

The (t,p) reaction on ^{66}Ni

B. P. Kay (York)

C. J. Chiara (Maryland/Argonne)

R. Raabe (Leuven)

INTC meeting, Oct 31-Nov 1, 2012.

Requested shifts: 18 shifts

Beam: 5 MeV/u ^{66}Ni

Target: tritiated Ti

Installation: solenoidal spectrometer

Overview

Motivated by rigorous discussion on the structure of ^{68}Ni at the Zakopane conference in September (two results in 2012, one from GANIL and one from Argonne, and another coming soon)

Technique

Only other charged-particle approach is through $^{70}\text{Zn}(^{14}\text{C}, ^{16}\text{O})$ two-proton removal
 ^{14}C targets or beams are tricky—using e.g. HELIOS at Argonne is not an advantage

Easier to use two-neutron adding on to ^{66}Ni

γ -ray work discussed shortly

So ... ^{68}Ni at $Z = 28$ and $N = 40$

Robustness of shell gaps brought into question

$N = 40$ not magic below ^{68}Ni (or even at ^{68}Ni ?) e.g. ^{66}Fe , ^{64}Cr , and ^{67}Ni

Proposed proton intruder states important in low-lying structure of $^{64,66}\text{Mn}$, $^{65-68}\text{Co}$ ($\pi p_{3/2}$ from above $Z = 28$), and $^{67,69,71}\text{Cu}$ ($\pi f_{7/2}$ from below $Z = 28$)

^{68}Ni

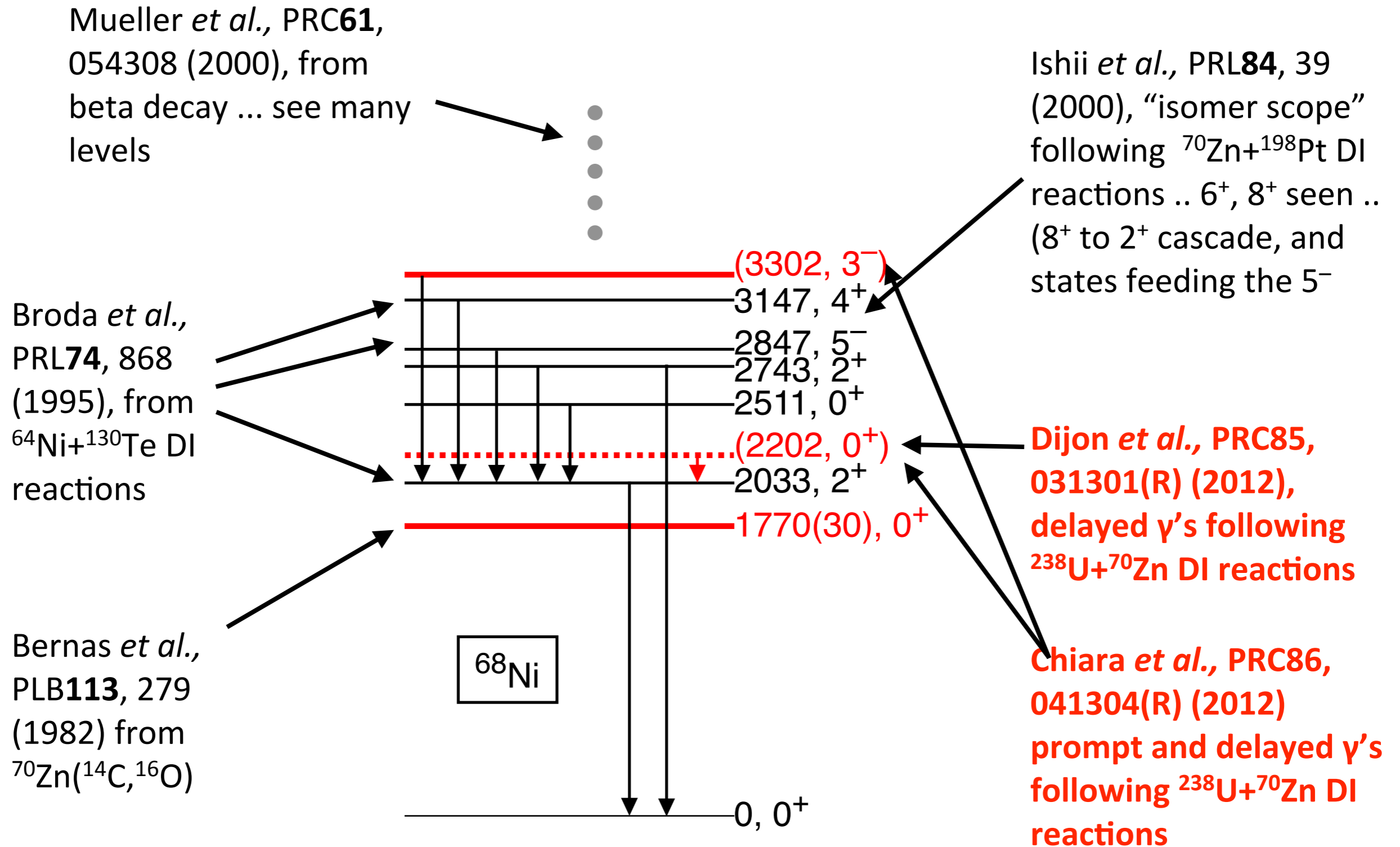
First excited state is a 0^+ level

First 2^+ high in excitation energy

Decays with a low $B(E2:2^+ \rightarrow 0^+)$ transition strength

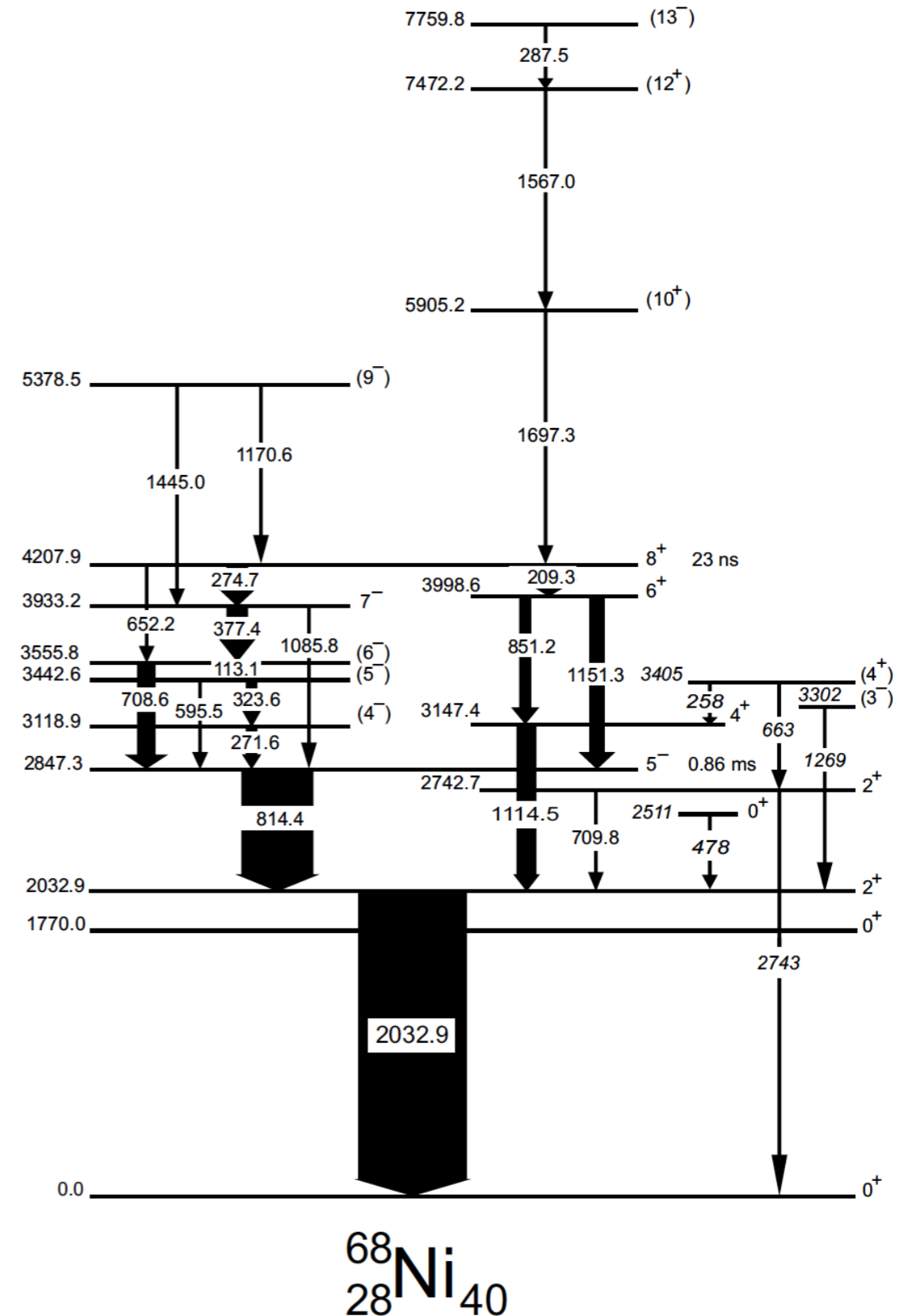
Mass measurements show no indication of enhanced stability, and several theoretical studies question the “doubly-magic” nature of ^{68}Ni

Low-lying states in ^{68}Ni

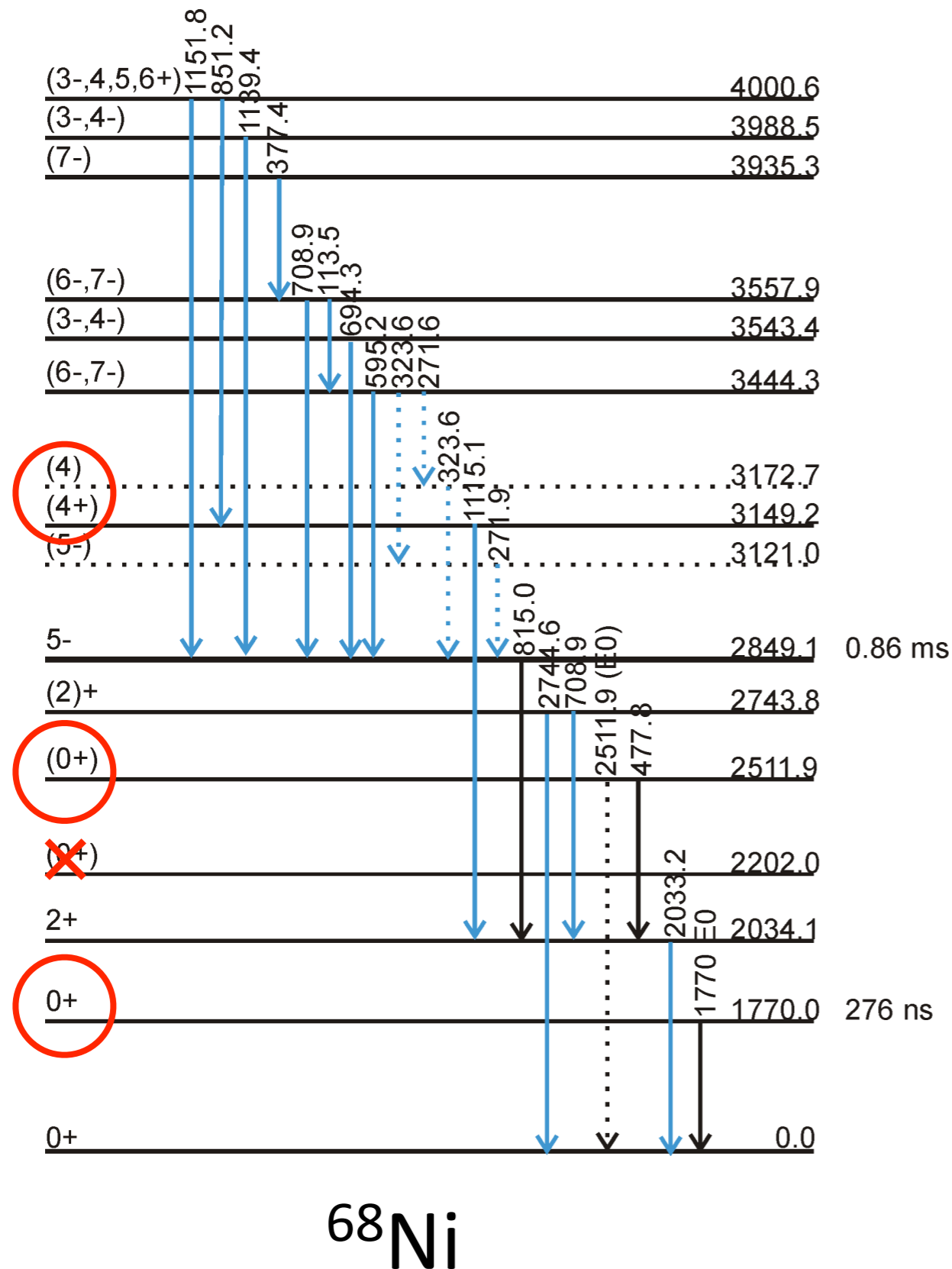


Some key questions to address

- The 1770(30) state:
 - is it there? what is its energy?
- The 2202 keV, 0^+ of Dijon *et al.*:
 - Confirm, or otherwise, the findings of Chiara *et al.*
- Is the 3302-keV state the 3^- state in ^{68}Ni ?
 - An important gauge of octupole collectivity
- Confirm the 4^+ states at 3147 (lowest) and 3405 keV
- Assign spin-parity of states fed by the β decay of the low-spin isomer in ^{68}Co , perhaps help with the debate as to whether it's 1^+ or 3^+
- Neutron configurations of these states



Comment on previous measurement with T-REX

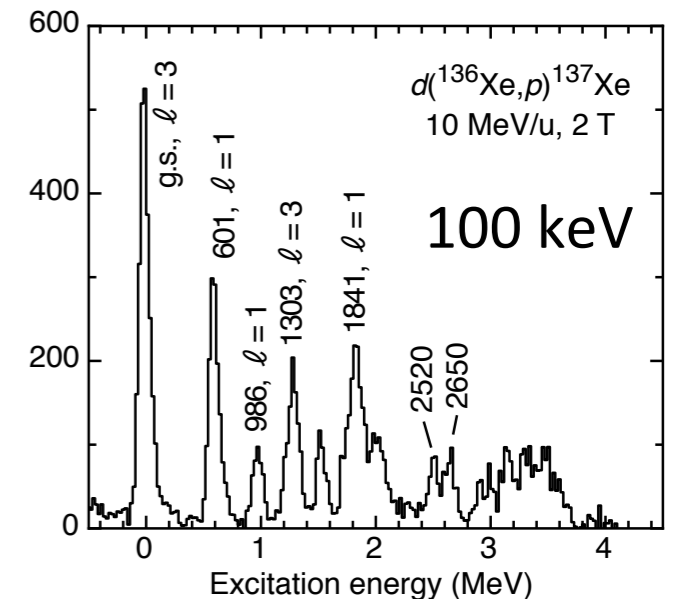
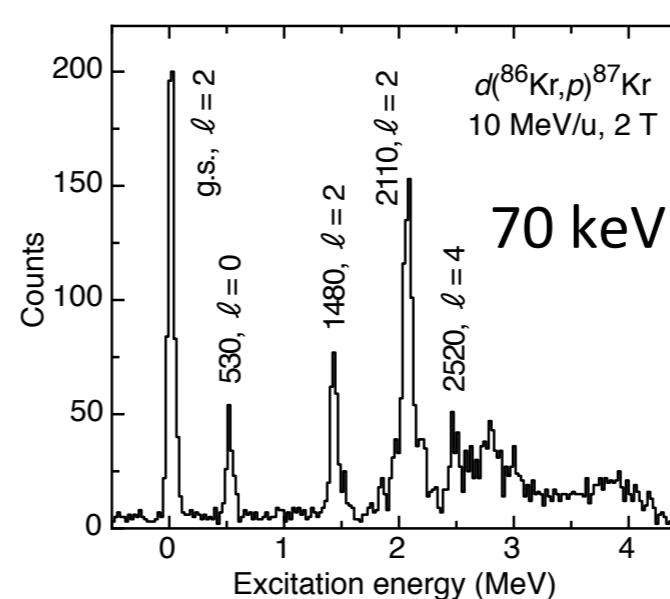
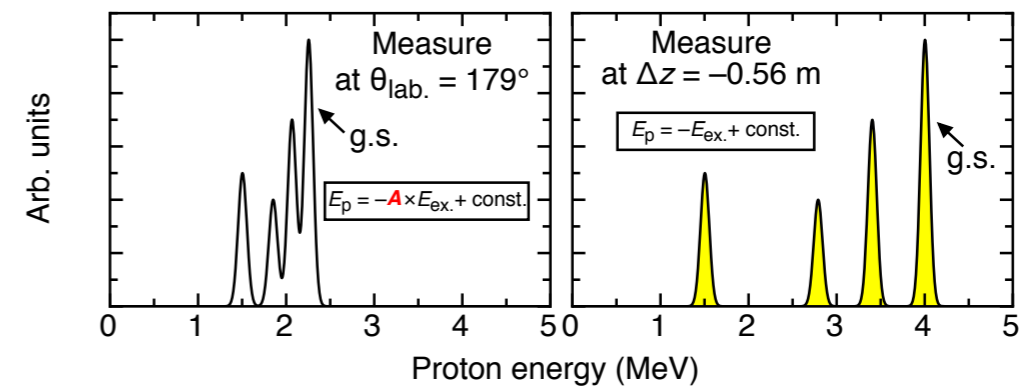
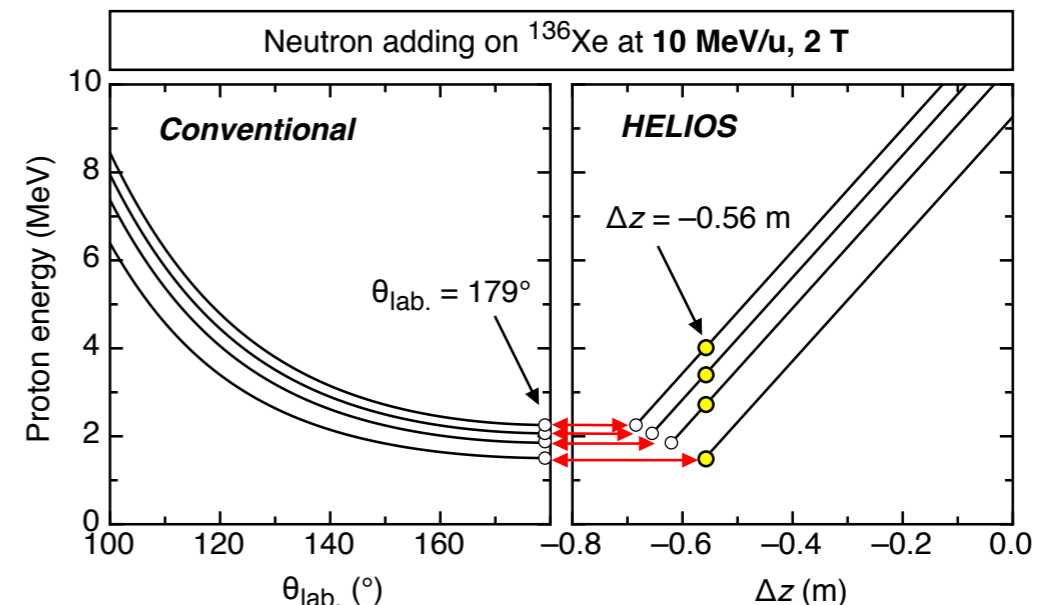


- (t,p) on ^{66}Ni studied at ISOLDE in September 2011 using T-REX and Miniball (IS504)
- Beam energy of 2.65 MeV/u, 4.2×10^6 pps with better than 86% purity
- The 'Munich' Ti:t target which is $500 \mu\text{g}/\text{cm}^2$ Ti, $40 \mu\text{g}/\text{cm}^2$ t
- Charged-particle resolution of ~ 1000 keV at FWHM
- Preliminary analysis suggests ground state and 2034-keV 2^+ state seen. No evidence of 0^+ states at 1770, 2511 keV (isomeric)

Why choose a solenoidal spectrometer

Pure charged-particle spectroscopy:

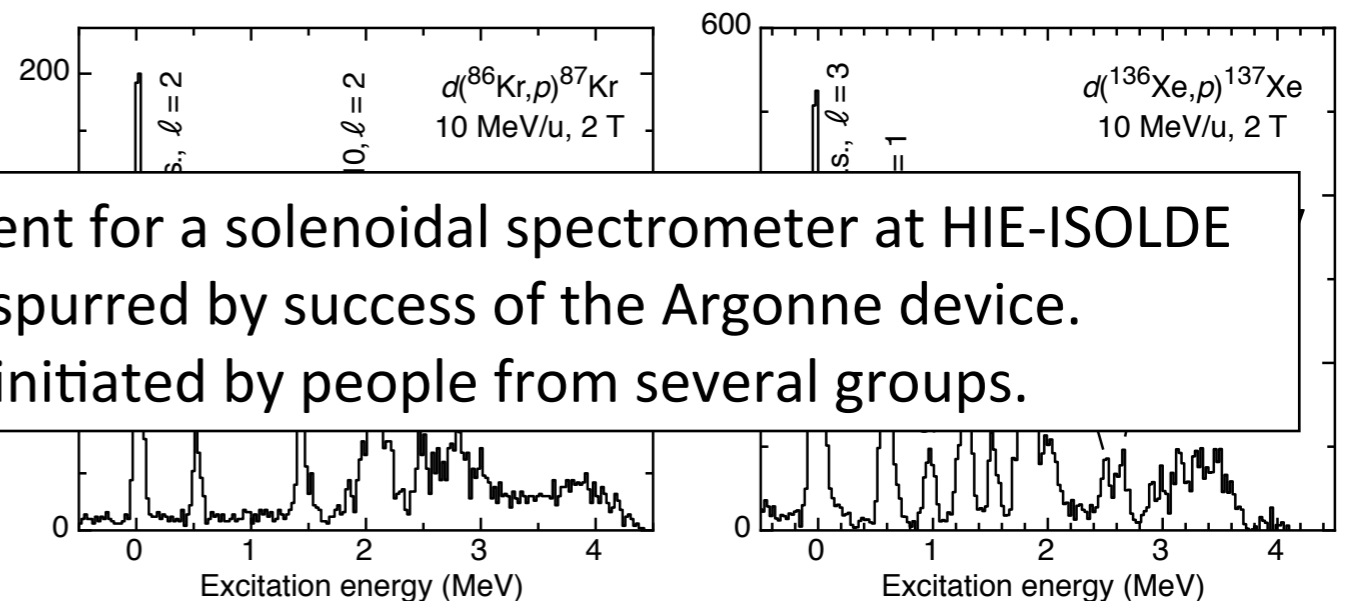
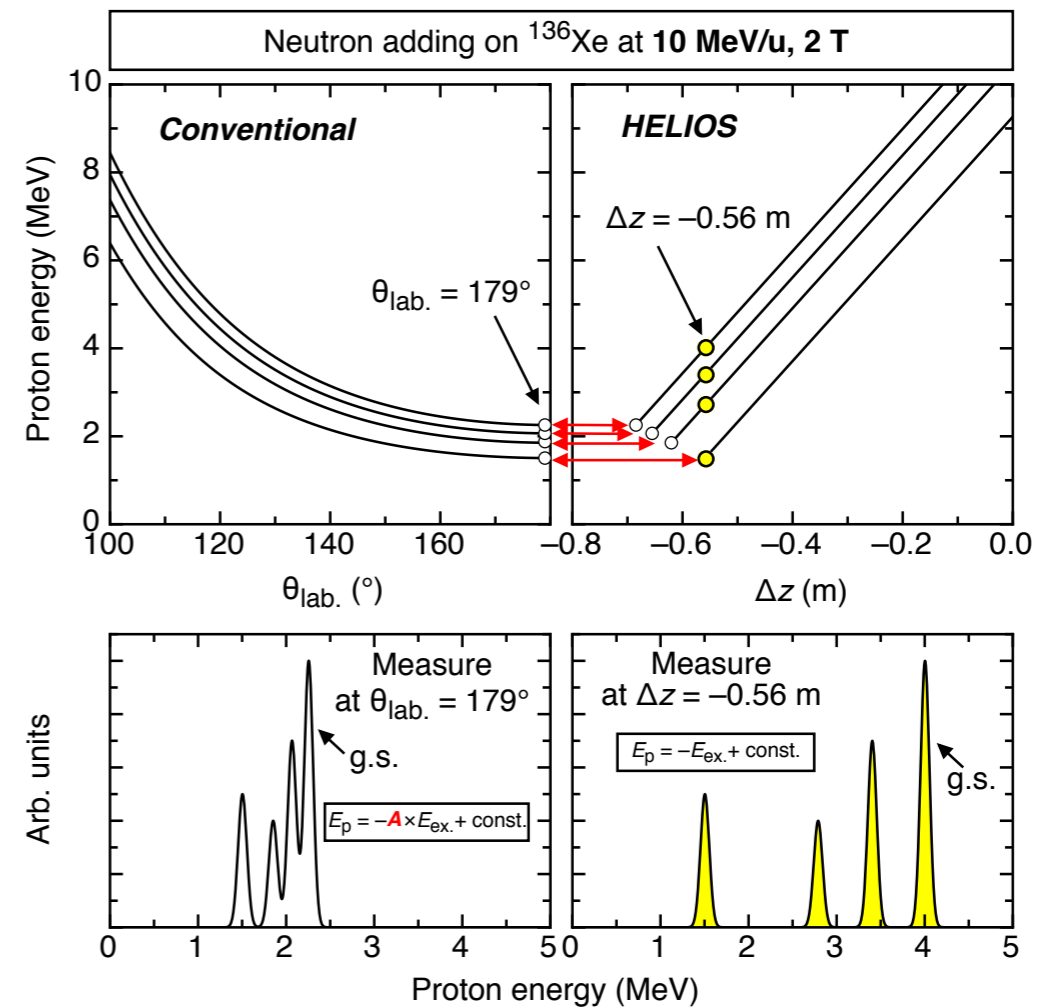
- Resolution:
 - charged-particle spectroscopy with ~ 100 -keV resolution
- No γ -ray coincidence required:
 - with several isomeric states known, including those under question, it is challenging to do γ -ray spectroscopy
- The (t,p) populates non-yrast states which may not be otherwise seen in γ -ray work
- Robust angular distributions, pretty unambiguous J^π assignments (if sufficient statistics)



Why choose a solenoidal spectrometer

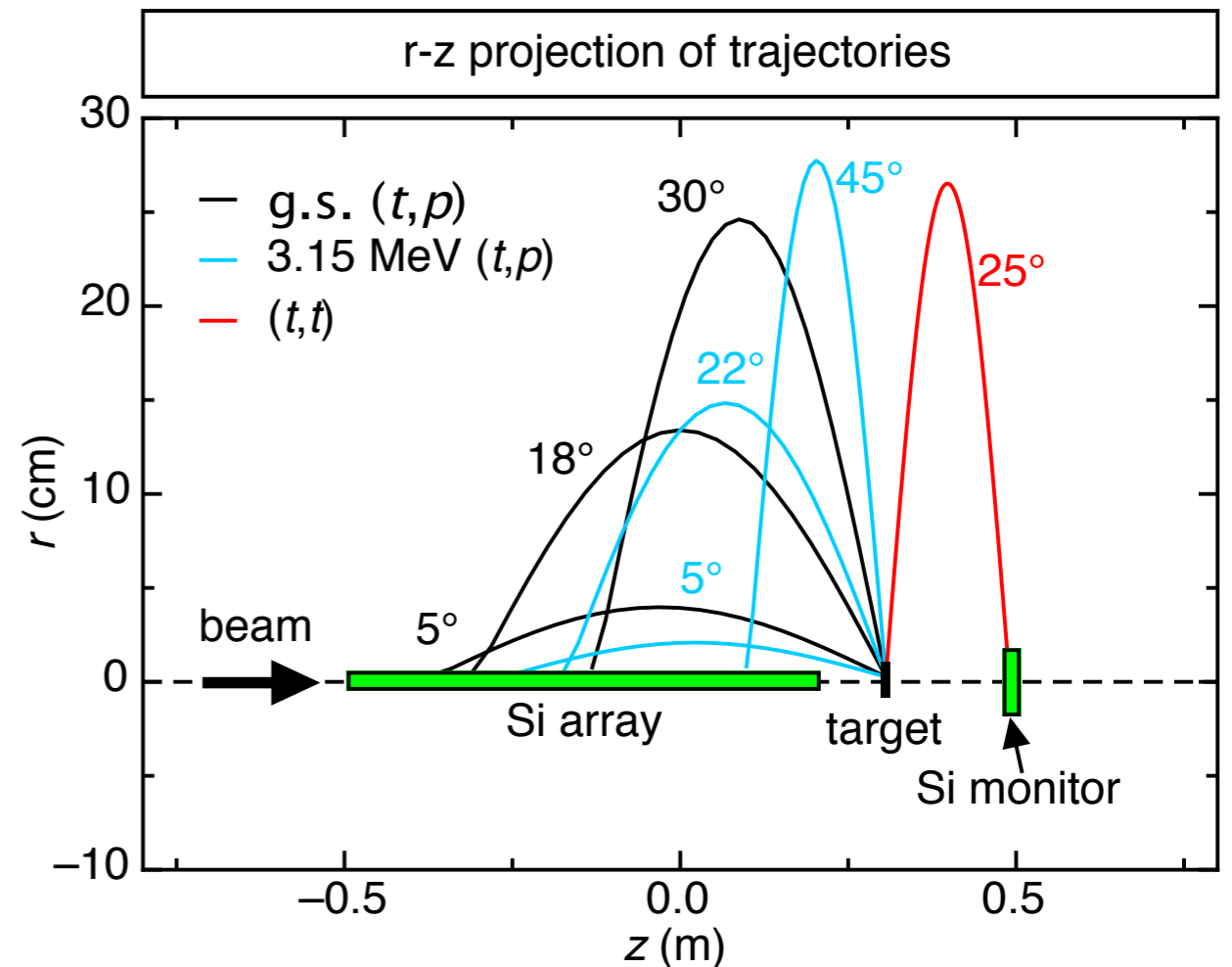
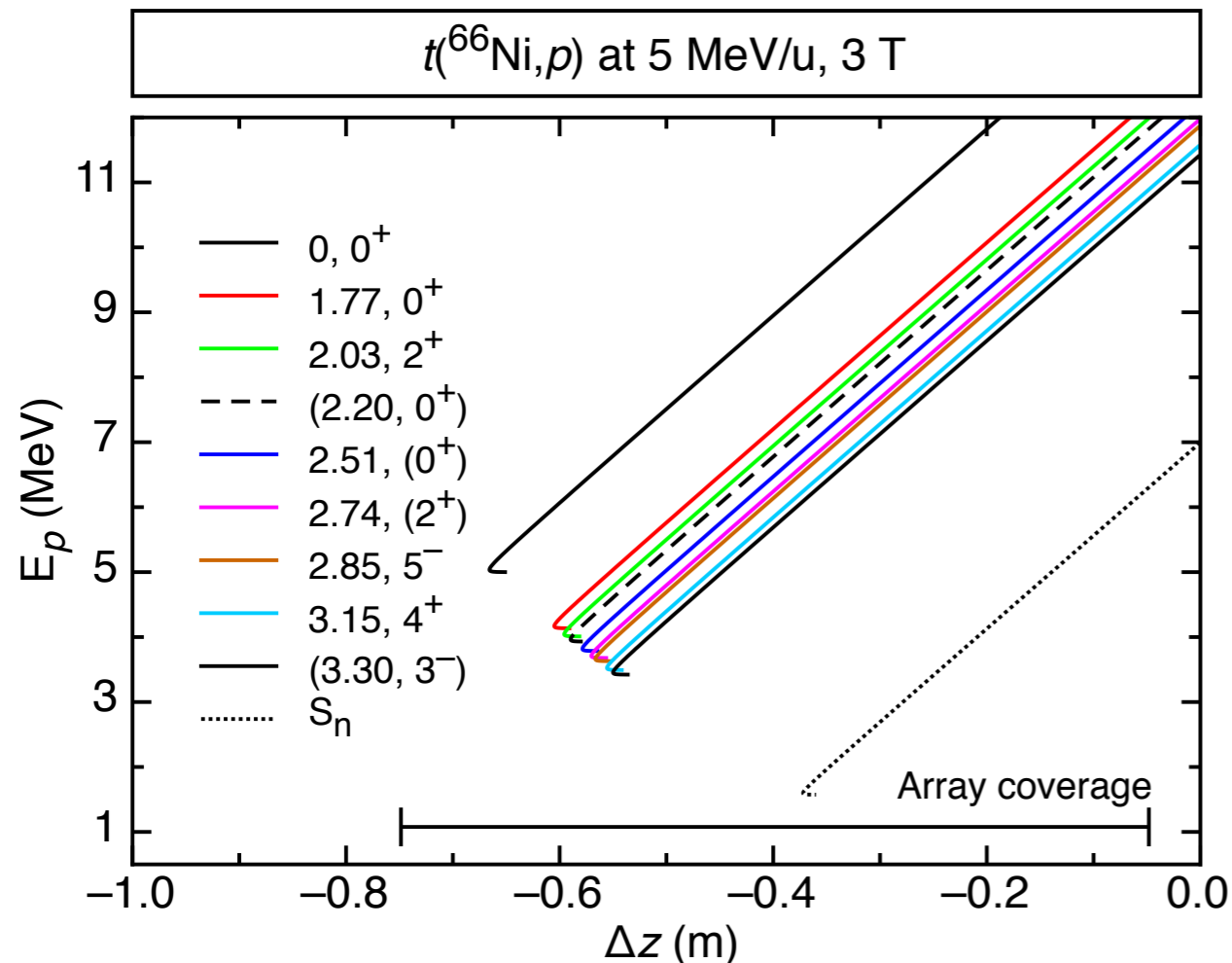
Pure charged-particle spectroscopy:

- Resolution:
 - charged-particle spectroscopy with ~ 100 -keV resolution
- No γ -ray coincidence required:
 - with several isomeric states known, including those under question, it is challenging to do γ -ray spectroscopy
- The (t,p) populates non-yrast states which may not be otherwise seen in γ -ray work



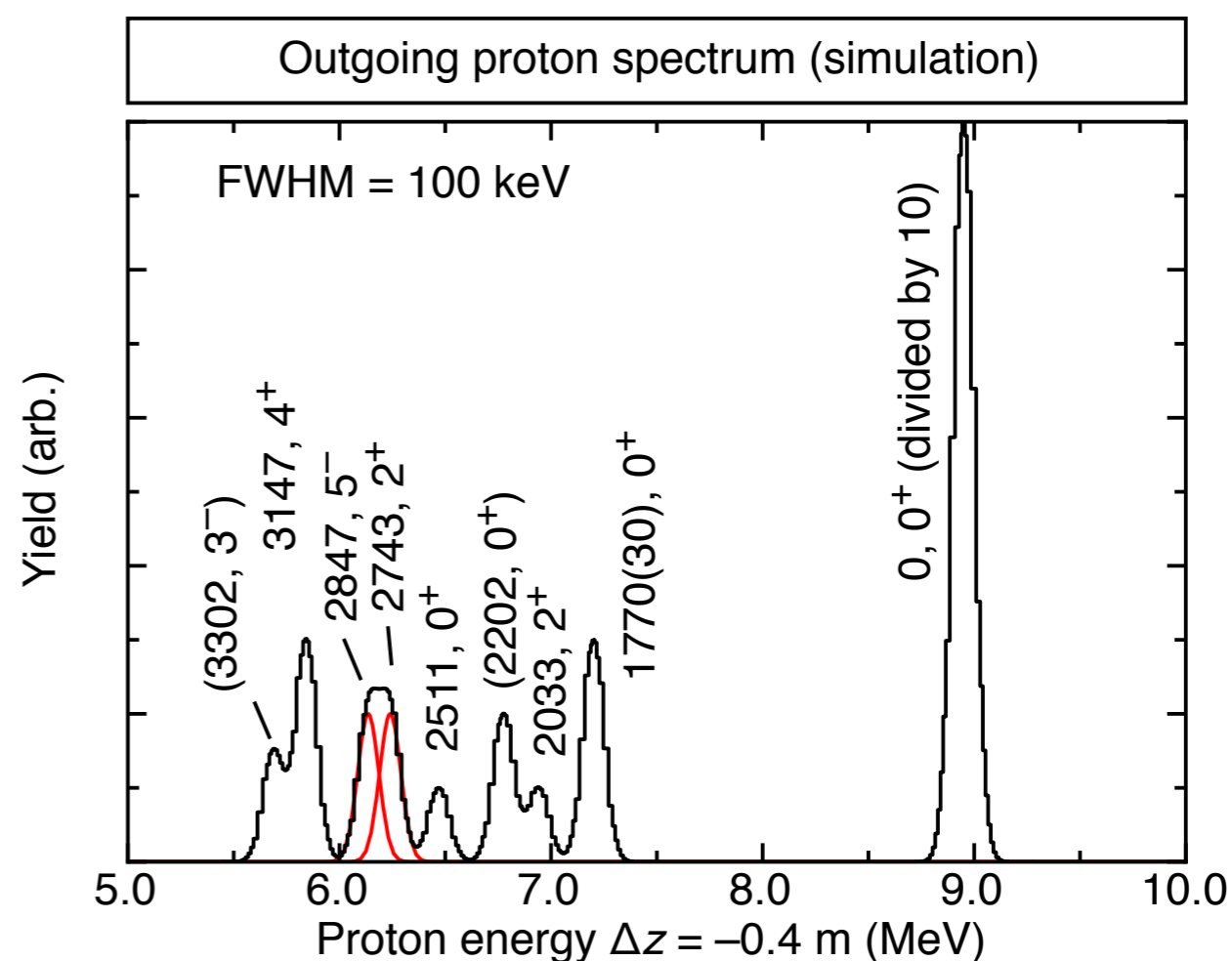
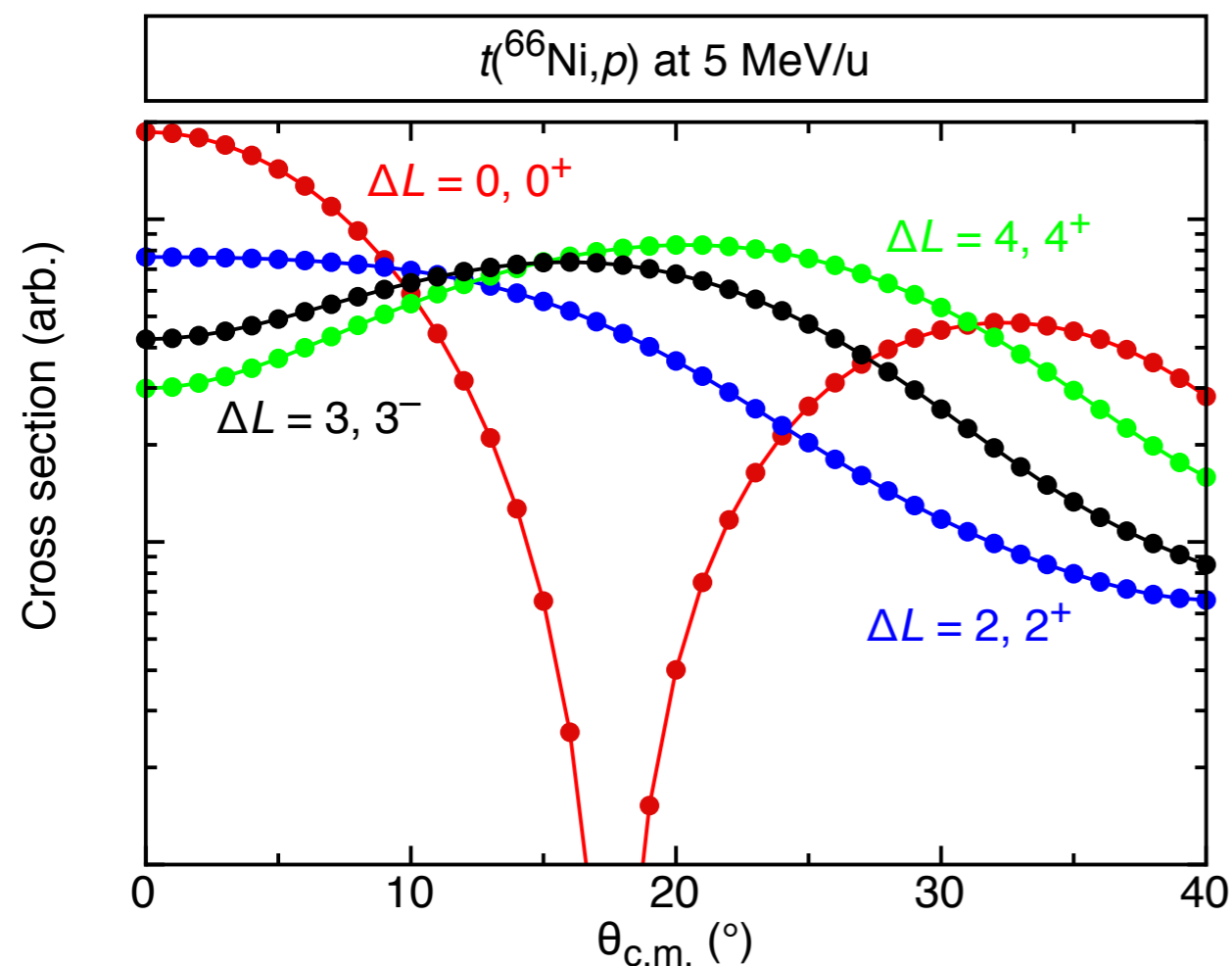
In 2010 the INTC endorsed a Letter of Intent for a solenoidal spectrometer at HIE-ISOLDE (CERN-INTC-2010-031; INTC-I-099) spurred by success of the Argonne device. Subsequently a project has been initiated by people from several groups.

Solenoidal spectrometer set up



- Though the focus is on low-lying states, will in practice populate all states up to and beyond S_n
- Essentially a 'singles' experiment—no recoil detection necessary, nor any explicit light-ion identification
- Other open channels, including (t,α), (t,d), and ($t,^3\text{He}$), either go forward or do not overlap in E versus Δz , and are also strongly suppressed due to Q value
- Only the 'tail' of protons from fusion-evaporation seen, easily dealt with

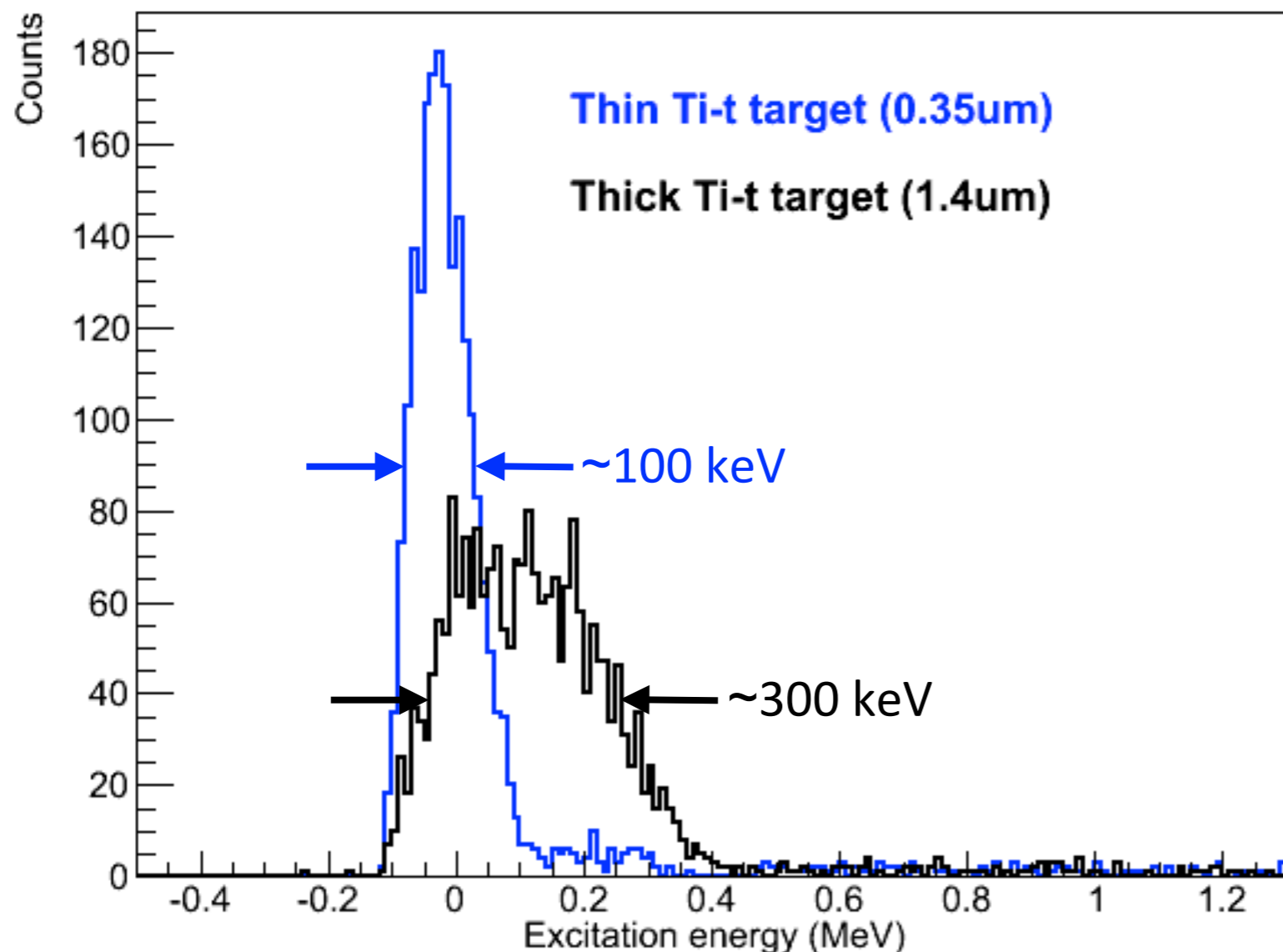
Solenoidal spectrometer set up



- Even a modest Si array (e.g. the Argonne prototype of 35-cm length) would cover sufficient angle range
- It is clear a Q -value resolution (FWHM) of ~ 100 keV is important – greater than 150 keV would limit the extraction of useful information
- The semi-continuous angular coverage from essentially $0 \leq \theta \leq 45^\circ$ should allow for unambiguous ΔL assignment
- Dominantly single-step transfer of a correlated pair of neutrons (other open channels strongly suppressed)

Target considerations

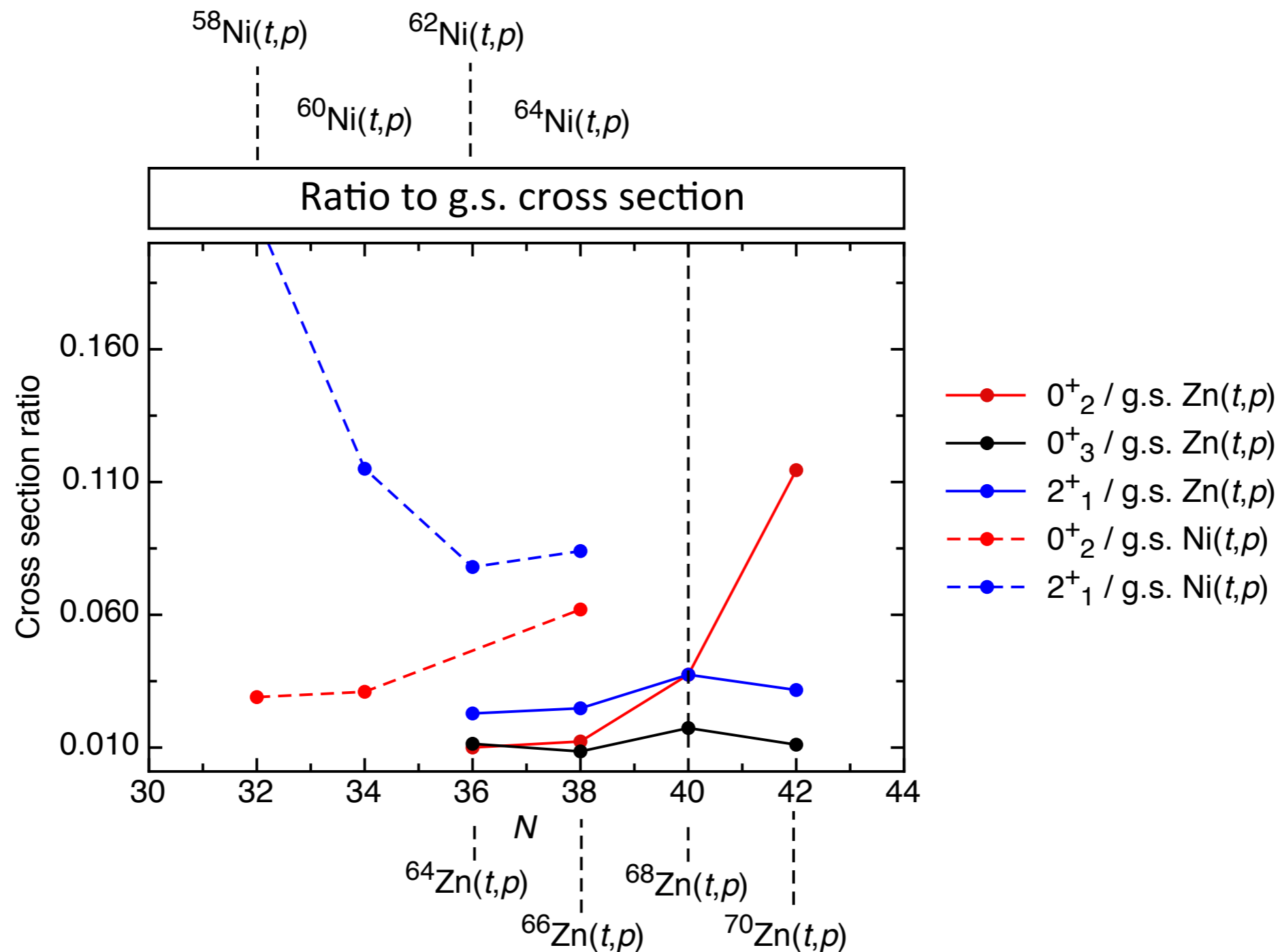
- Will require a 'thin' target to get the estimated 100-keV c.m. resolution
- Simulations suggest a 0.35 μm Ti:t foil ideal ($125 \mu\text{g}/\text{cm}^2$ Ti, $10 \mu\text{g}/\text{cm}^2$ t)
- This is a factor of four times thinner than the 'Munich' target used in e.g. the (t,p) reaction on ^{30}Mg by Wimmer *et al.*, Phys. Rev. Lett. **105**, 252501 (2010) with T-REX
- This requires development and safety considerations (interest at TRIUMF and Argonne in such targets may lead to all round better exploration of Ti:t targets)



- Simulation assumes $125 \mu\text{g}/\text{cm}^2$ Ti, $10 \mu\text{g}/\text{cm}^2$ t
- A ^{66}Ni beam at 5 MeV/u (330 MeV)
- 3-mm beam spot
- 0.1% energy spread of beam
- 50-keV intrinsic Si resolution
- (Si will probably be much better, beam may be slightly worse, effect minimal)

Comment on transfer cross sections

Not only can the excitation energy and J^π be determined, but the cross section can tell us the degree to which neutron configurations play a role in the final state. Some limited data in the region. Some caution has to be taken interpreting the cross sections.



Summary

- It is important to pin down the energies and spins of low-lying states in ‘doubly-magic’ ^{68}Ni . In particular:
 - The energy (or existence?) of the 1770-keV state
 - What is the energy of the 3^- state? Is it at 3302 keV?
 - Resolve the question marks about the 2202-keV state (not there?)
 - ...
- Significant benefits using the (t,p) reaction with a solenoidal spectrometer. Other charged-particle reactions have suffered from poor resolution. Gamma-ray spectroscopy cannot probe all states
- The intensity and purity of the ^{66}Ni beam at ISOLDE, and the resolving power of a solenoidal spectrometer, present the possibility for a detailed study of ^{68}Ni that will highly complement previous studies of this nucleus
- Rate estimates are straight forward and detailed in the proposal – we request 18 shifts