Studies of n-rich nuclei using DIC with radioactive beams

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Goals of the collaboration

- Krakow experience:
  - Thick target experiments (LNL, Argonne,..)
  - Thin target experiments (LNL)
  - Isomerscope at Oak Ridge
- GANIL experience:
  - Thin target experiments
  - One experiment of deep inelastic reactions using RIBs

➔Development of a setup for a combined prompt and delayed spectroscopy in the region located beyond ^{68}Ni

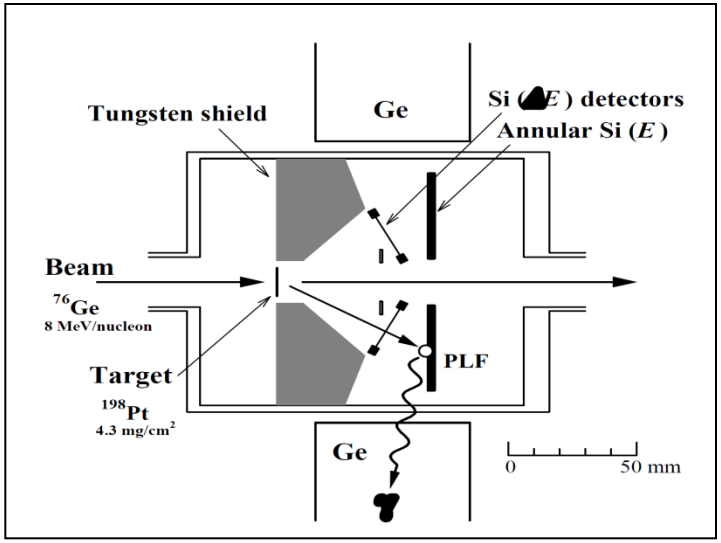
➔Benefit from the expertise acquired in both labs to envisage the opportunities with RIBs

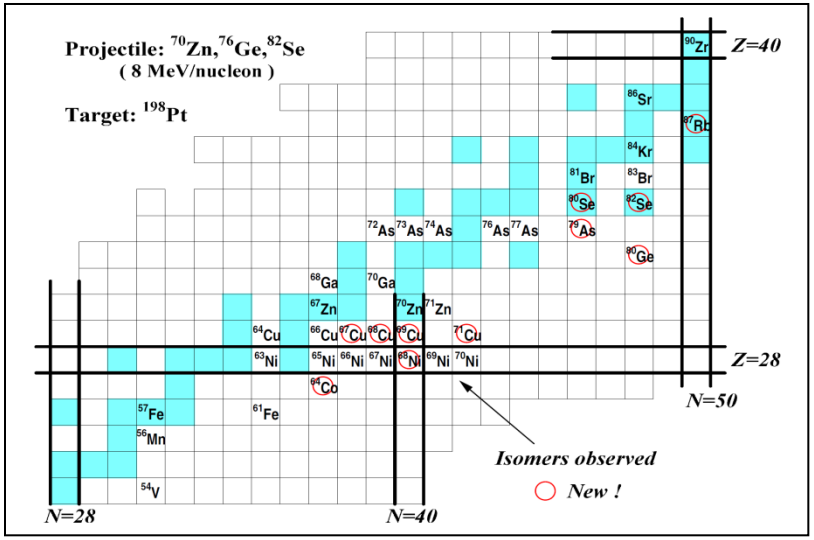
Physics from DIC studies of sub-μs neutron-rich isomers: The Krakow approach

- **populate neutron-rich nuclei via DIC using accelerated RIBs**
- stop products in front of a high efficiency Ge detector setup
- measure gamma coincidences in isomeric decays in 10-1000 ns range (fragment tagging, in-beam events rejected)
- Isomer-scope setup developed as part of the RIB-152 project at HRIBF, Oak Ridge (2006-2011): *„Structure of neutron-rich Cu and Zn isotopes produced in deep-inelastic transfer reactions with radioactive ion beams"*

Isomer-scope – an instrument to observe ns-μs isomers produced in deep-inelastic collisions

T. Ishii et al., NIM A395, 210 (1997)

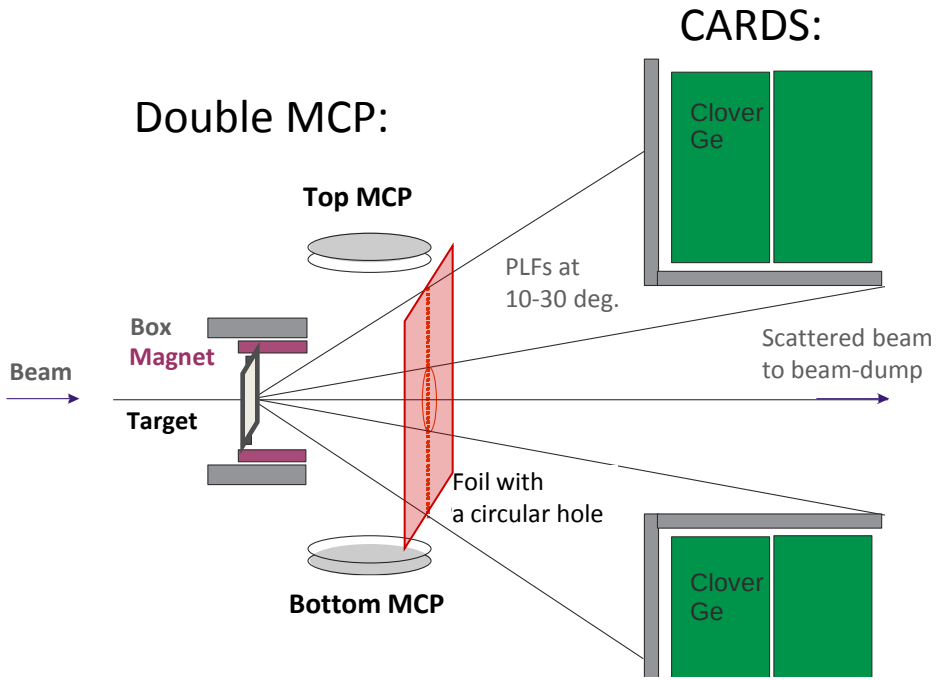




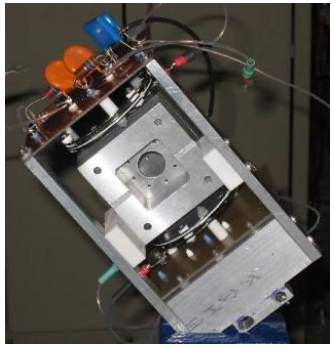
- PLF detected and identified by ΔE-E detectors: four 20 μm Si ΔE and one annular Si E detector
- four Ge detectors around the Si-E, shielded from the target
- measured ΔE-E-γ-(γ)

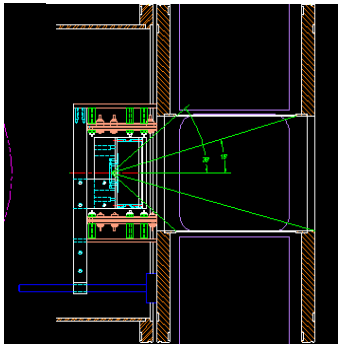
- ^{70}Zn, ^{76}Ge, ^{82}Se low-intensity beams (~0.1 pnA) on heavy targets
- sensitivity down to about 10 μb
- many new isomers observed: ^{64}Co, ^{68}Ni, ^{67,68,69,71}Cu, ^{80}Ge, ^{79}As, ^{80,82}Se

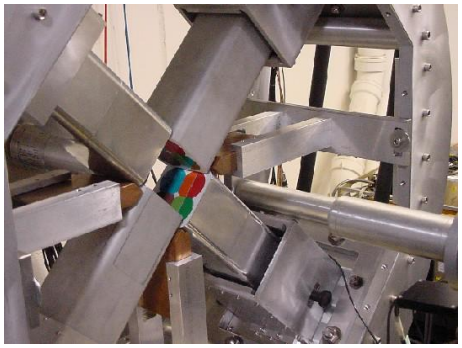
UT / Kraków Isomer-scope for experiments with RIBs



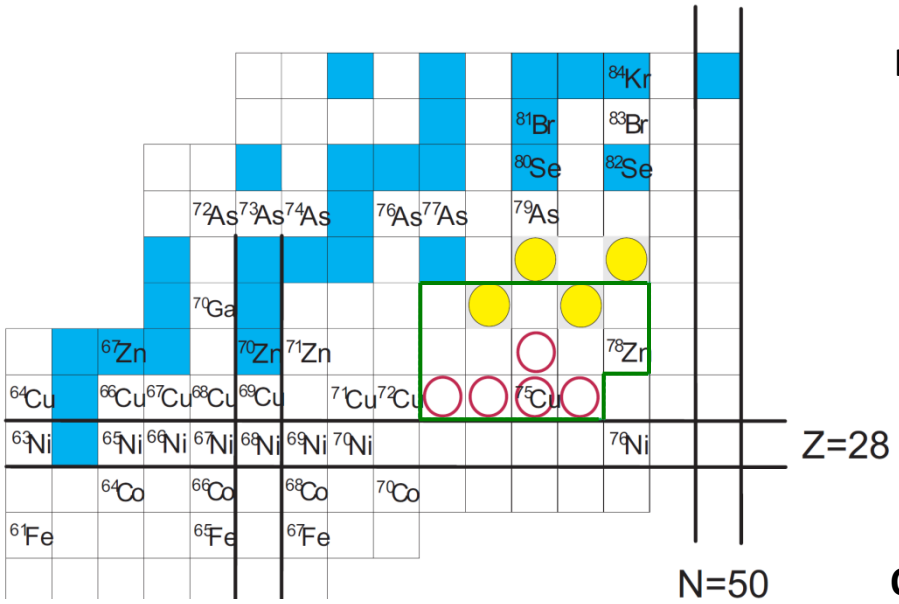
- radioactive beams of A ≈ 80 on ^{124}Sn or ^{130}Te target (~2 mg/cm^2)
- MCP tagging on PLFs emitted at and around the grazing angle, 10-30 deg. – MCP efficiency ≥ 90%
- scattered beam ions produce no signal
- CARDS: 4 Clover Ge detectors in a close geometry to measure time stamped $\gamma(-\gamma)$ isomeric decay events in 10-1000 ns range



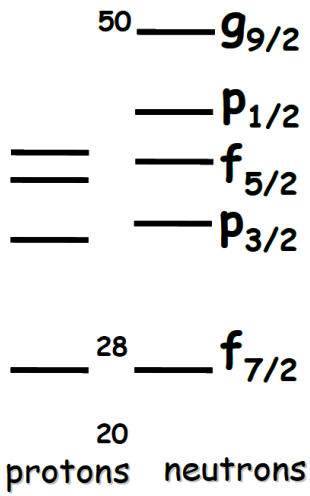




Isomer-scope experiments: RIBs from ORIC beams



Isomers arise from $\nu g_{9/2}$ orbitals



Isomers in neutron-rich Cu and Zn isotopes:

- in Cu isotopes - find yrast configurations dominated by $\nu g_{9/2}$ similar to the known $\nu g_{9/2}^2$ configurations of Ni isotopes
- investigate the role of proton-neutron residual interactions, between $f_{5/2}$, $p_{3/2}$ protons and $g_{9/2}$ neutrons

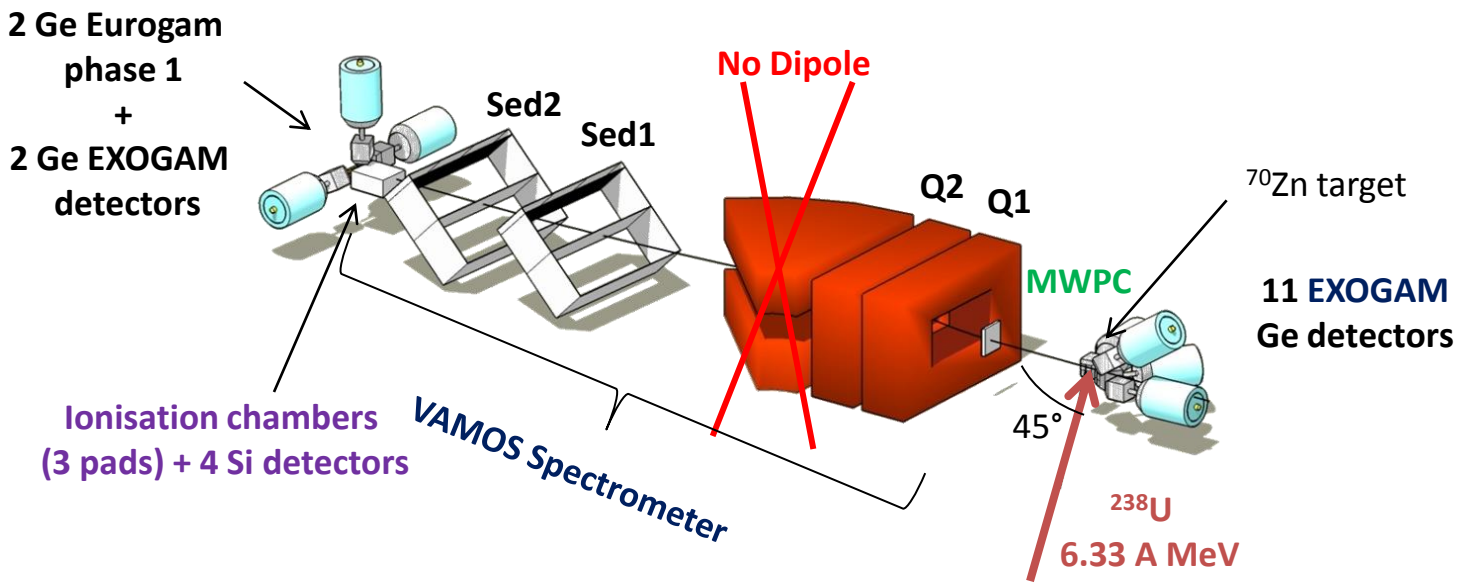
Original RIB-152 plan based on ORIC beams:

- ^{76,78}Ga and ^{78,80}Ge post-accelerated beams at 2 x 10^5 – 10^6 ions/sec on ^{124}Sn target
- Isomers in $^{73\text{-}76}$Cu, ^{76,78}Zn
- a 5 days experiment, from the available rate estimates

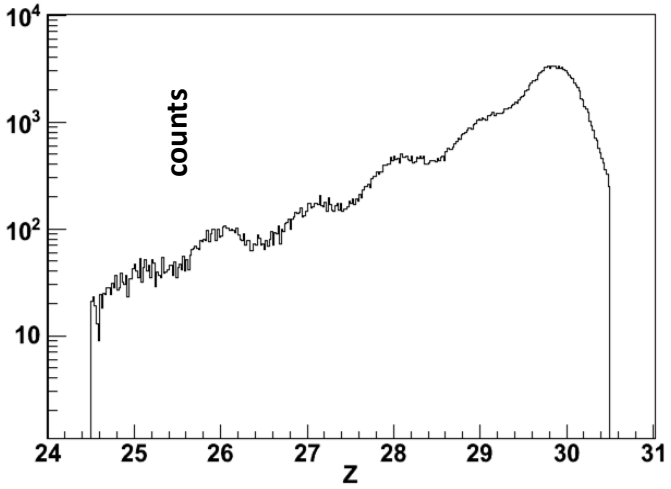
The GANIL approach: prompt and delayed γ-ray spectroscopy

- prompt and delayed transitions ➔ need a combined setup to measure both
  - use of deep inelastic reactions to populate low-lying states in moderately exotic nuclei
  - measure the recoils (full identification): VAMOS
  ➔ thin targets
  - measure prompt gamma rays: EXOGAM
  - measure delayed coincidences: Ge dets at the focal plane

The complete setup



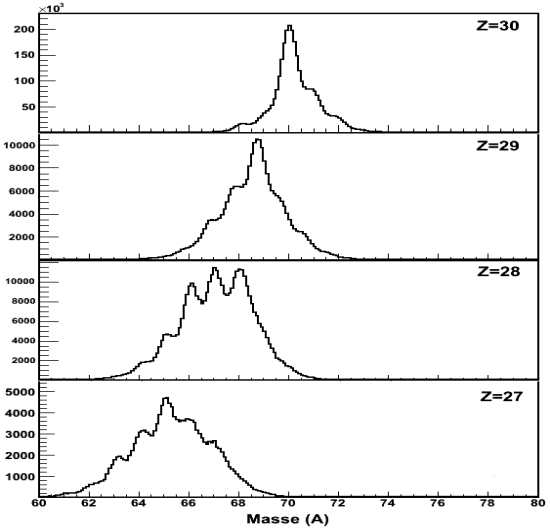
Z identification



$\Delta M/M=1.2\%$

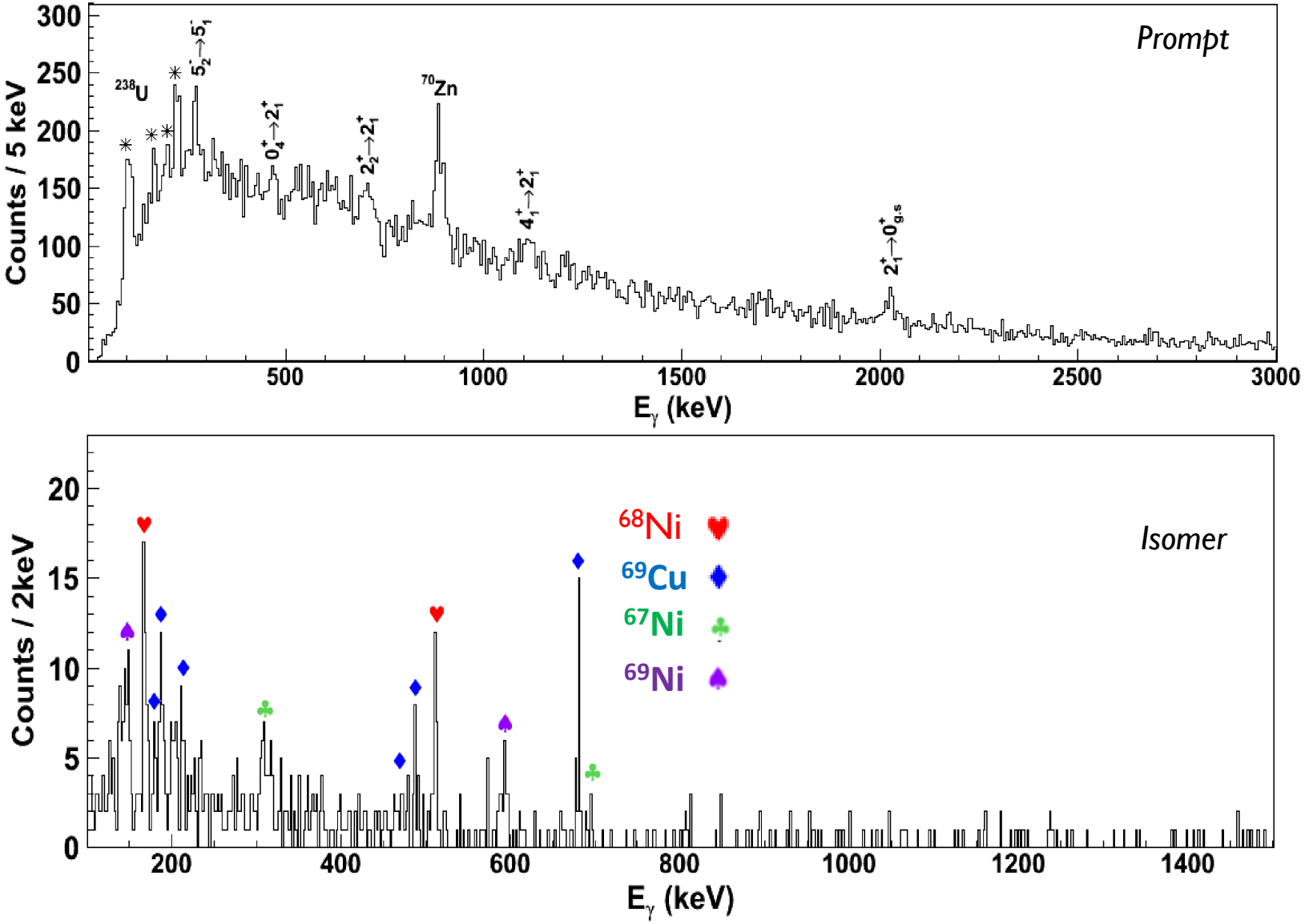
$\Delta Z/Z=1.1\%$

M identification



π(2p-2h) intruder state in ^{68}Ni

A. Dijon, *et al.* PRC.85 (2012) 031301



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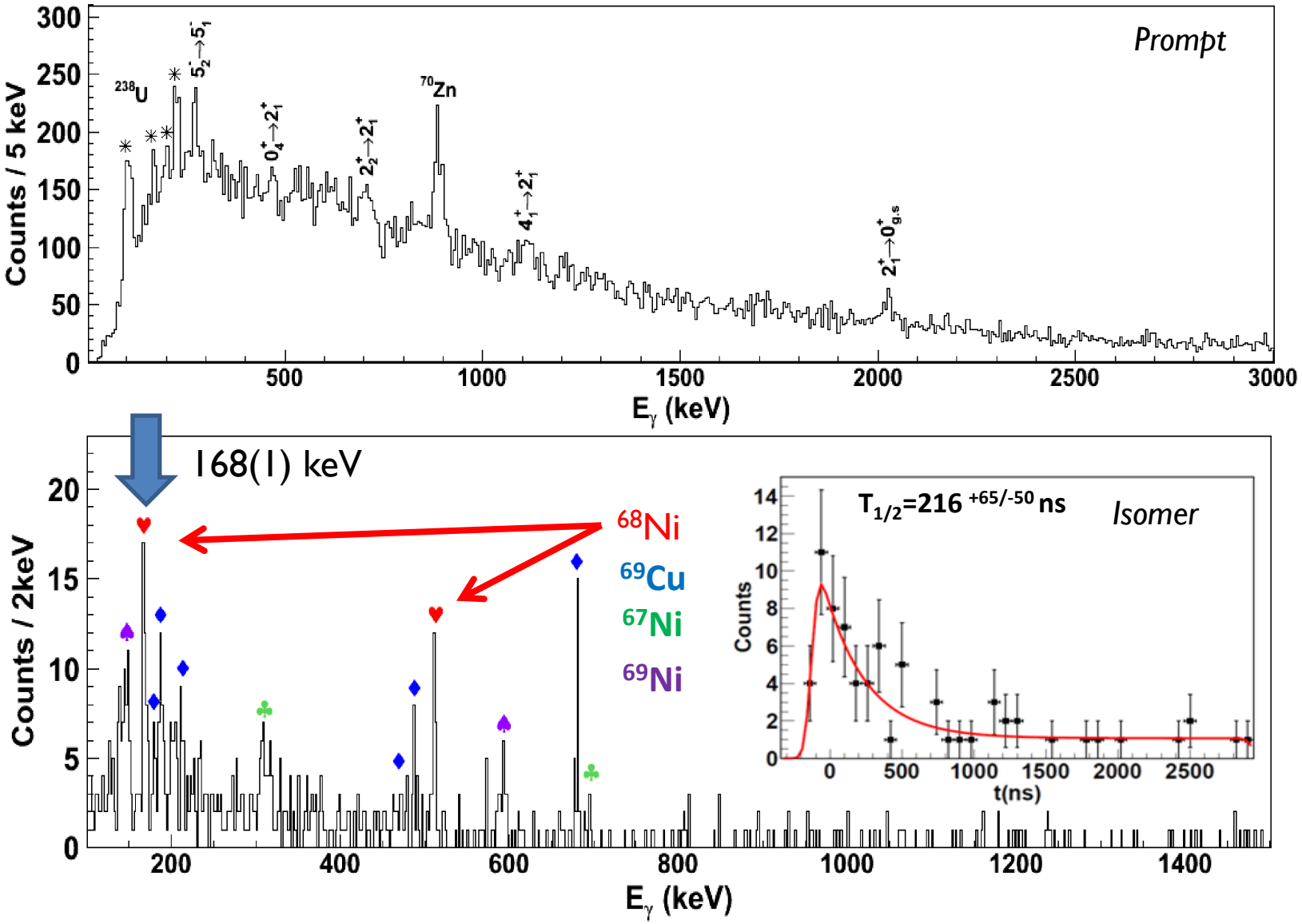

π(2p-2h) intruder state in ^{68}Ni

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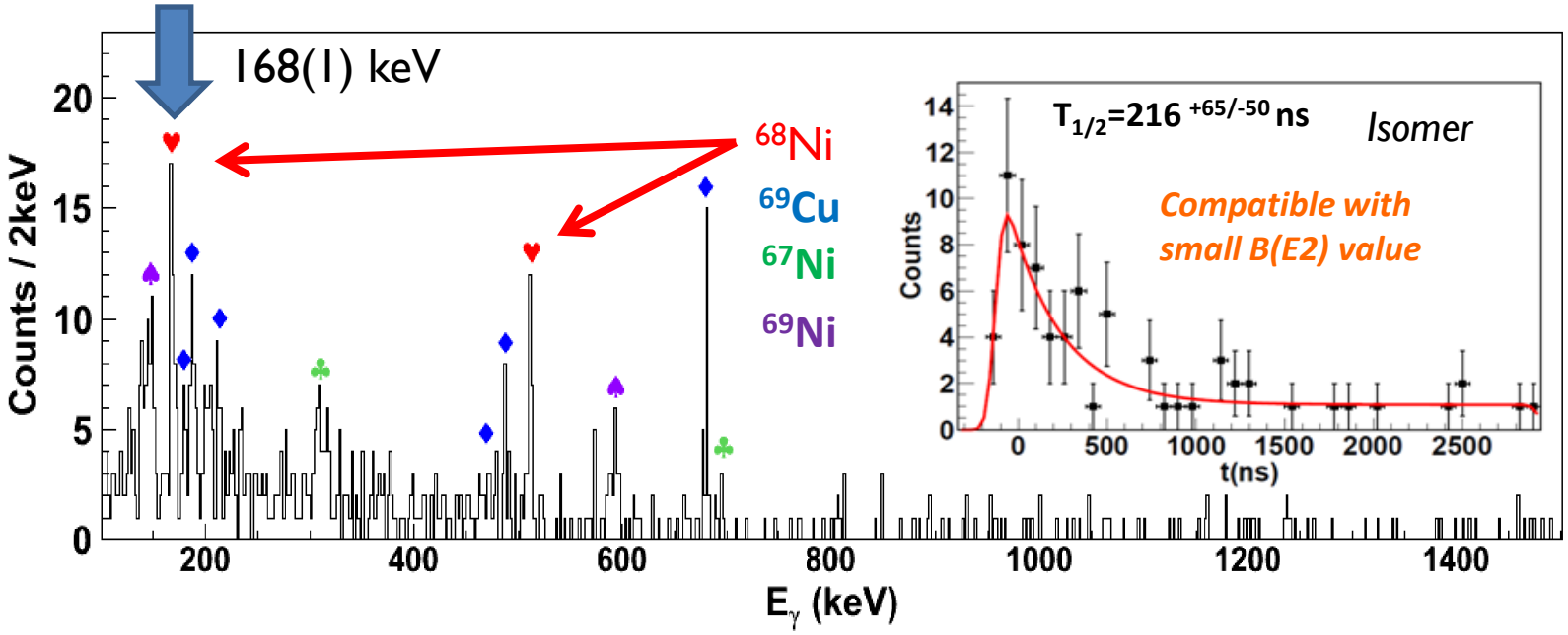
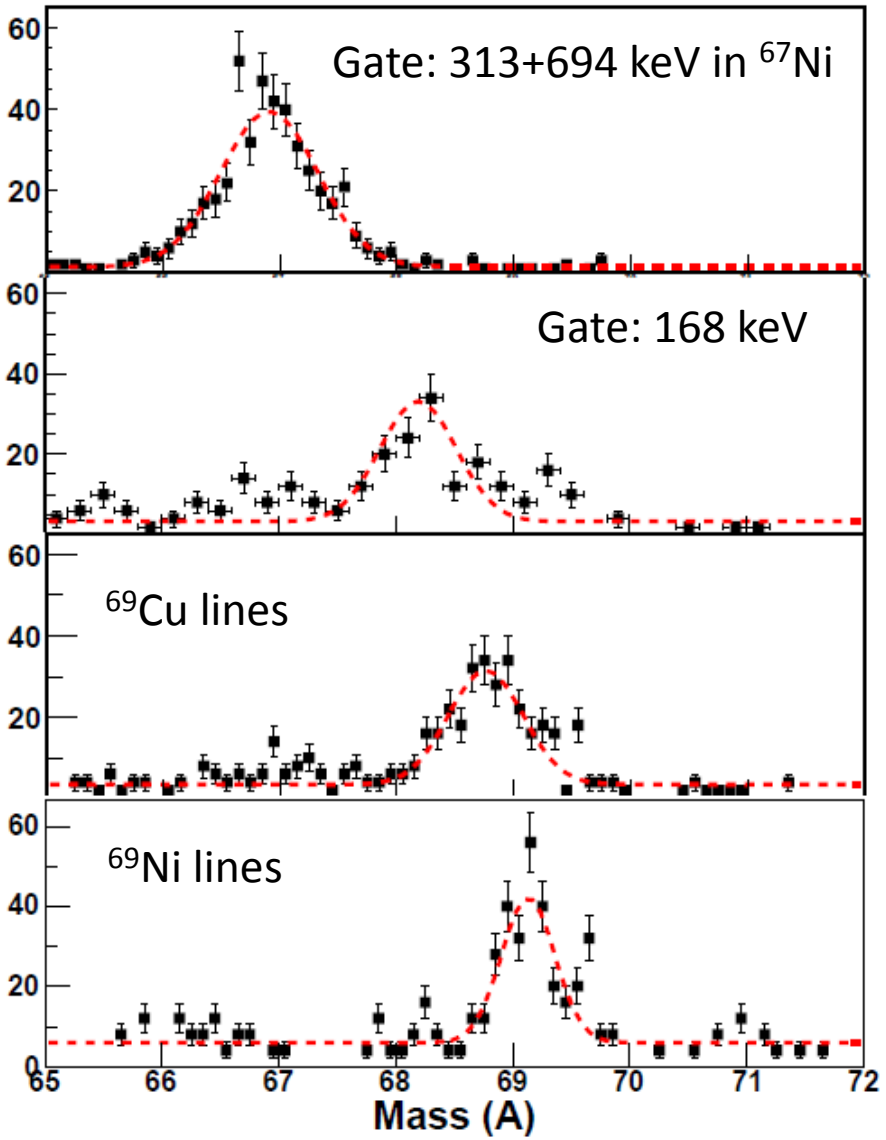
Transitions	Half-life
E1	0.1 ps
E2	300 ns
M1	6 ps
M2	20 µs

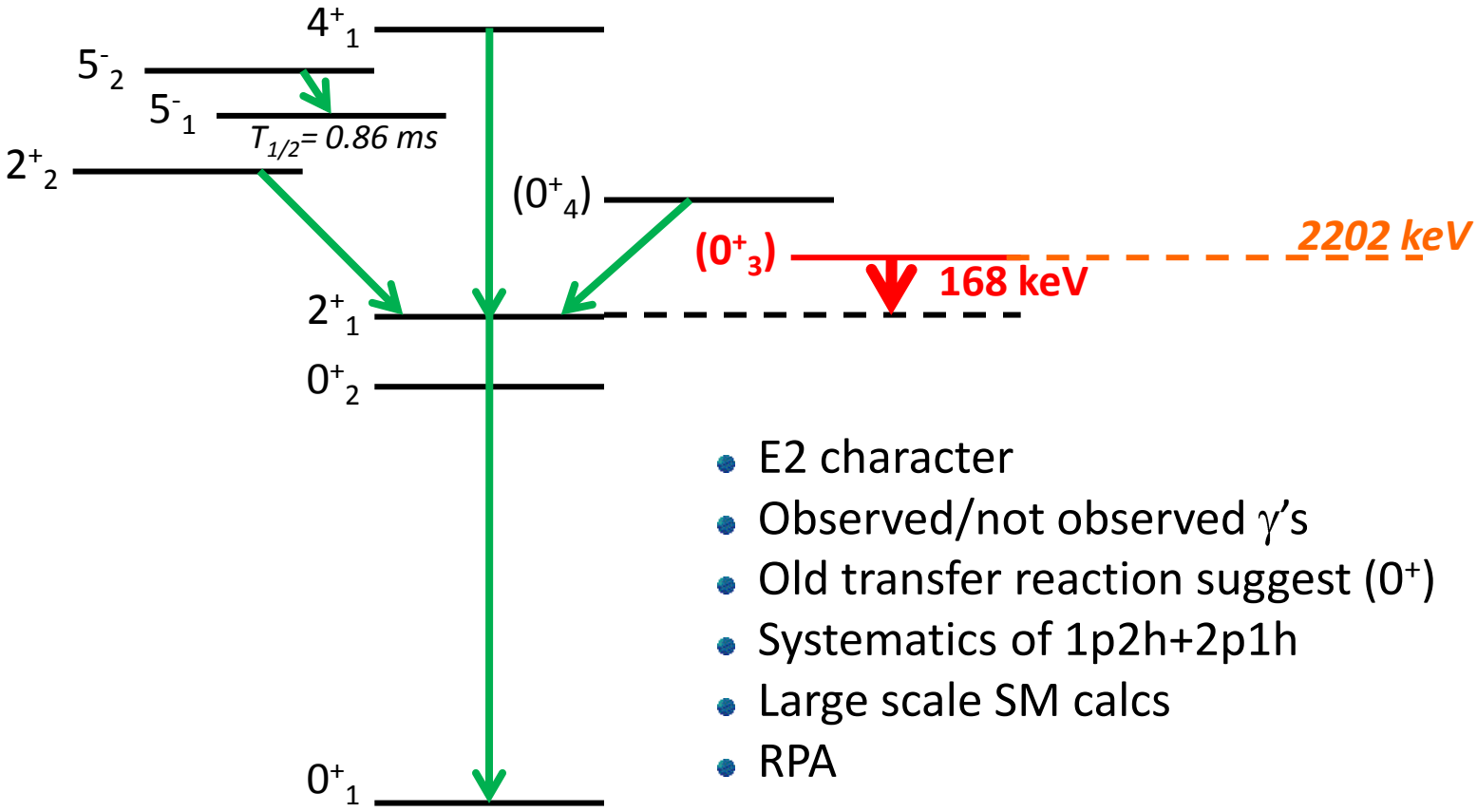


How sure are we that it is in ^{68}Ni?

- Gamma-ray spectra obtained after gating on ^{68}Ni identification (but ^{67,69}Ni and ^{69}Cu contaminants are still present)
- Gate on gamma-rays and look mass spectra :
  - known γ's in ^{67,69}Ni and ^{69}Cu give the right masses
  - gate on 168 keV (and also 511) gives A=68



Low-energy spectrum in ^{68}Ni



- E2 character
- Observed/not observed γ's
- Old transfer reaction suggest (0^+)
- Systematics of 1p2h+2p1h
- Large scale SM calcs
- RPA

➔ This new isomer is a highly deformed 2p2h states and has proton character

Main conclusions from ^{68}Ni

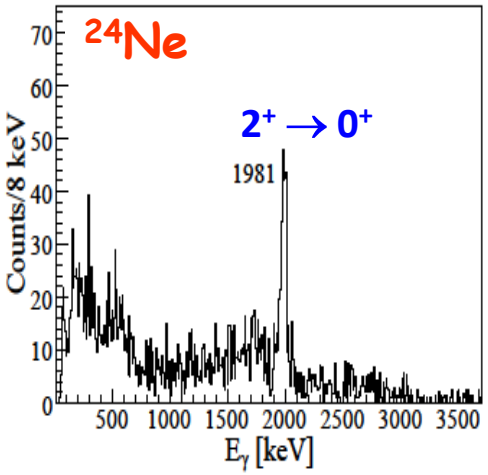
- Analysis confirms a very large n-p correlation energy with a g.s. which is mainly doubly-magic (largest of the nuclear chart)

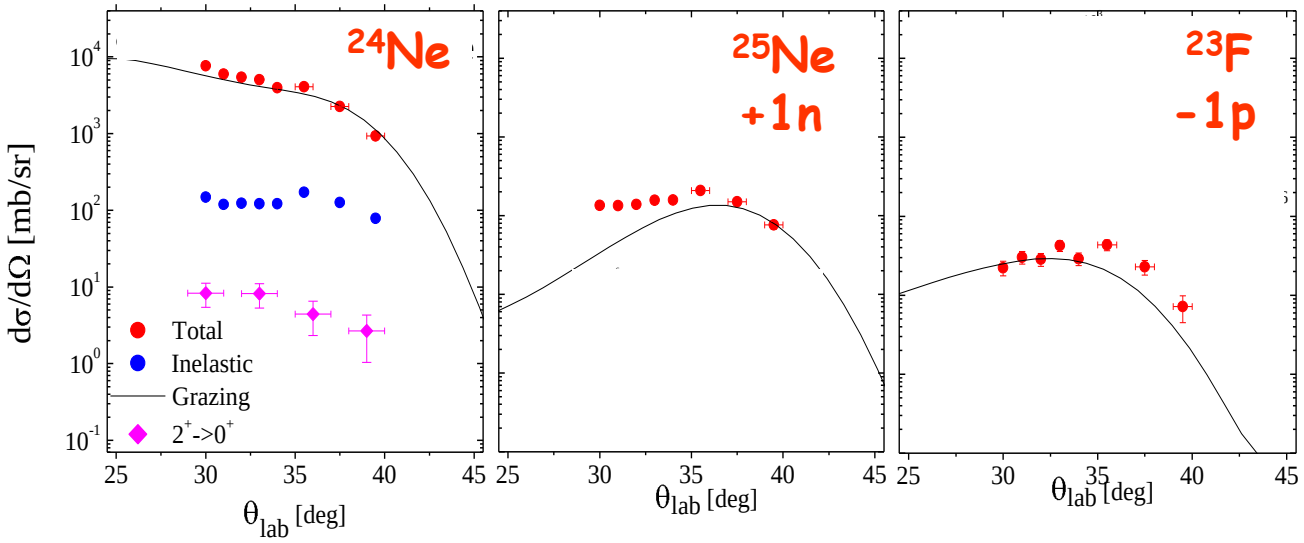
- The low-energy 2p-2h intruder state is evidence for shape coexistence. Consistent with observations in N=40 isotones (Co, Fe).

- To go beyond: need to measure electrons as well (and also increase the gamma efficiency to have prompt-delayed coincidences) ➔ **a topic of common interest**

Deep inelastic reaction using RIB at GANIL

^{24}Ne (SP1, 1.5 10^5 pps) + ^{208}Pb *@ 7.9 MeV/A*
EXOGAM + VAMOS





- Study of reaction dynamics and access to first excited states in one nucleon transfer channels
- Semiclassical calculations (GRAZING) give reasonable agreement also for reactions induced by RIBs

G.Benzoni, F.Azaiez et al., EPJA45(2010)287

G. Pollarolo. A.Winther, Nucl.Phys.A594 (1995)203

Summary

- Collaboration under development
- Common interests identified
- Possible improvement of existing setup at GANIL identified
- Need to optimize setup with stable beam before envisaging reactions with radioactive beams (Zn, Ga, Ge, As)