Gamma-ray Spectroscopy with GRETINA at NSCL

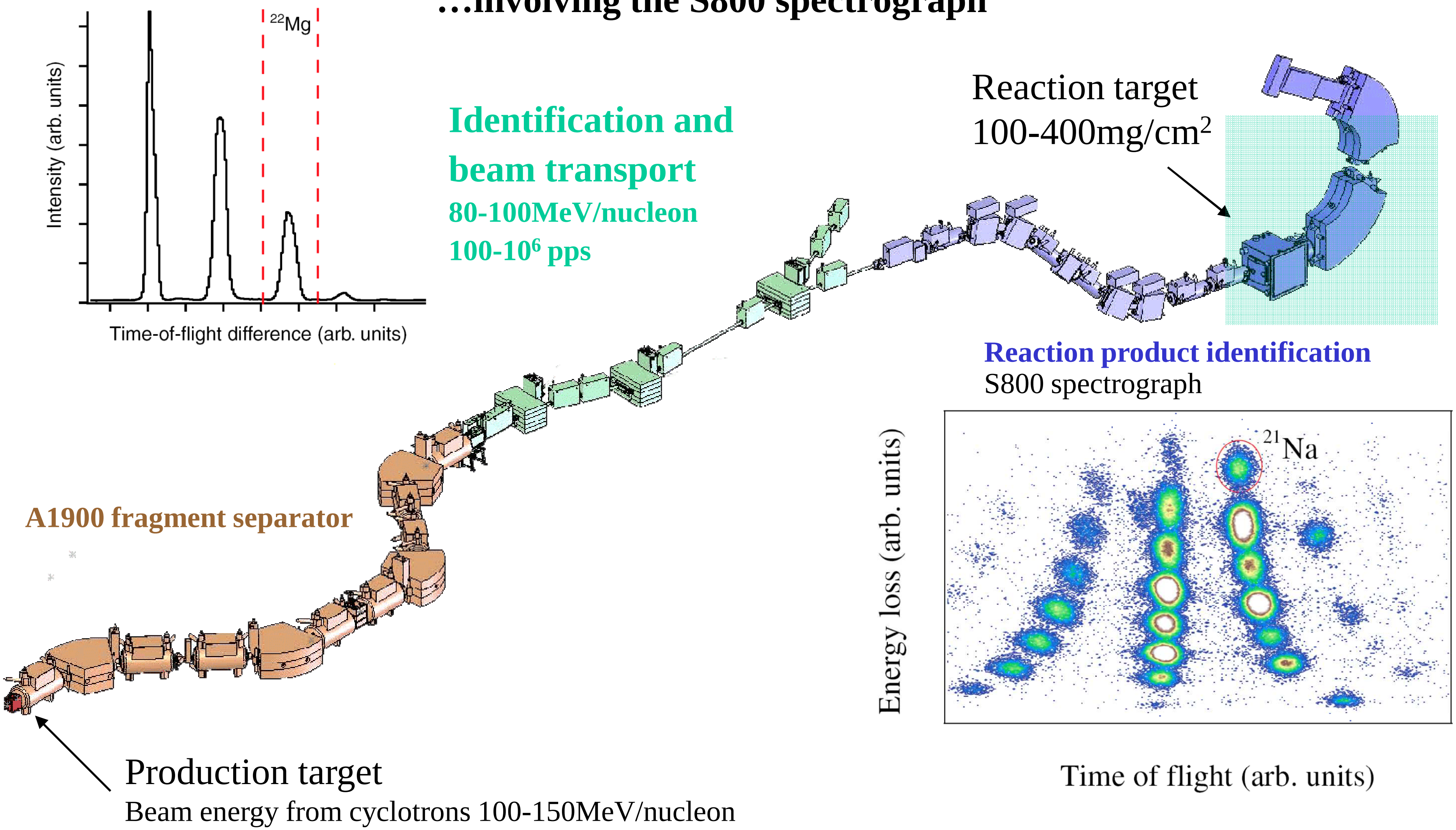
Dirk Weisshaar, NSCL/MSU

GRETINA @ NSCL

GRETINA was funded by U.S. DEPARTMENT OF ENERGY

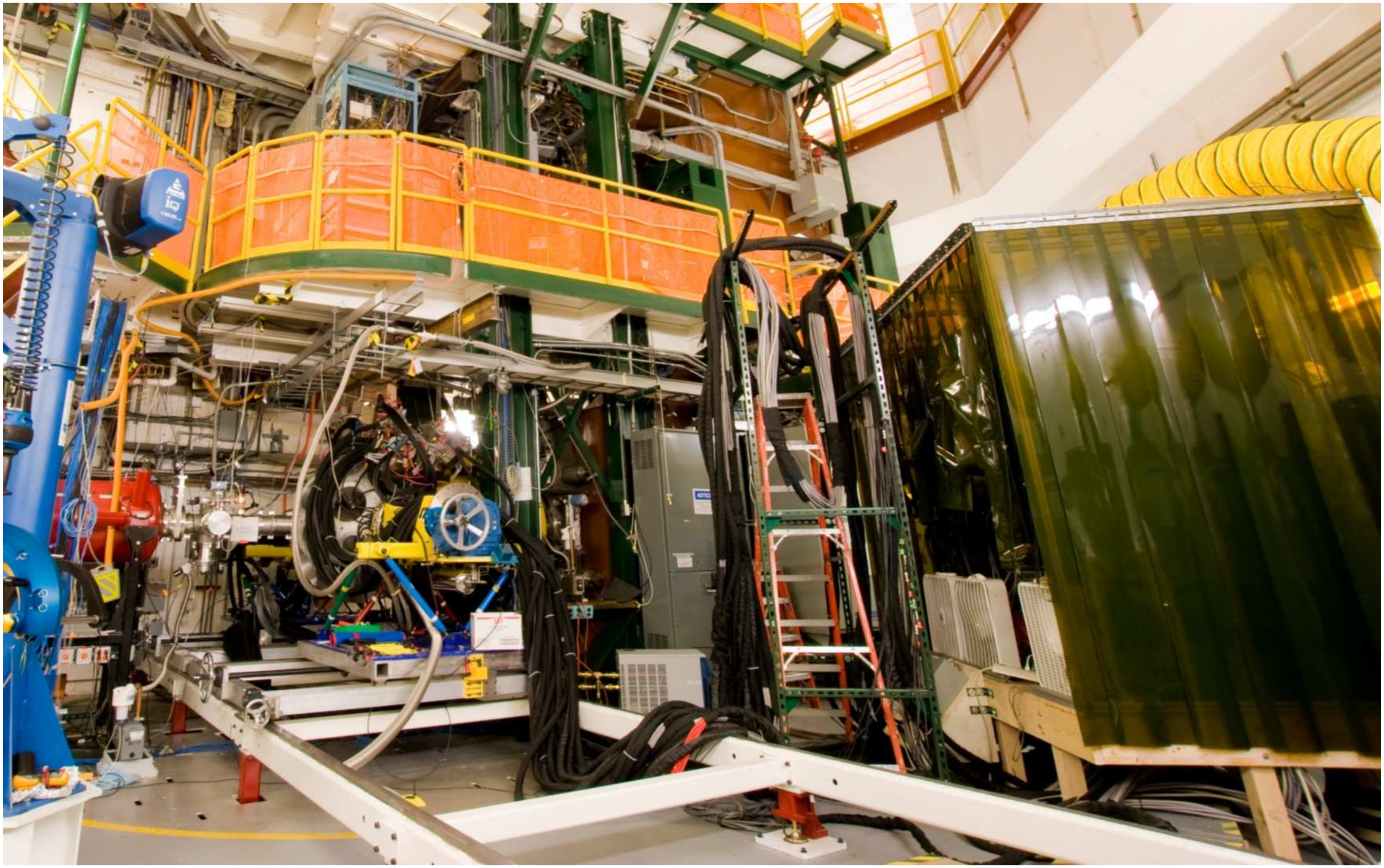
Layout of a fast-beam experiment at NSCL…

…involving the S800 spectrograph

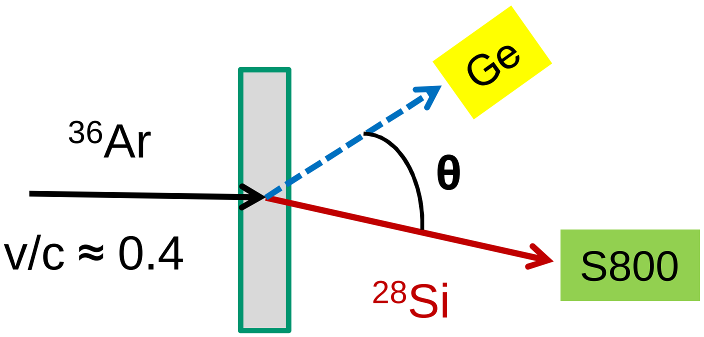


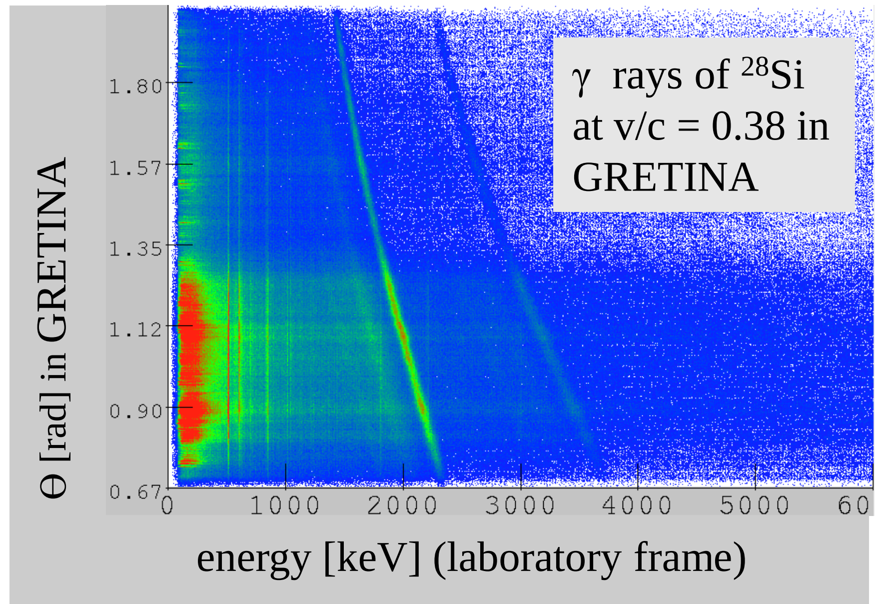
Length ~80m (260 ft)
(linear distance)

(Find) **GRETINA in S3 vault**



Gamma spectroscopy with fast beam





(Obvious) requirements for a spectrometer:

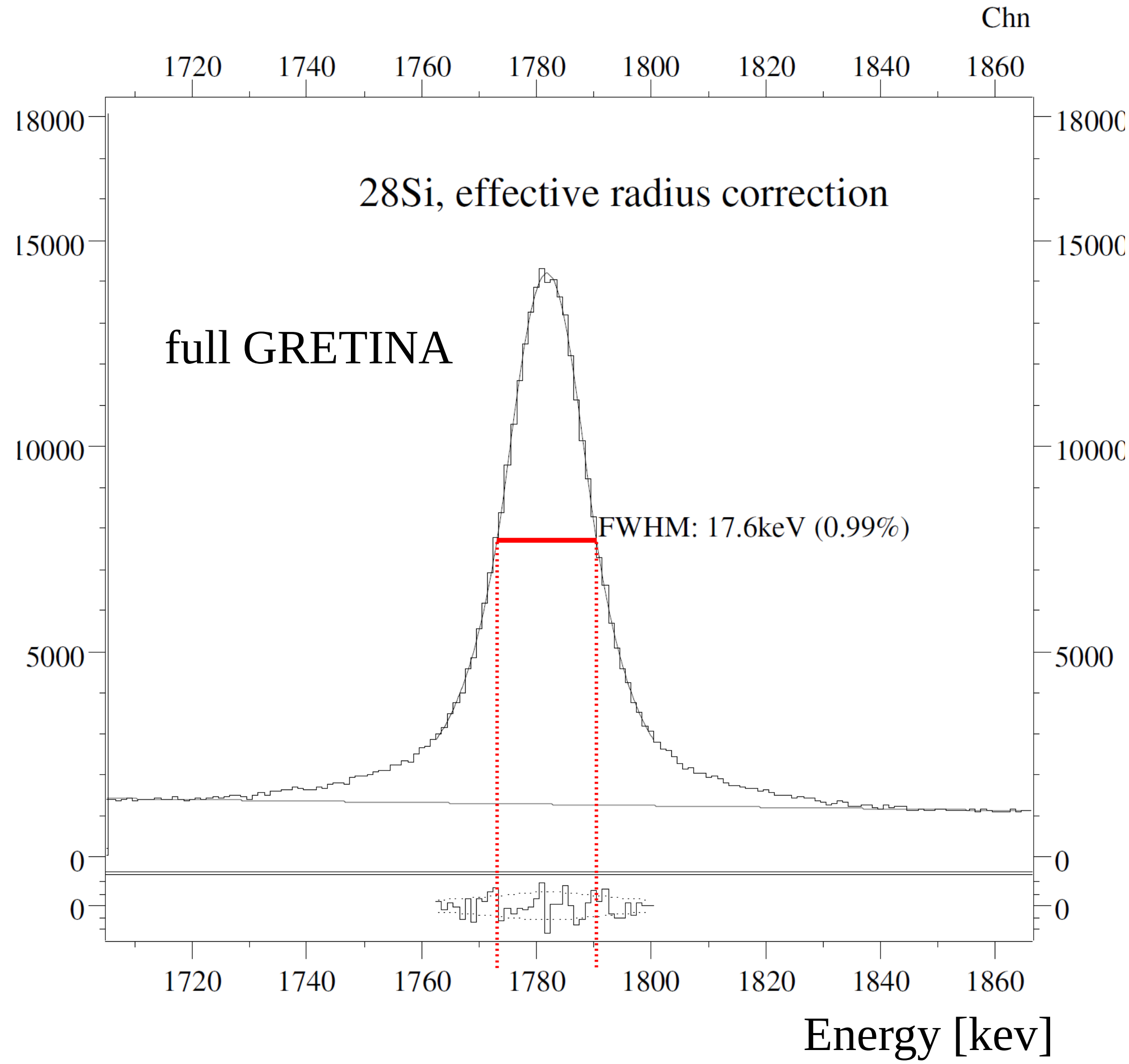
Doppler-shift correction
→ Spatial resolution
Lorentz Boost
→ Detection efficiency at forward angle

…and GRETINA is a perfect match

FWHM after Doppler-shift reconstruction

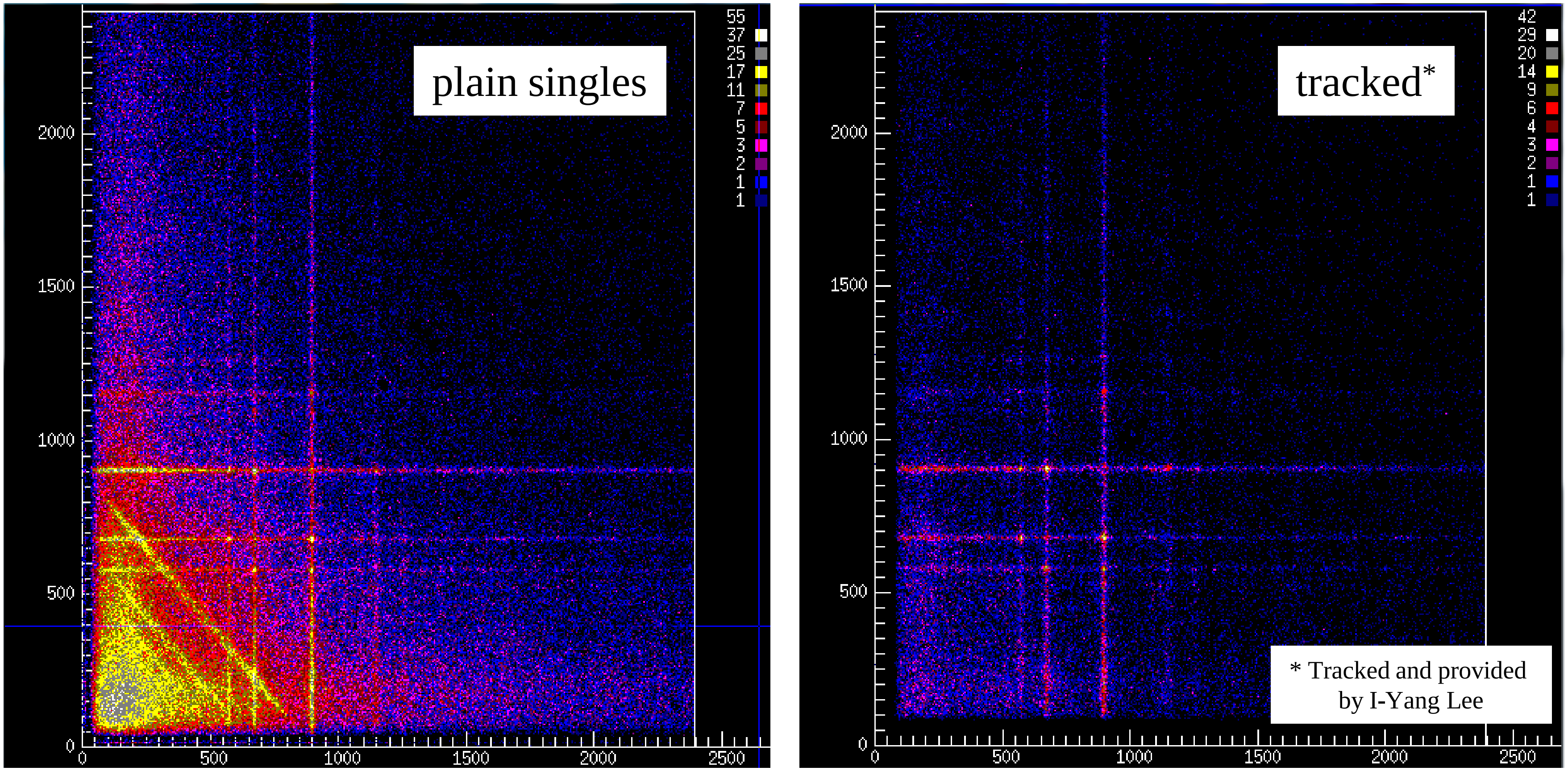
^{28}Si from ^{36}Ar
on 47 mg/cm^2 Be
v/c = 0.38

Measured FWHM of 1.00% meets expectation based on σ=2mm spatial resolution!



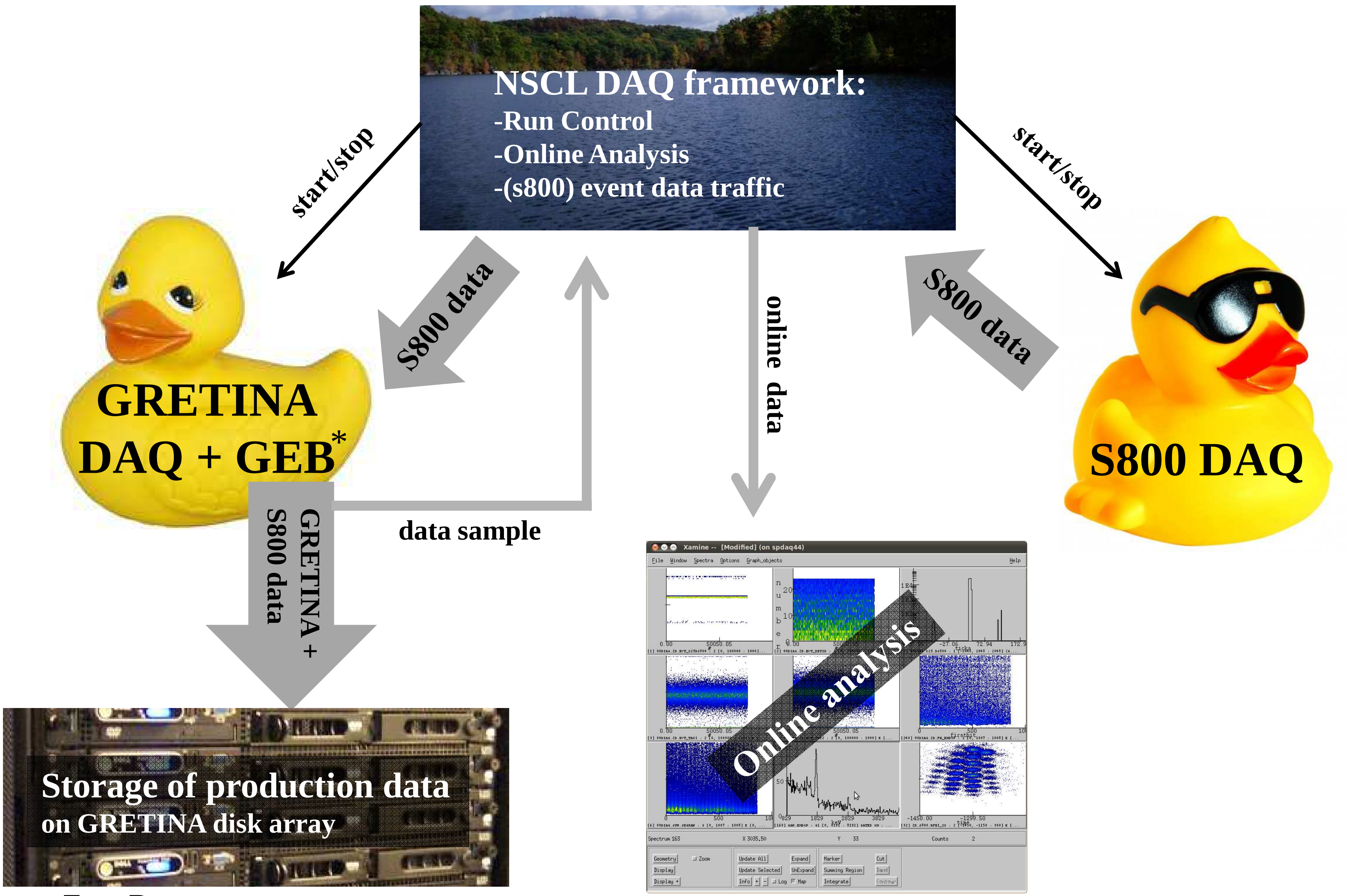
…but GRETINA does much more

^{64}Ge γ-γ, produced from ^{65}Ge on ^{9}Be at v/c=0.4



Reduction of Compton background by tracking allows – for the first time – gamma spectroscopy with fast beams with spectral quality comparable to arrays with anti-Compton shield, i.e. GammaSphere.

GRETINA/S800 data acquisition



*Gretina Event Builder

GRETINA Experiments at NSCL

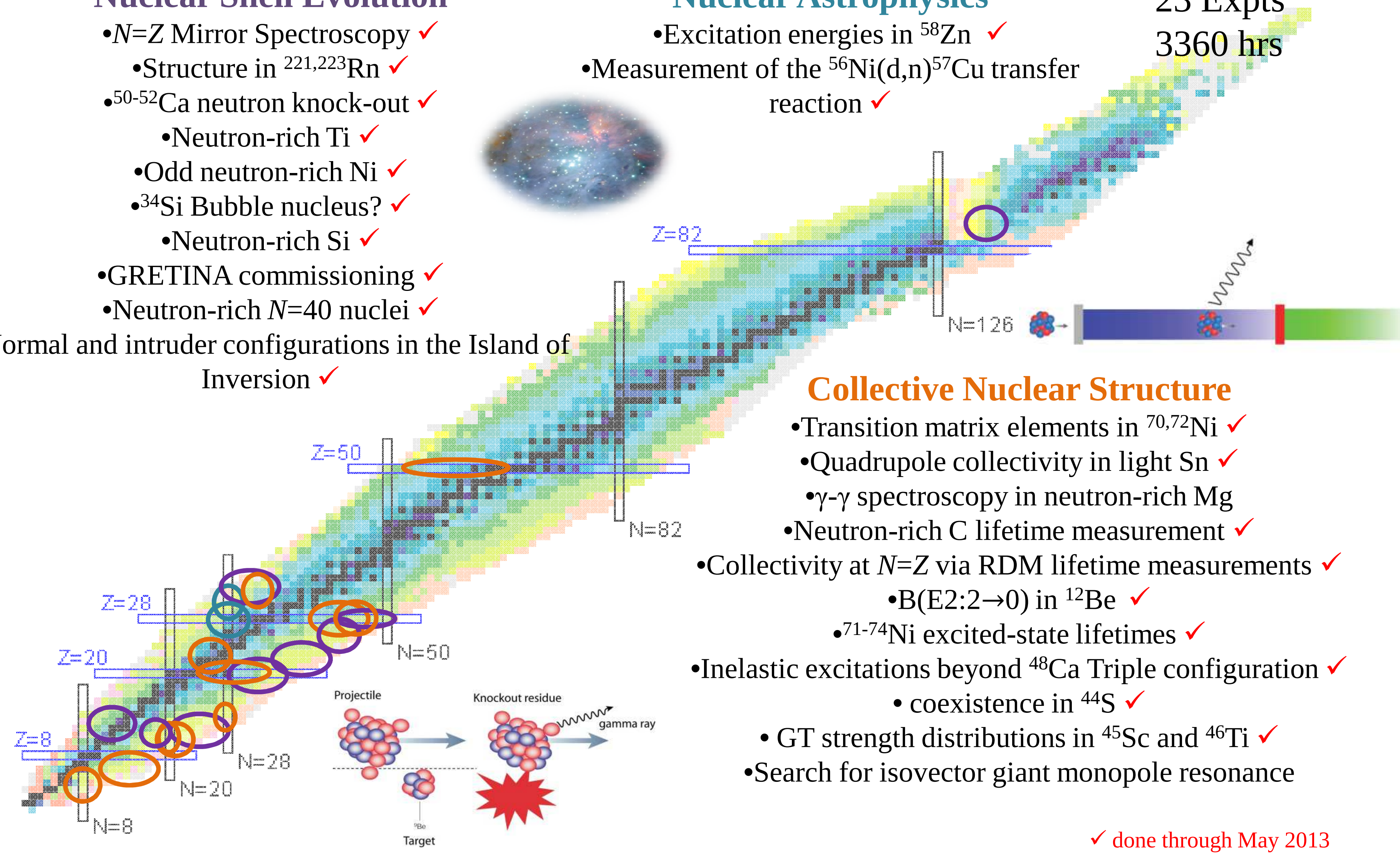
23 Expts
3360 hrs

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 of the ^{56}Ni(d,n)^{57}Cu transfer reaction ✓



Collective Nuclear Structure

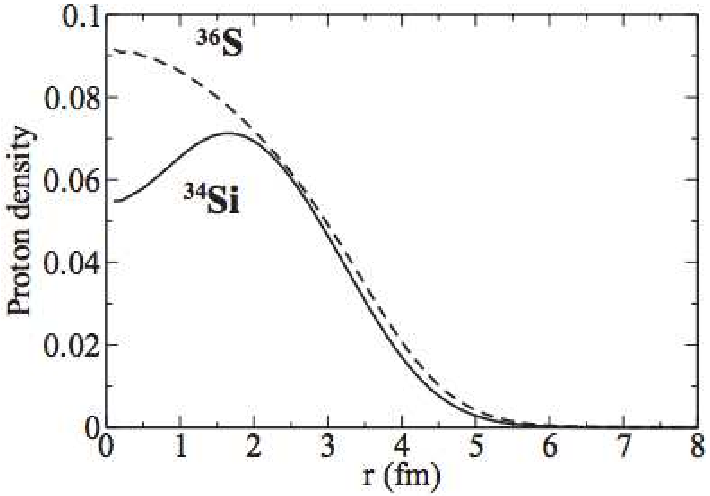
•Transition matrix elements in ^{70,72}Ni ✓
•Quadrupole collectivity in light Sn ✓
•γ-γ spectroscopy in neutron-rich Mg
•Neutron-rich C lifetime measurement ✓
•Collectivity at *N*=*Z* via RDM lifetime measurements ✓
•B(E2:2→0) in ^{12}Be ✓
•$^{71\text{-}74}$Ni excited-state lifetimes ✓
•Inelastic excitations beyond ^{48}Ca Triple configuration ✓
• coexistence in ^{44}S ✓
• GT strength distributions in ^{45}Sc and ^{46}Ti ✓
•Search for isovector giant monopole resonance

✓ done through May 2013

prepared by H. Crawford, LBNL

Is there a bubble in ^{34}Si ?

O. Sorlin, GANIL

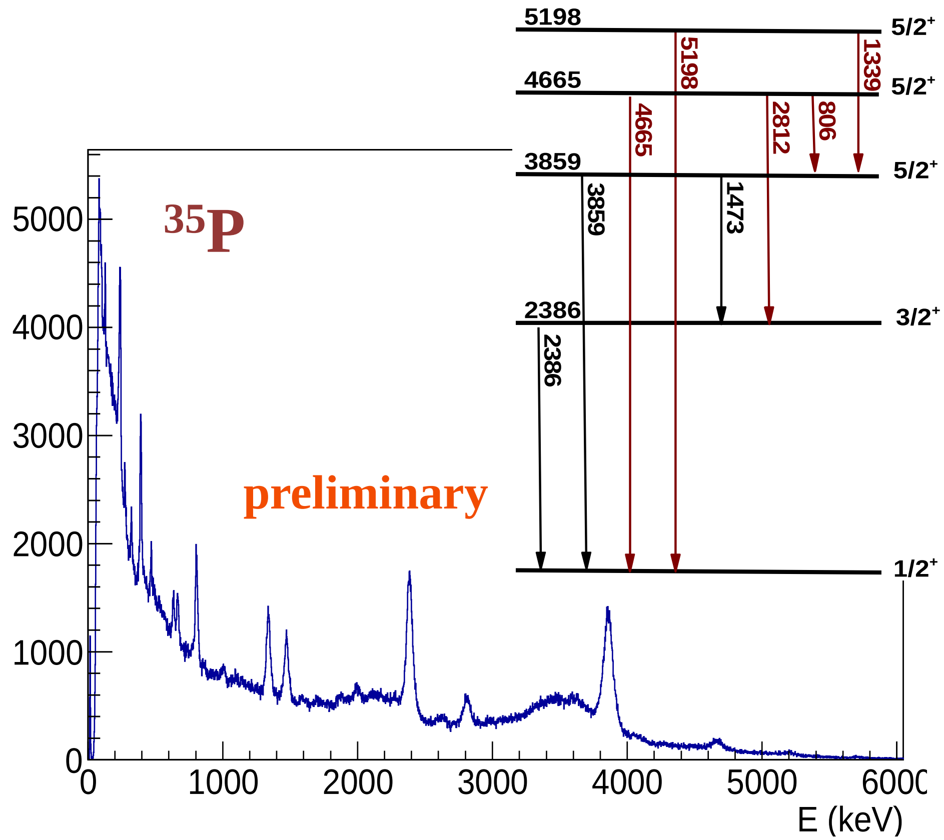


M. Grasso et al., PRC 79 (2009).

Orbital	$S^{exp}(^{36}S)$	$S^{SM}(^{36}S)$	$S^{SM}(^{34}Si)$
$\pi 1d_{5/2}$	6.0(12)	5.85	5.76
$\pi 2s_{1/2}$	1.63(32)	1.88	0.08
$\pi 1d_{3/2}$	0.31(6)	0.27	0.16

Experiment with GRETINA + S800

- **^{36}S(-1p)^{35}P :** comparison with known occupancies / levels from (d,^{3}He)
  ➔ Validation of the experiment
- **^{34}Si(-1p)^{33}Al :** Occupancies to be determined :
  - Spectroscopic factors
  - l assignment from $p_{//}$ distribution

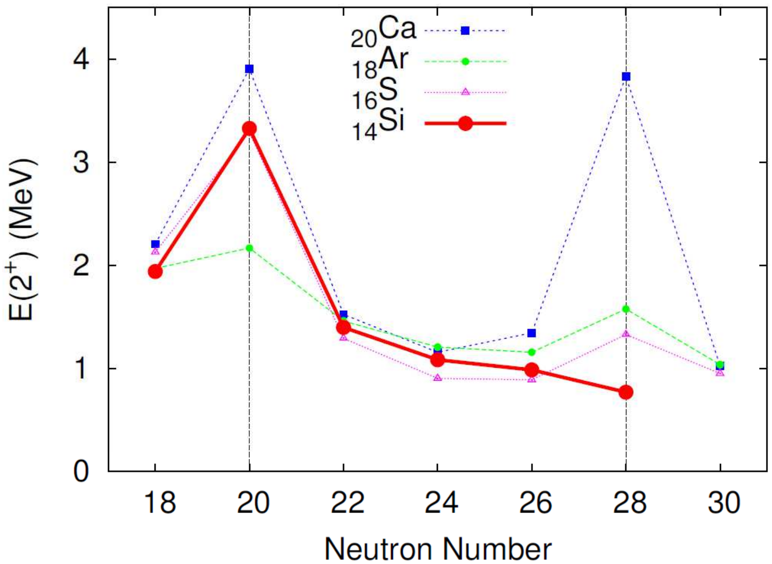


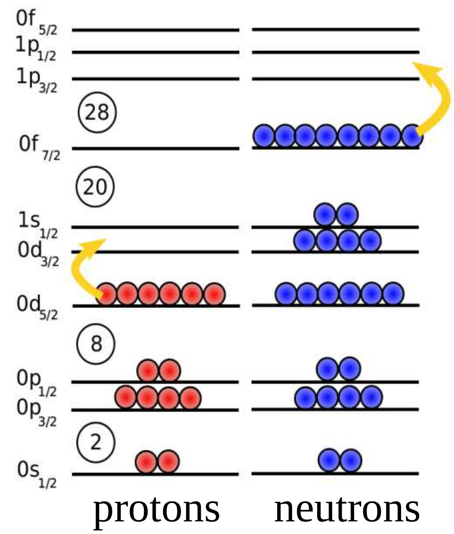
prepared by A. Mutschler, IPN Orsay

Single-particle structure of neutron-rich Si isotopes

R. Stroberg, NSCL

Breakdown of n=28 shell gap





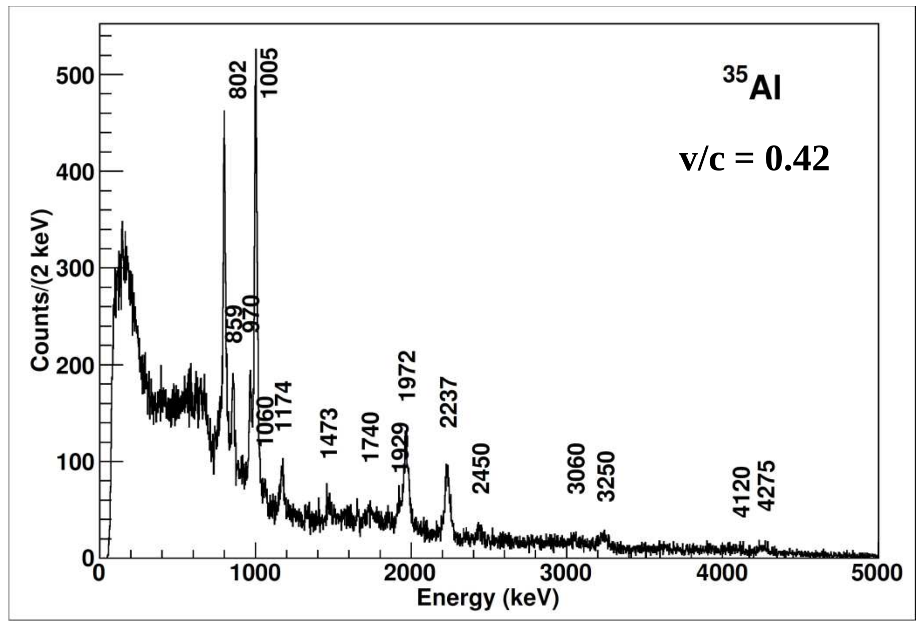
What are the contributions of protons and neutrons to the enhanced collectivity at ^{42}Si?

Can this be accounted for by the tensor force?

T. Otsuka et al. PRL 95, 232502 (2005)

Measurement of single-particle structure of n-rich Si approaching ^{42}Si by means of neutron and proton knockout.

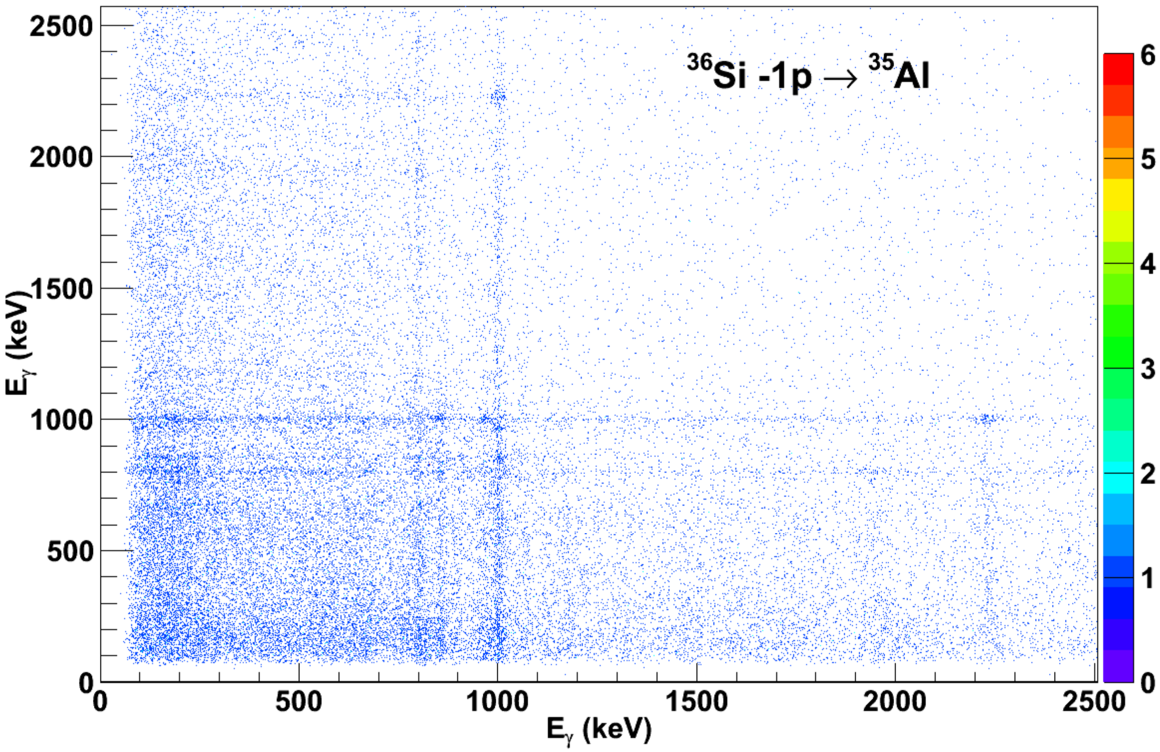
Experimental 'tidbit':
Few or no excited states known in knockout residues from n-rich Si.

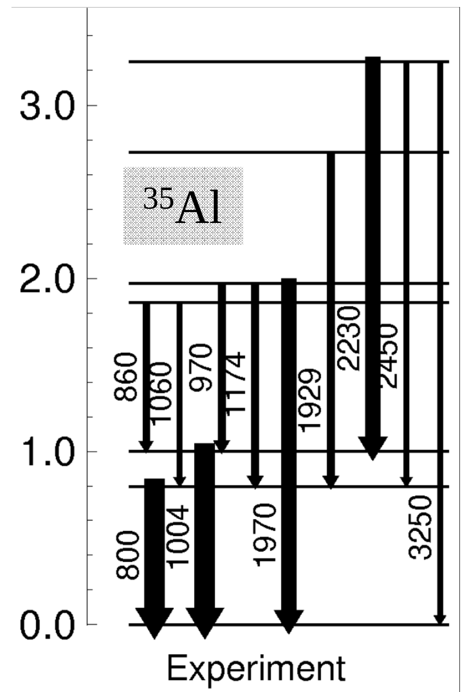


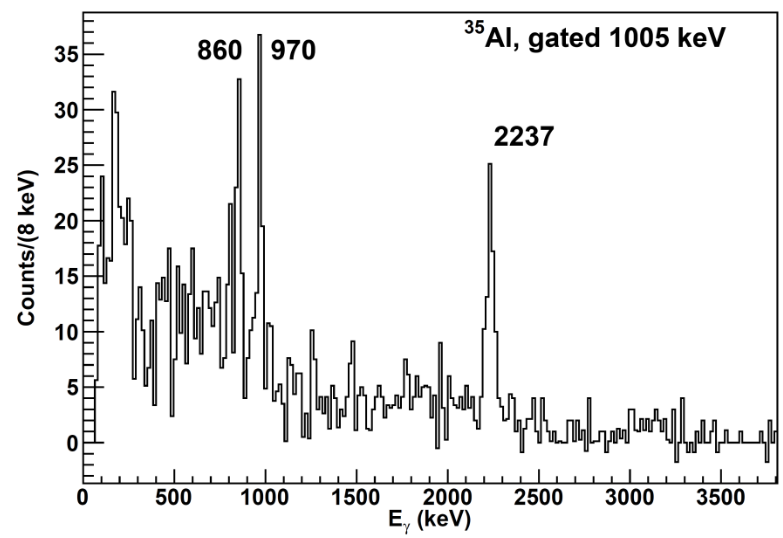
prepared by R. Stroberg, NSCL

Single-particle structure of neutron-rich Si isotopes

R. Stroberg, NSCL







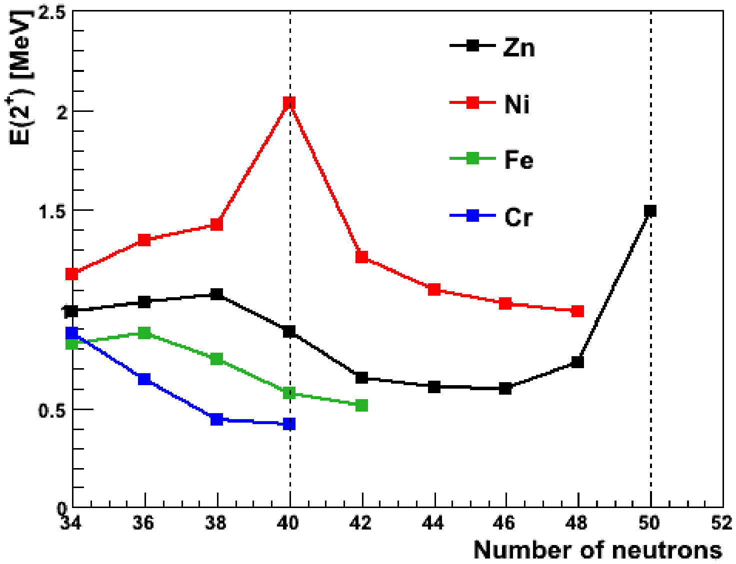
Gamma-gamma coincidence analysis using tracked GRETINA data.

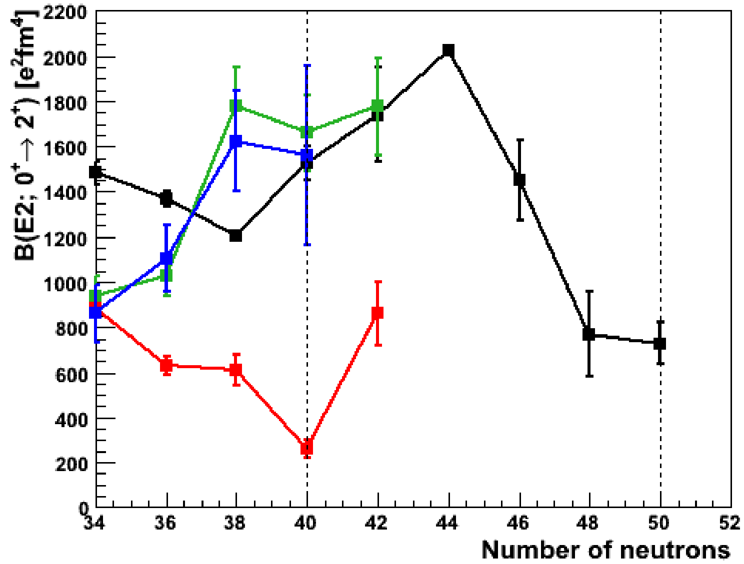
prepared by R. Stroberg, NSCL

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

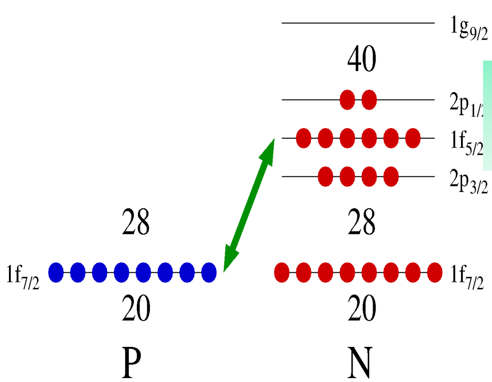
K. Wimmer, CMU

Shell evolution around N=40

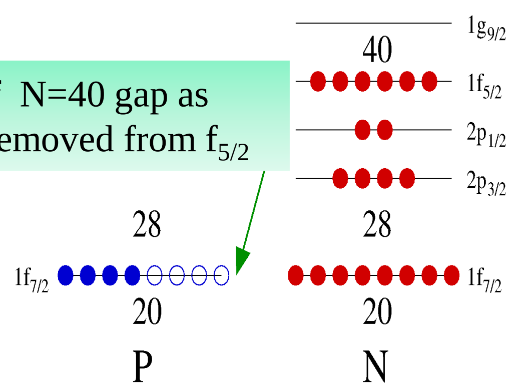




B. Pritychenko et al., At. Data Nucl. Data Tables **98 (2012) 798,**
T. Baugher et al., Phys. Rev. C **86 (2012) 011305(R), H. L. Crawford et al., submitted**



Reduction of N=40 gap as protons get removed from $f_{5/2}$



Experiment:
Probe intruder occupation ($1g_{9/2}$, $2d_{5/2}$) by means of neutron knockout from $^{64,66}Fe$ and ^{68}Ni

T.Otsuka et al., PRL 95 (2005) 232502, S. M Lenzi et al., PRC 82 (2010) 054301

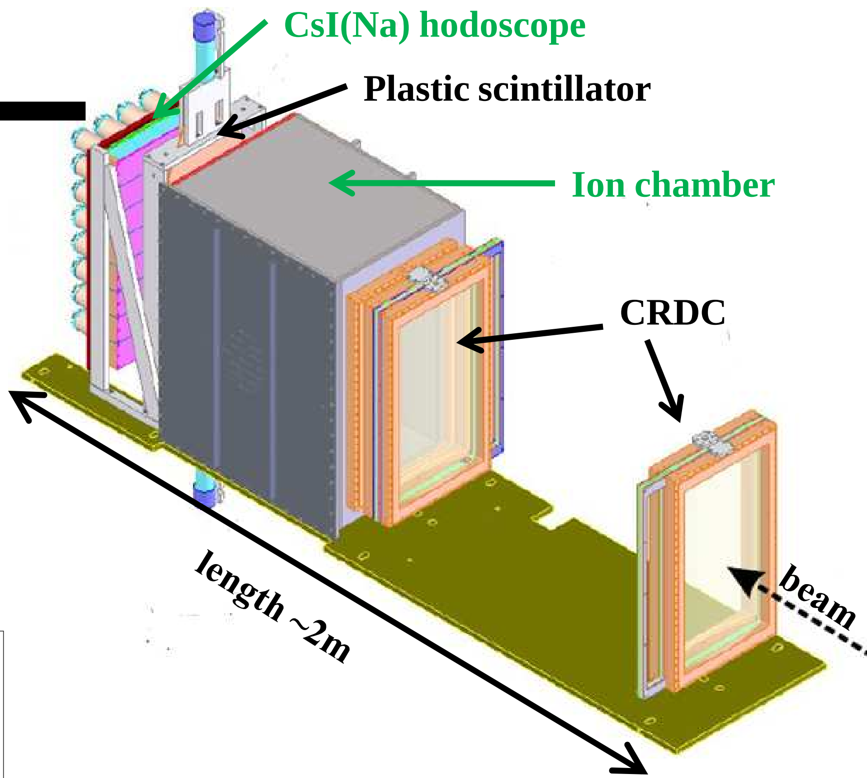
prepared by K. Wimmer, CMU

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

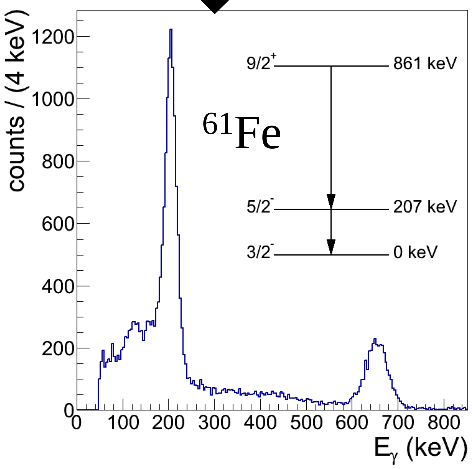
K. Wimmer, CMU

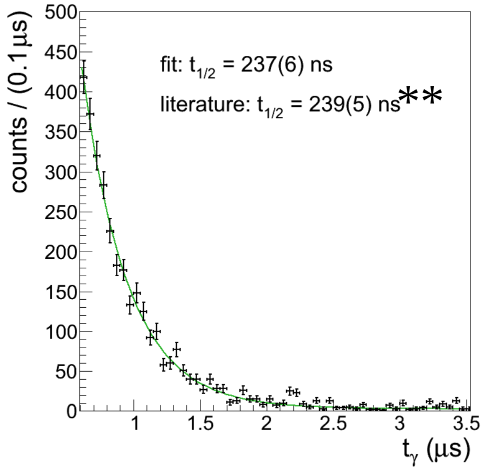
Challenge: Many isomeric states in this region
→ Implementation of isomer tagging in S800

S800 Focal Plane Detectors

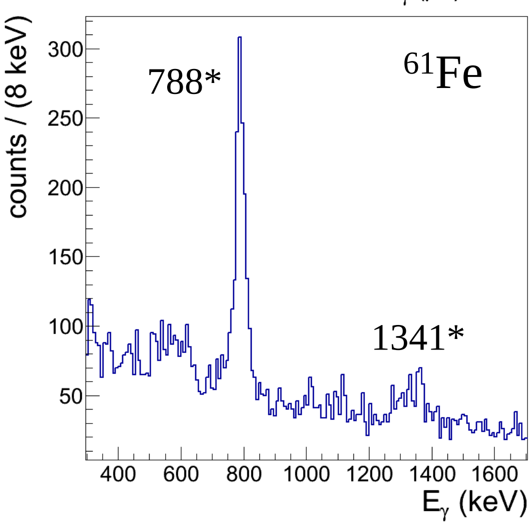


Delayed γ-ray coincidence in hodoscope





Correlated with prompt γ ray in GRETINA



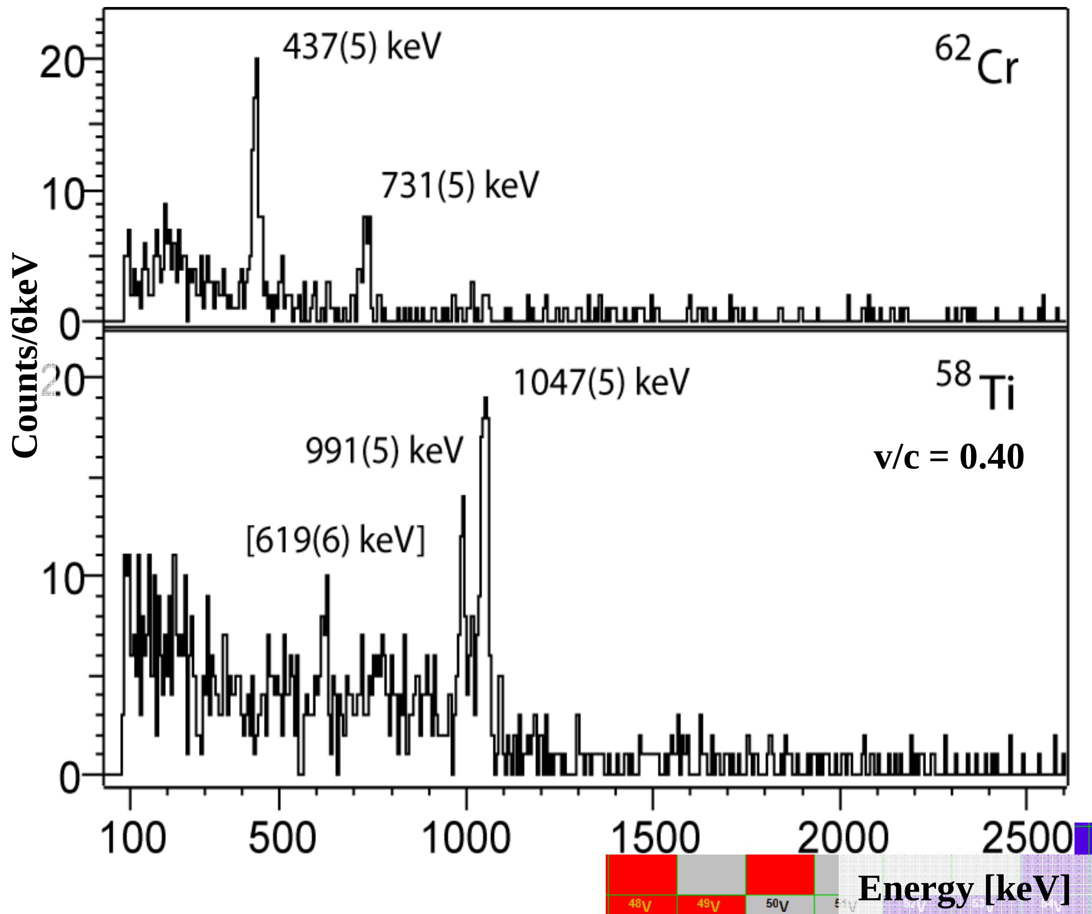
(**) I. Mateae al., PRL 93 (2004) 142503

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

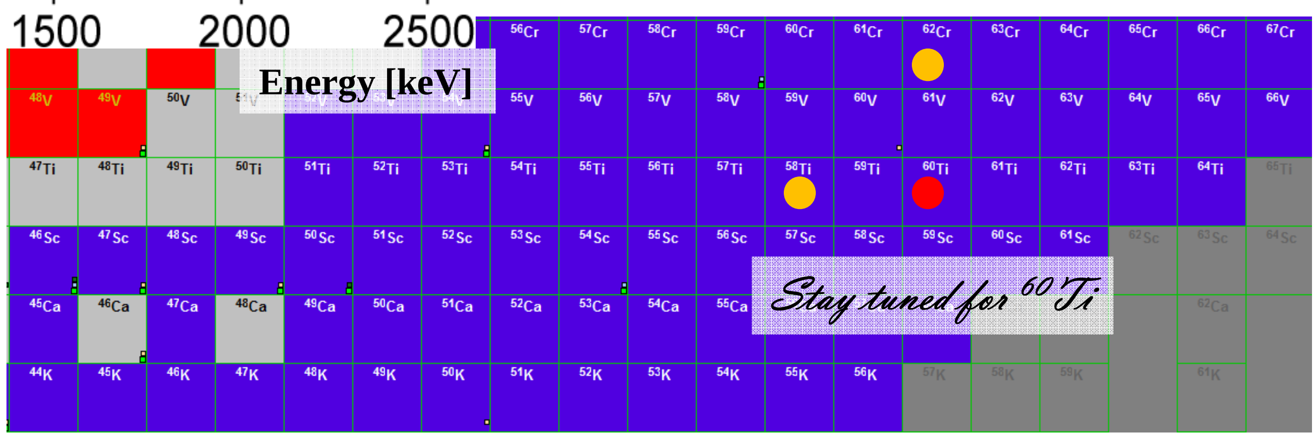
prepared by K. Wimmer, CMU

γ-ray spectroscopy of neutron-rich Ti isotopes

A. Gade, NSCL



- 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

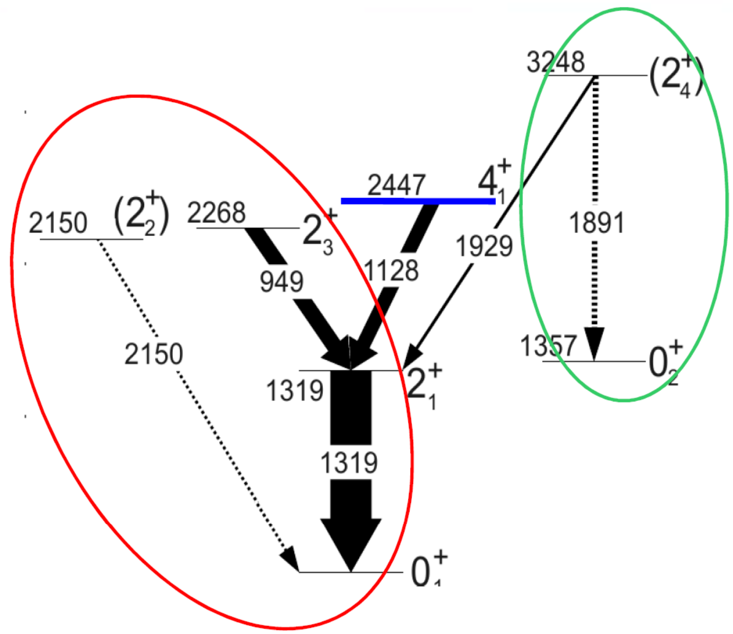


A. Gade, R.V.F. Janssens et al., to be published

Triple Configuration-Coexistence in N=28 ^{44}S

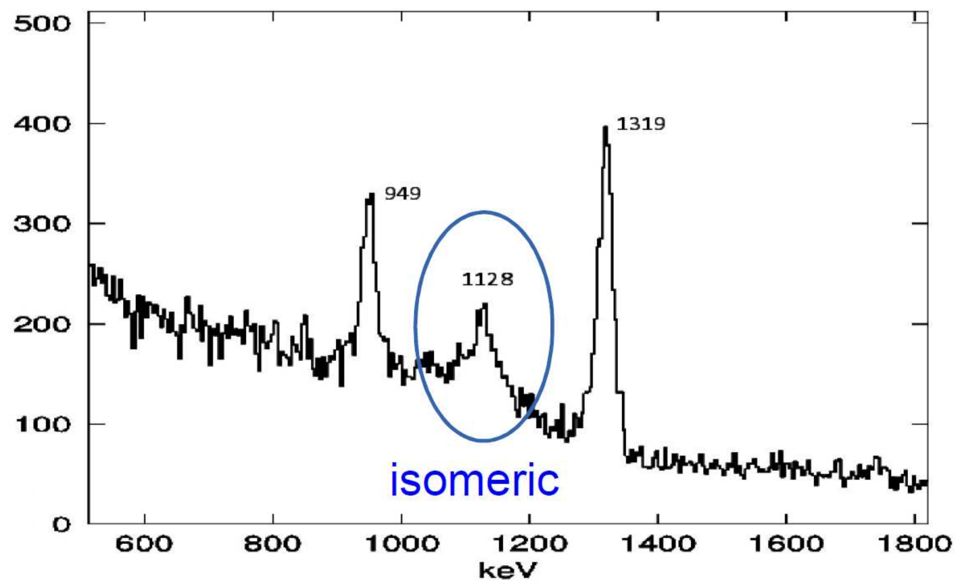
I. Wiedenhöver, FSU

- In 44S, the N=28 shell is broken through Neutron (2p-2h), coexisting with magic (0p-0h) configuration
  T. Glasmacher et al., PLB 395 (1997)
  C. Force et al., PRL 105 (2010)



- Shell model predicts third configuration: (1p, 1h), characterized by isomeric K=4 band-head
  D. Santiago-Gonzales PRC 83 (2012)

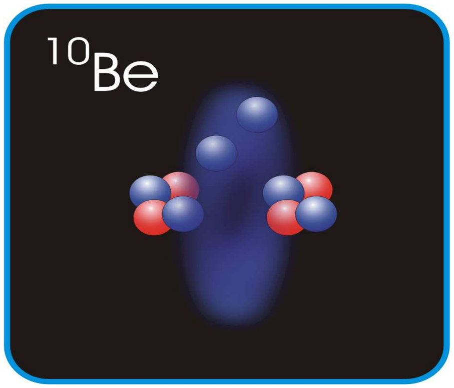
- Isomeric life-time ~50 ps is observed in GRETINA-plunger experiment

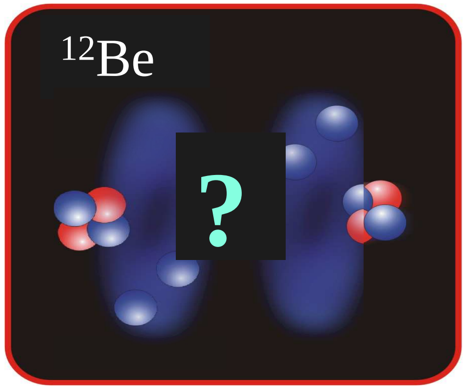


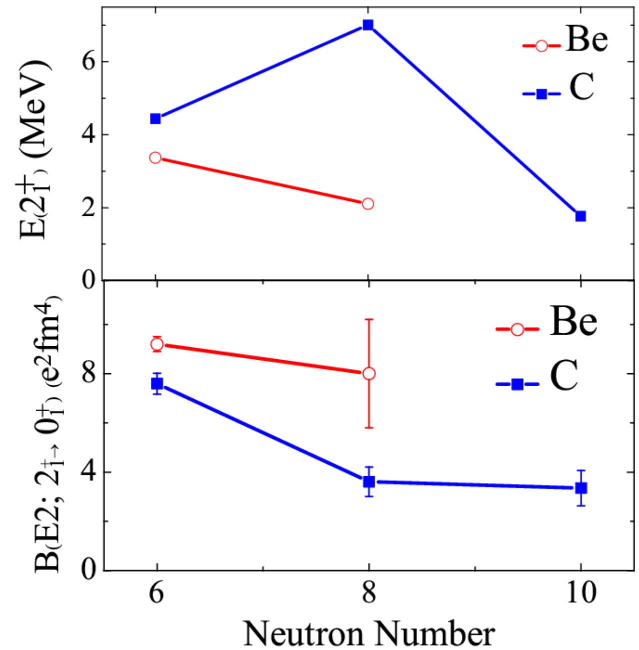
prepared by J. Parker, D. Santiago-Gonzales, FSU

A precise measurement of the B(E2,$2^+ \rightarrow 0^+$) in ^{12}Be

E. McCutchan, BNL







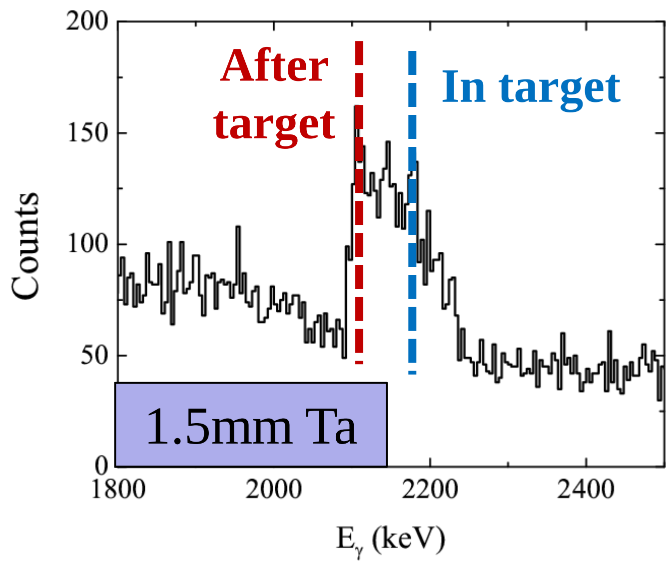
Effect of adding two neutrons

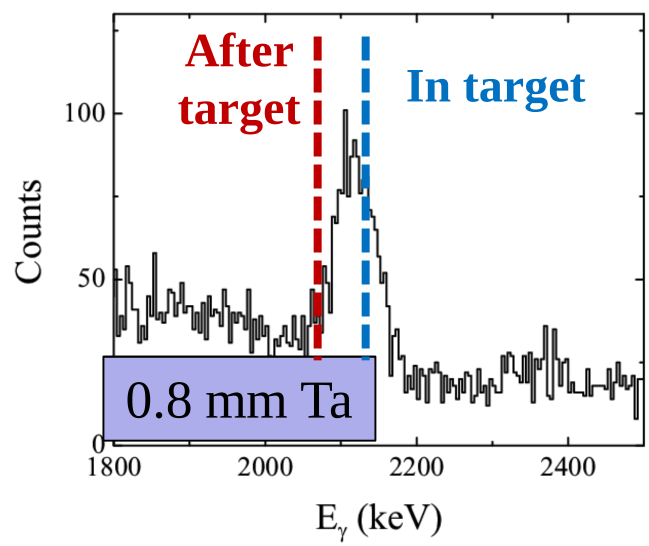
A "Nuclear Molecule"? : B(E2) increases

An "N=8" spherical cloud? : B(E2) decreases

Thick target DSAM

- 55 MeV/A ^{12}Be beam
- 3 different targets
- GRETINA + S800



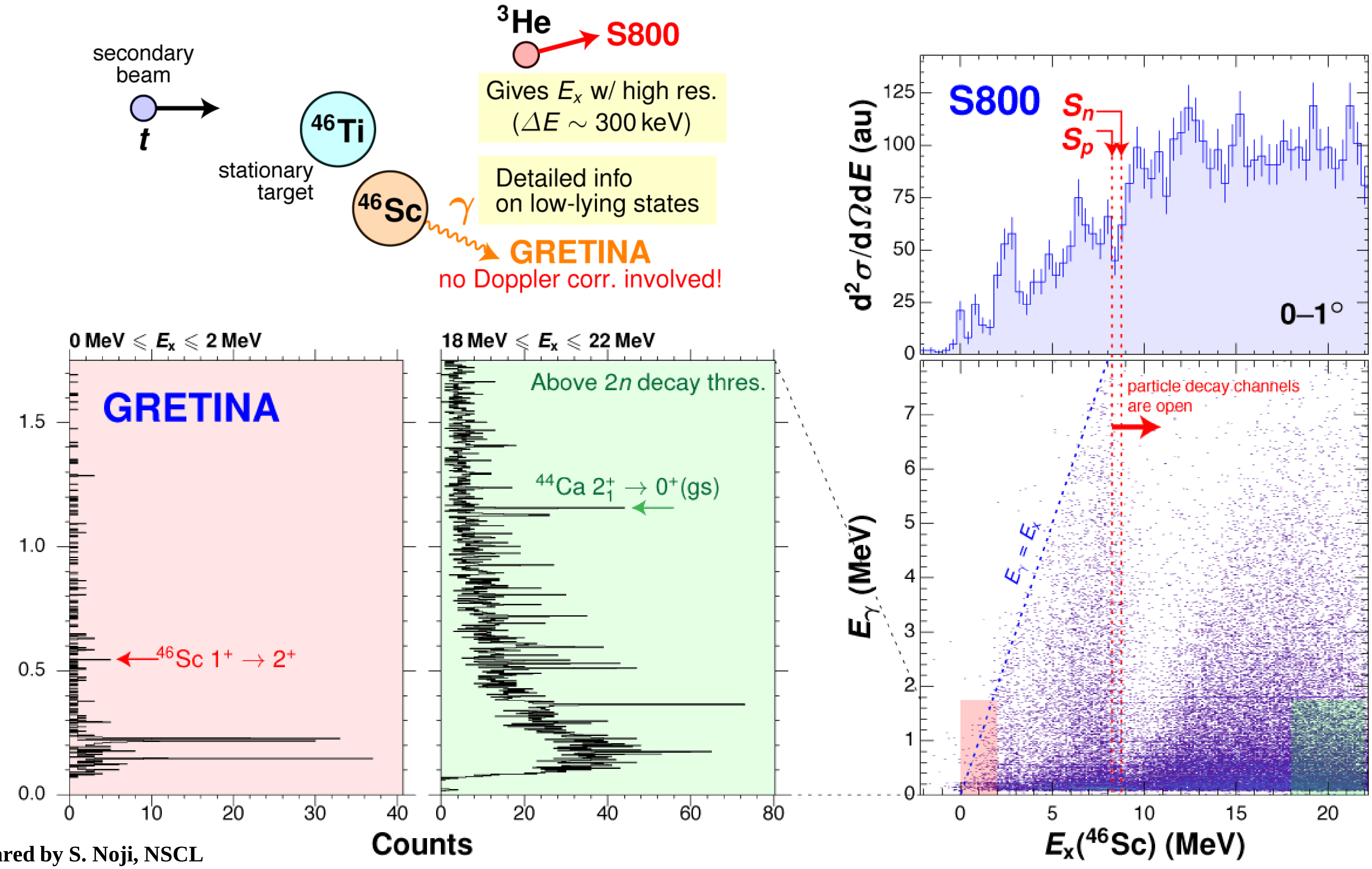


prepared by E. McCutchan, BNL

GT strength distribution in ^{45}Sc and ^{46}Ti

R.G.T. Zegers, NSCL

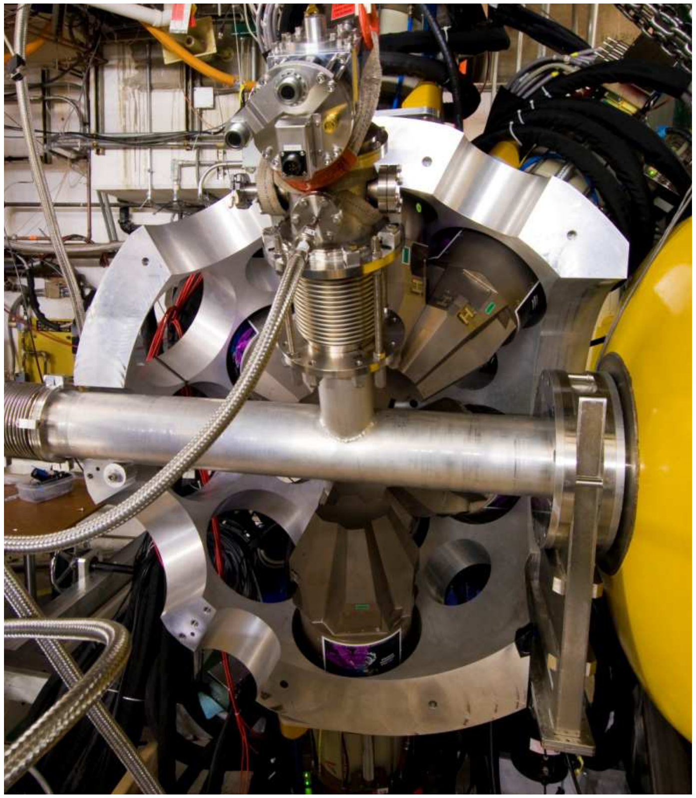
- ***B*(GT) in lightest *pf*-shell: Electron capture rates of astrophysical importance**
- **High resolution (*t*,^{3}He) measurement on ^{45}Sc & ^{46}Ti at 115 MeV/*u***

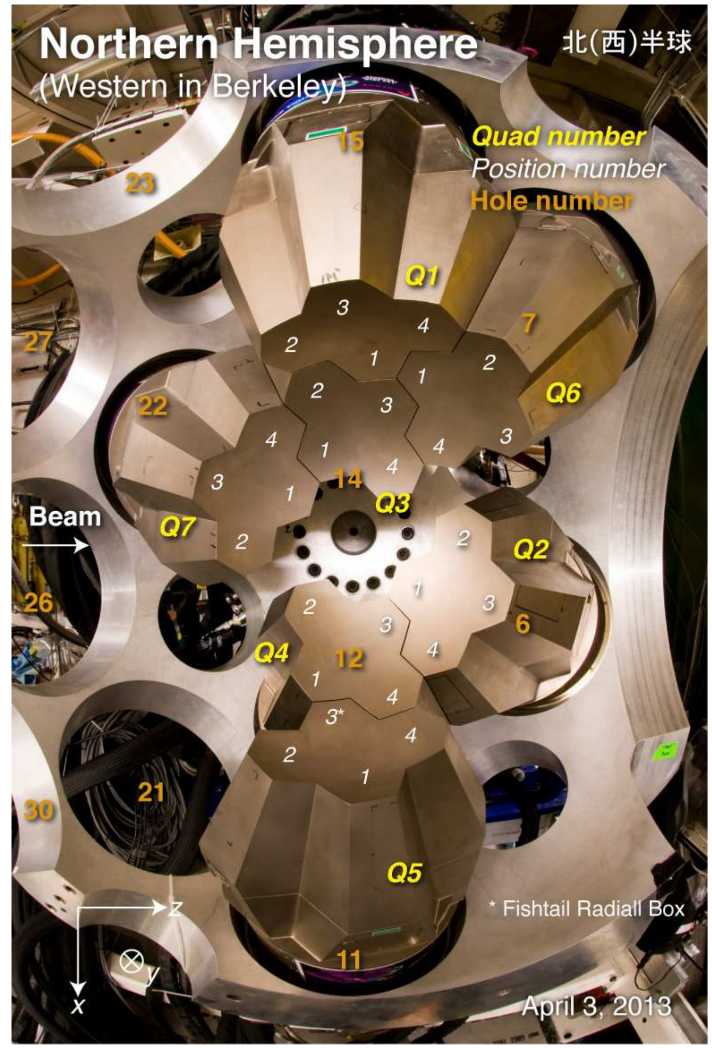


prepared by S. Noji, NSCL

Liquid Hydrogen target and GRETINA

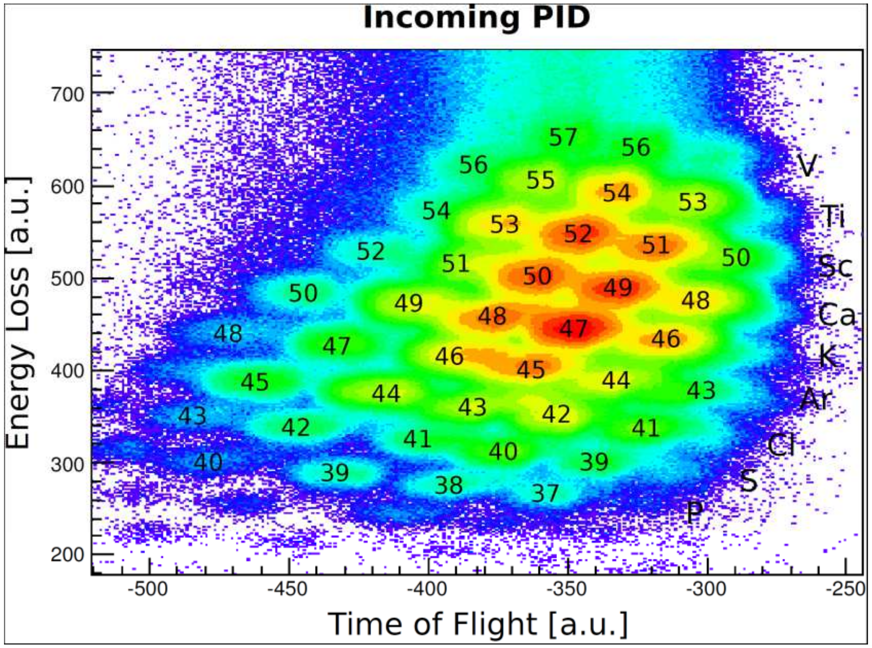
R.G.T. Zegers, NSCL and L. Riley, Ursinus College





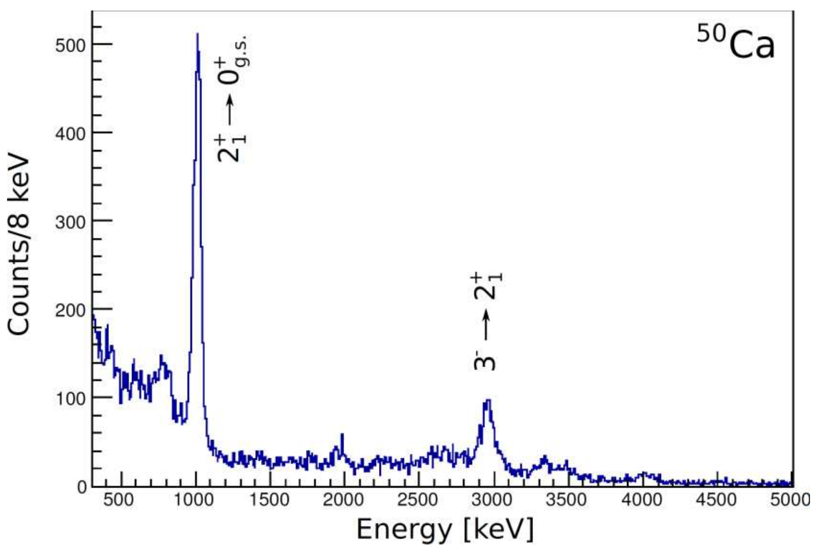
Inelastic Excitations Beyond ^{48}Ca

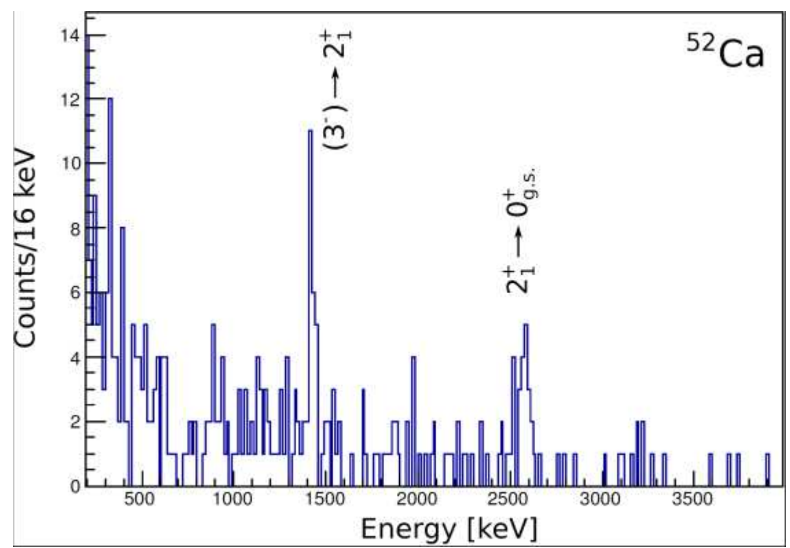
L. Riley, Ursinus College



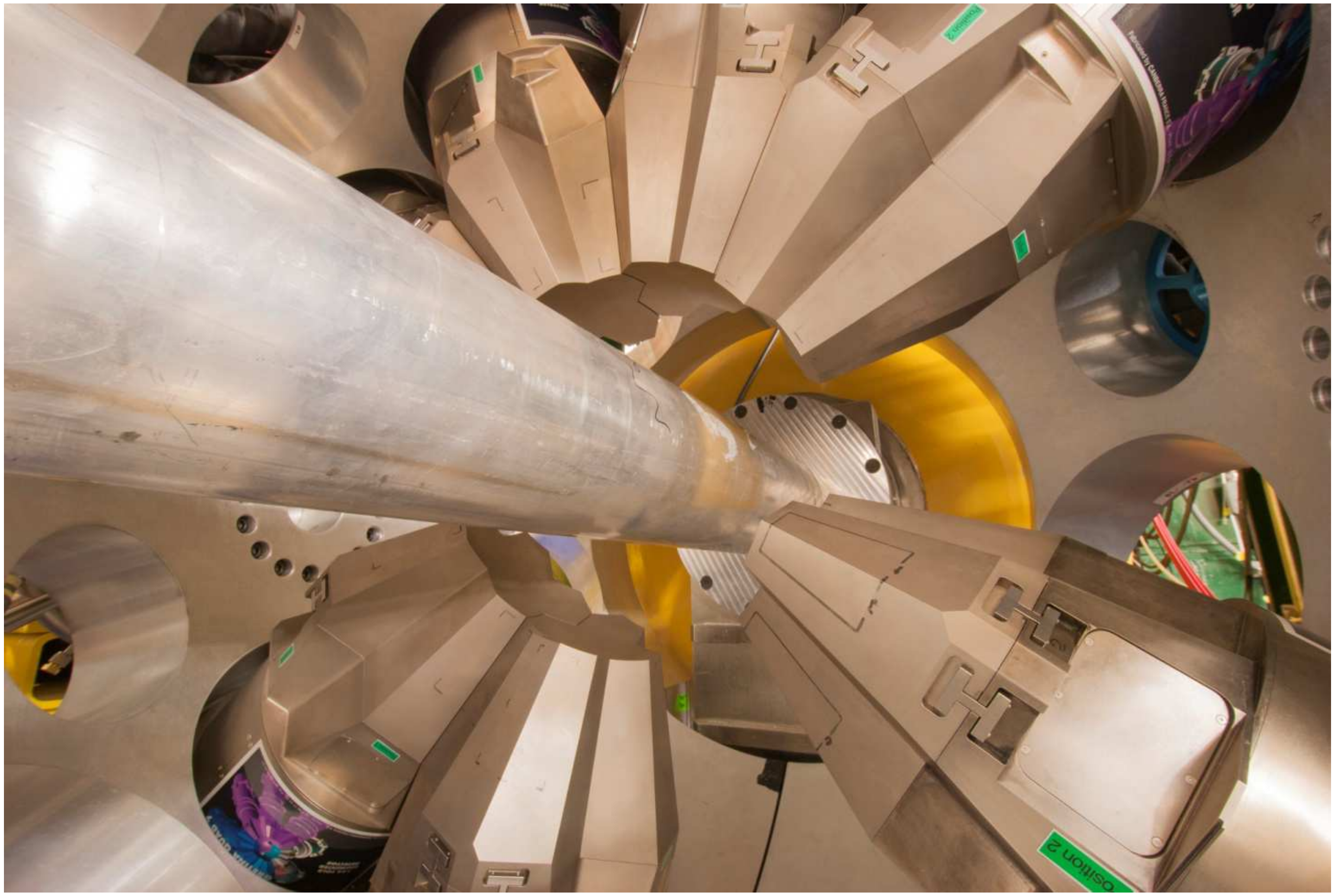
Probing the proton and neutron contributions to collectivity in n-rich, even Ca and Ti isotopes.

→ Determine deformation lengths by Proton scattering in inverse kinematics





What is GRETINA doing right now?



Summary

- GRETINA and the S800 spectrograph are a powerful combination for in-beam gamma-ray spectroscopy with fast beam
- In the almost 1-year long campaign, over 20 PAC-approved experiments have been completed successfully (>3000 hours)
- GRETINA delivered (and still delivers) data of high spectroscopic quality
- GRETINA ran (and hopefully still does) reliably over the whole campaign

Acknowledgement *(for getting and keeping GRETINA running 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: 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)

GRETINA was funded by the US DOE - Office of Science. Operation of the array at NSCL is supported by NSF under PHY-1102511(NSCL) and DOE under grant DE-AC02-05CH11231(LBNL).