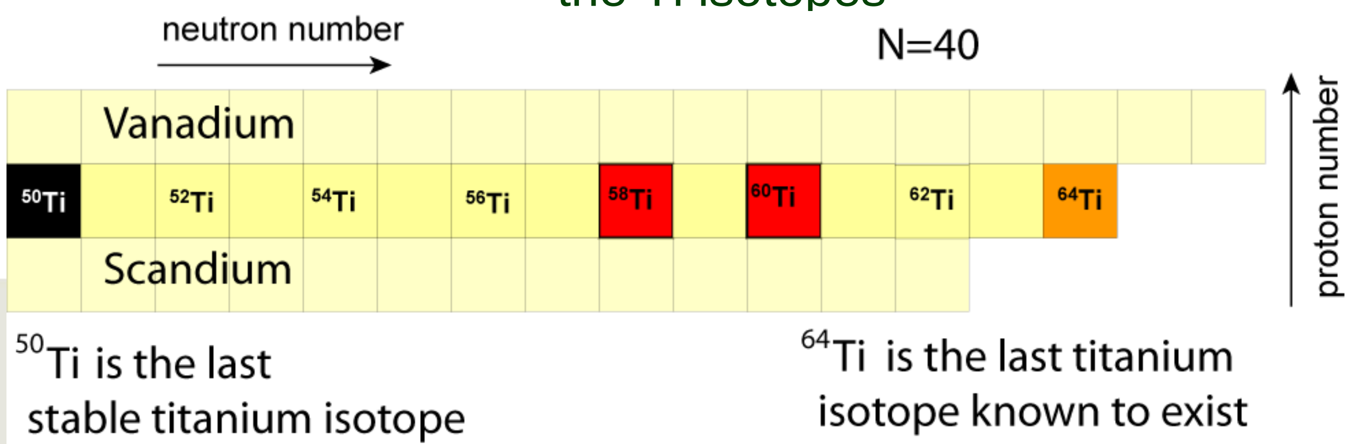
(*) as reported in
S. Lunardi et al., PRC 76 (2007) 034303

Shell evolution around N=40 in neutron-rich Ti isotopes



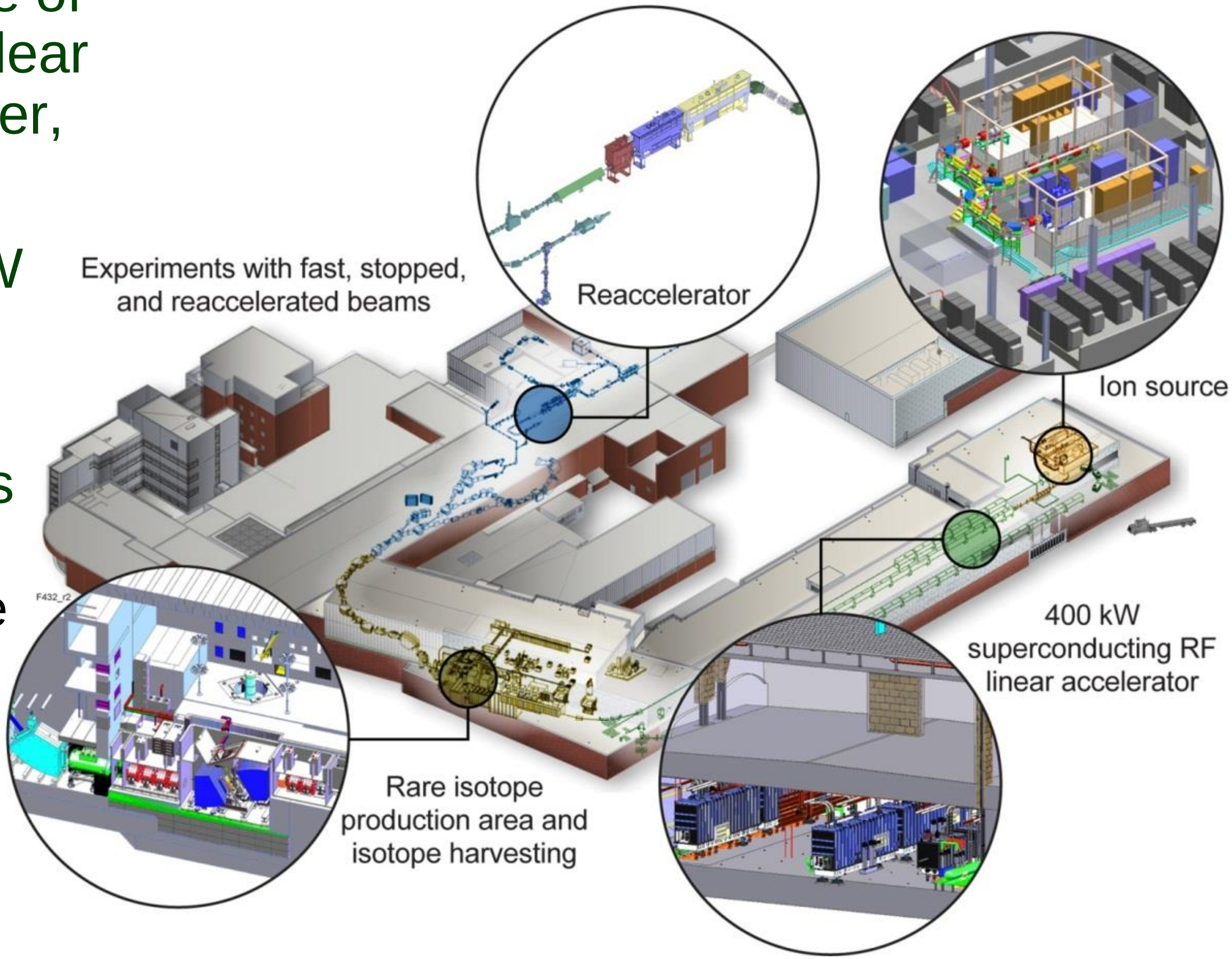
- The structure of neutron-rich Ti-Ni isotopes is subject to shell evolution largely driven by the monopole parts of the pn tensor force
- Excited states are often one of the first benchmarks. Only one excited state was known in ^{58}Ti, nothing in ^{60}Ti.
- Excited states in ^{58,60}Ti were populated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

- Event-by-event Doppler reconstructed spectra for ^{62}Cr and ^{58}Ti – including nearest neighbor addback (*Stay tuned for ^{60}Ti*)



Facility for Rare Isotope Beams, FRIB

- Funded by DOE Office of Science Office of Nuclear Physics. T. Glasmacher, Project Director
- Key Feature is 400 kW beam power (5 x10^{13} ^{238}U/s)
- Separation of isotopes in-flight
  - Fast development time for any isotope
  - Suited for all elements and short half-lives
  - Fast, stopped, and reaccelerated beams



FRIB history and progress

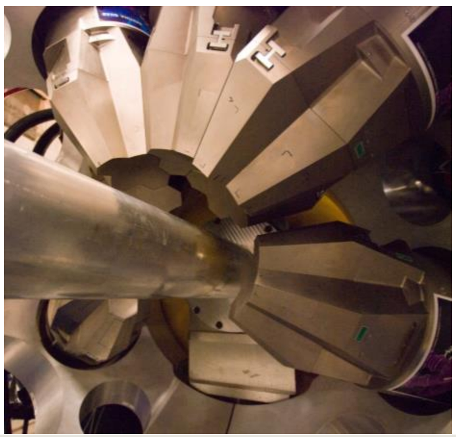
- 8 June 2009 – DOE-SC and MSU sign Cooperative Agreement
- Sept 2010 – Critical Decision 1 approved, DOE issues NEPA FONSI
- April 2012 – Lehman review, baseline and start of civil construction
  - Project is ready *“to establish the performance baseline when funding profile guidance from DOE is provided”*
- Oct 2012 – Lehman mini review
- February 2013 - NSAC Tribble subcommittee states “proceeds with FRIB” even in no-growth budget scenarios. DOE provides funding guidance to FRIB
- August 2013 – CD 2/3a approved (baseline, start civil construction April 2014)
- Fall/winter 2013/14 – 26 reviews prior to CD-3b (all reviews open to DOE and MSU)
  - 6 project-level peer reviews: 2 ASAC, 1 ESAC, 1 ESHAC, 1 PMAC, 1 EVMS
  - 20 technical reviews
- 23-25 April 2014 – MSU President’s Independent CD-3b review
- 24-26 June 2014 – DOE-SC OPS CD-3b review (technical construction)
- Jun 2022 (Dec 2020) – CD-4 (early completion)

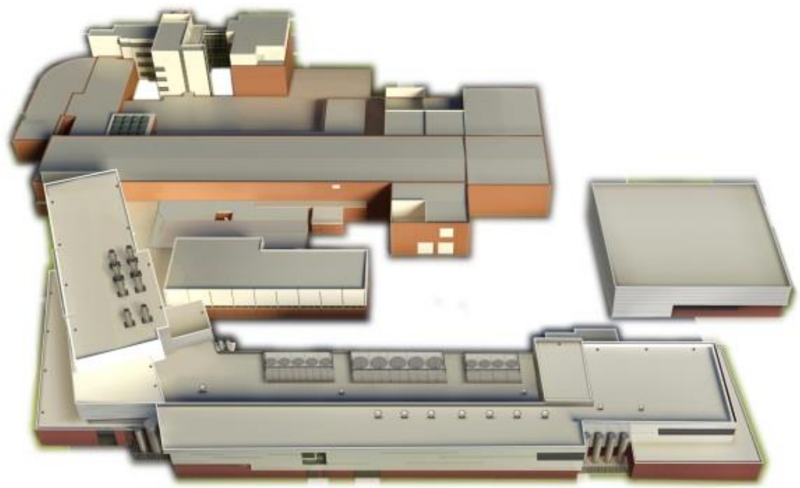
FRIB Site ready for civil construction

- Ready to begin civil construction upon notice to proceed from DOE-SC
- Site preparation is complete; placement of pilings for the earth retention system is complete
- Live web cameras are linked from frib.msu.edu

Summary and outlook

- GRETINA at NSCL was a great success – all 24 runs were completed successfully
- GRETINA is presently being set up at ANL for its second science campaign
- At the 2013 GRETINA User Workshop at ANL, the community endorsed a proposal that will have GRETINA return to NSCL for a second fast beam campaign in 2015
- FRIB is baselined, ready for construction, and managed to early completion in Dec 2020





Partners in crime …

- Some science slides contributed by:
  - Chris Langer and Fernando Montes (MSU)
  - Shumpei Noji and Remco Zegers (MSU)
  - Kathrin Wimmer (CMU)
  - AG (MSU) and Robert V.F. Janssens (ANL)

@

Acknowledgement *(for getting and keeping GRETINA going at NSCL)* :
LBNL: I.Y. Lee, A.O. Macchiavelli, C.M. Campbell, H. Crawford, M. Cromaz, C. Lionberger, A. Wiens
ORNL: D. Radford, J. M. Allmond
NSCL: **D. Weisshaar**, F. Recchia, T. Baugher, C. Langer, E. Lunderberg, A. Lemasson, S. Noji, M. Scott, D. Smalley, K. Wimmer, and R. Fox (NSCL DAQ), and D. Bazin, S. Williams (S800)

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