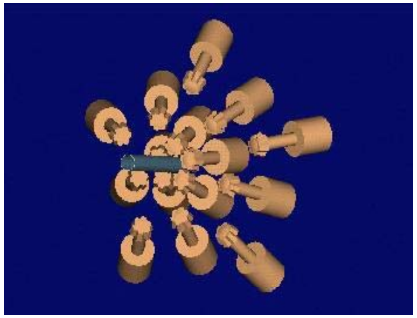
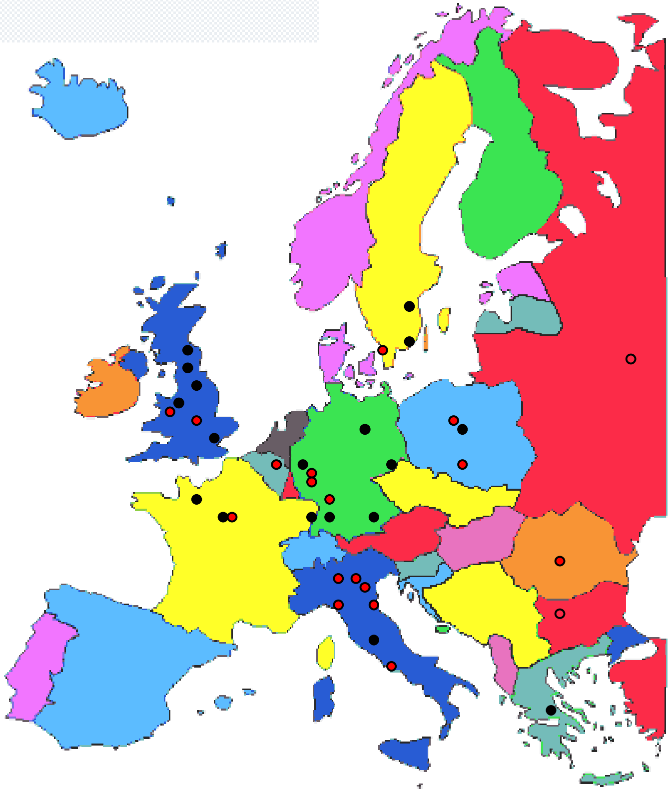


RISING experiments
Fast beam campaign in 2003

P. Reiter

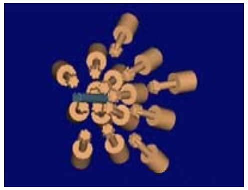
for the RISING collaboration

Universität zu Köln



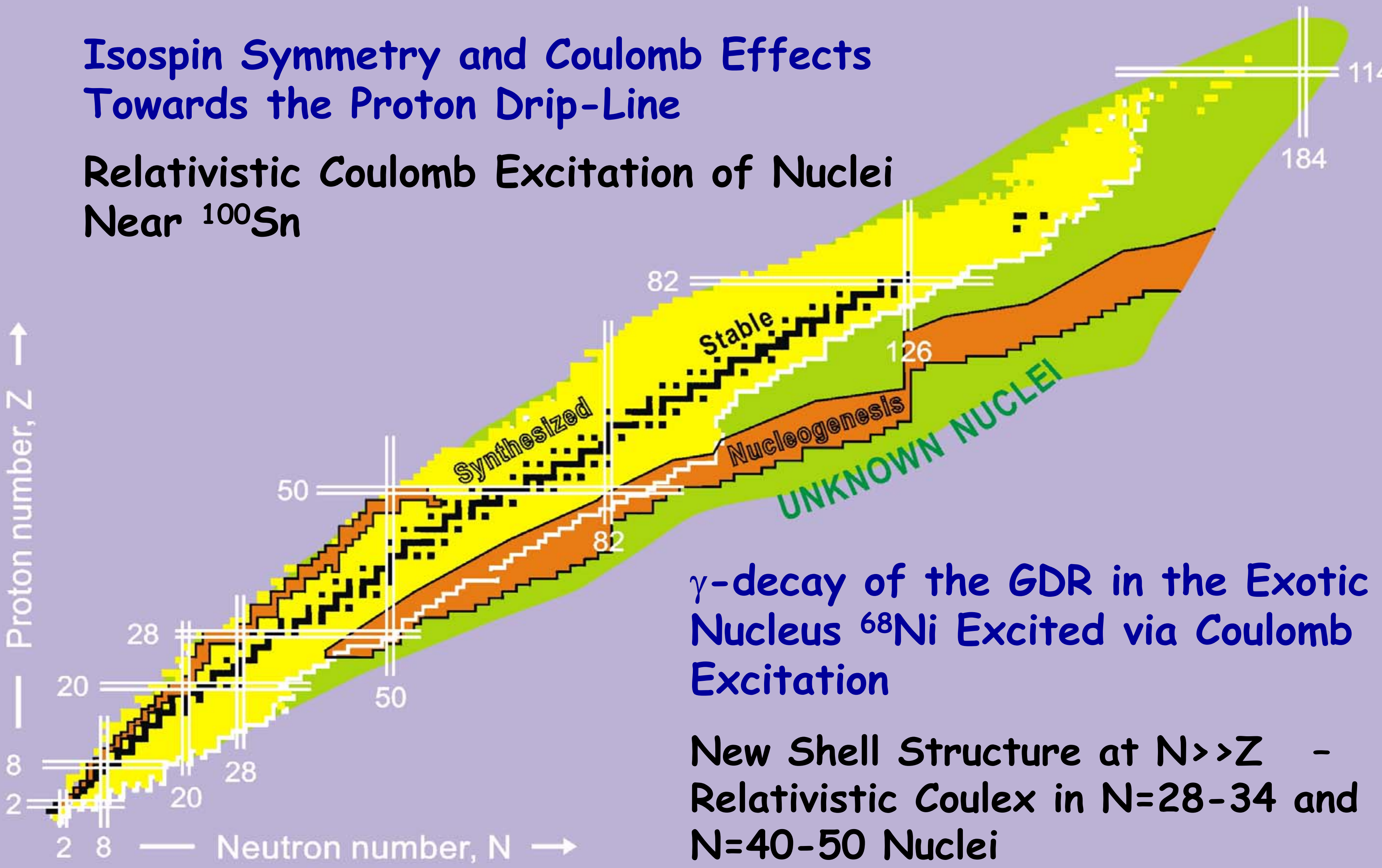
+ Canberra (Australia)

Outline: First Experiments



Isospin Symmetry and Coulomb Effects Towards the Proton Drip-Line

Relativistic Coulomb Excitation of Nuclei Near ^{100}Sn

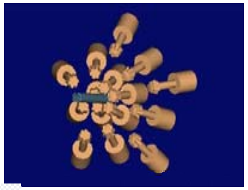


γ-decay of the GDR in the Exotic Nucleus ^{68}Ni Excited via Coulomb Excitation

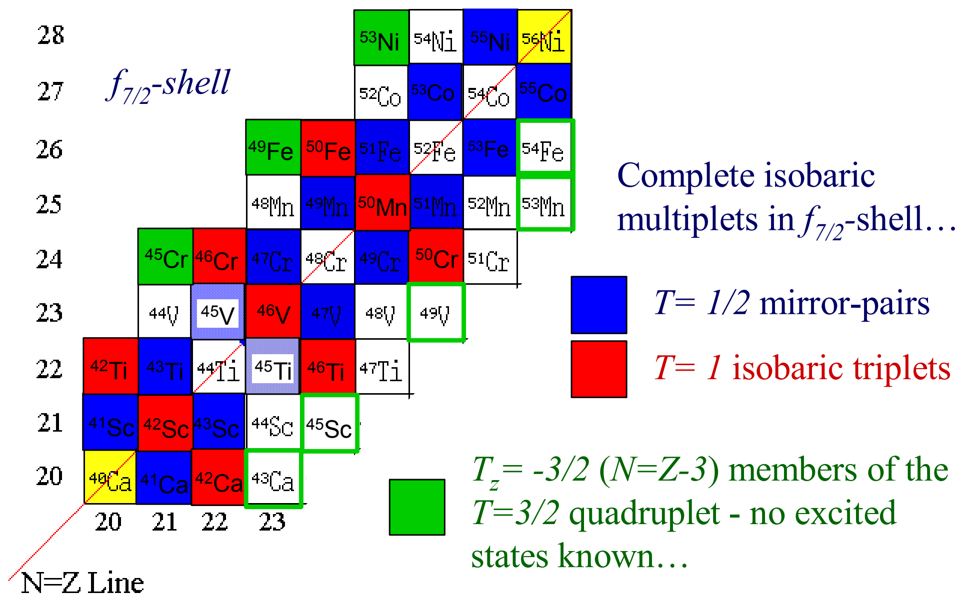
New Shell Structure at N>>Z – Relativistic Coulex in N=28-34 and N=40-50 Nuclei

Isospin Symmetry and Coulomb Effects Towards the Proton Drip-Line

RISING

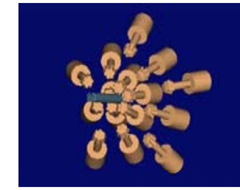


N~Z Collaboration (Keele, Daresbury, Lund, Surrey, York, GSI)
Spokesperson: M.A.Bentley (Keele University, U.K.)



- First identification of excited states in the T_z= -3/2 nuclei ^{45}Cr and ^{53}Ni identify ***T=3/2*** mirror pairs in $f_{7/2}$-shell
- Isospin symmetry and Coulomb effects towards the proton drip-line – *rigorous test of full fp-shell model*

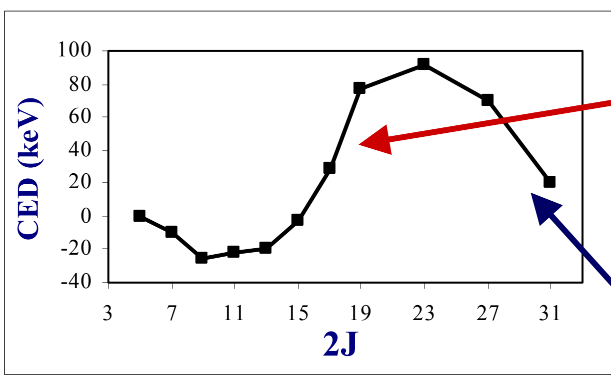
Isospin Symmetry and Coulomb Effects Towards the Proton Drip-Line



Studies of Coulomb energy differences (CED) as a function of spin are a remarkably sensitive probe of changes in nuclear structure…

- Spatial correlations of pairs of protons (pair alignments etc…)
- Changes in bulk deformation, and different orbital radii,
- Band-termination effects, etc.

- T=1/2 mirror pair $^{49}Mn/^{49}Cr$ - Coulomb Energy Differences
- CED defined as… $CED(J) = Ex(J)_{T_z -ve} - Ex(J)_{T_z +ve}$



Alignment of pair of protons in ^{49}Cr (neutrons in ^{49}Mn)

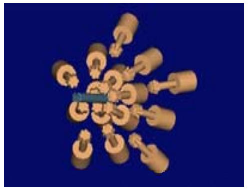
Proton alignments in ^{49}Mn (neutrons in ^{49}Cr)

C.D. O'Leary, M.A.Bentley et al. Phys. Rev. Lett ***79****(1997)4349*

- T=1 triplet, A=50 mirror pair $^{50}Fe/^{50}Cr$ (current limit)

S.M.Lenzi et al PRL ***87****(2001)122501*

Isospin Symmetry and Coulomb Effects Towards the Proton Drip-Line



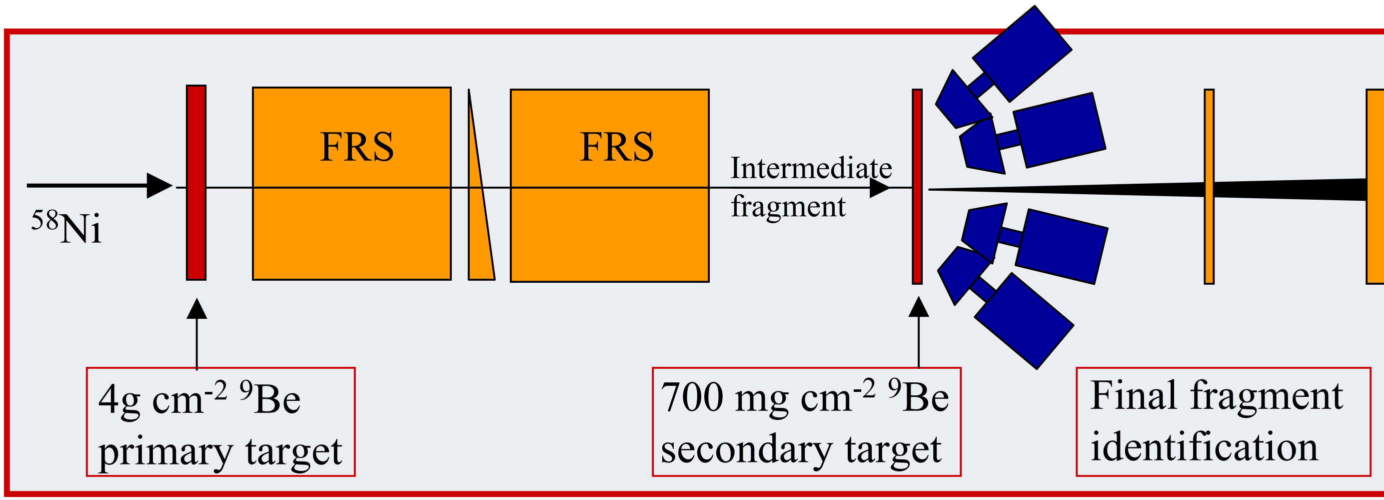
T=3/2 mirror-pairs?

- Large proton-excess, large difference in *Z* between mirrors
- Larger "one-body" contributions to CED (e.g. orbital radii)?
- Towards the drip line - how well does isospin symmetry hold?
- Coulomb distortions of proton wave-functions?
- Stringent test of shell-model

Isospin Symmetry and Coulomb Effects Towards the Proton Drip-Line

Experiment...

Nuclei of interest produced at RISING target via two-step fragmentation of ^{58}Ni.



- Largest production rate achieved when intermediate fragment is one or two nucleons away from nucleus of interest
(i.e. for ^{45}Cr, the intermediate fragment will be ^{46}Cr or ^{47}Cr).

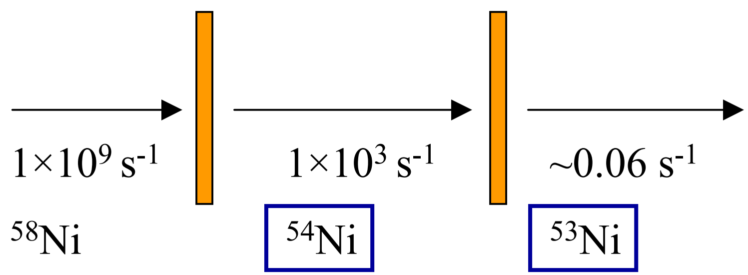
- Prompt gammas recorded using RISING, and fragments identified downstream (CATE) to produce fragment-gated gamma-ray spectra.

- Spectra recorded for ^{45}Cr and ^{53}Ni, and also their mirror partners - ^{45}Sc and ^{53}Mn. Level schemes constructed by comparison of “mirror spectra” and known levels of T_z=+3/2 nuclei.

Rate calculations…

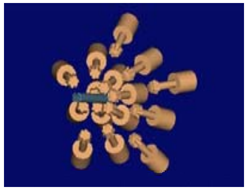
- FRS set up to choose one specific intermediate fragment (ε_{FRS} = 0.25, targets 4 g cm^{-2} (FRS) and 700 mg cm^{-2} (RISING))
- 1×10^{9} pps ^{58}Ni, primary and secondary cross-sections from *EPAX*

Example: ^{53}Ni



- Assume a gamma-ray transition in ^{53}Ni from a state populated with a 50% probability. Require few 100 counts in peak for identification. With ε_{RISING}= 0.03, yields 300 photo-peak counts in 12 shifts.
- 4 shifts required for same intensity for ^{45}Cr transitions.
- Require one shift each for the higher-yield mirror partners (^{45}Sc and ^{53}Ni) - to obtain "mirror-spectra" for comparison.
- Estimate three additional shifts for optimisation of FRS, 2 shifts for changes of FRS settings

γ-decay of the GDR in the Exotic Nucleus ^{68}Ni Excited via Coulomb Excitation

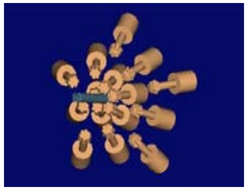


Collaboration: Angela Bracco et al. University of Milano, A. Maj et al. University of Cracow, T. Aumann et al. GSI, G. de Angelis et al. LNL Italy, S. Lenzi et al., University of Padua, C. Petrache et al. University of Camerino, G. La Rena, University of Napels, F. Azaiez, CEA Orsay

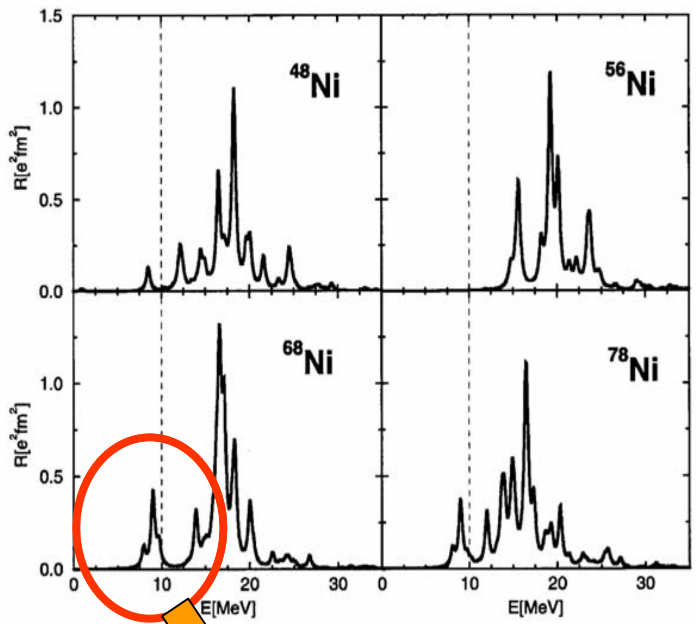
Spokesperson: **Angela Bracco University of Milano,**

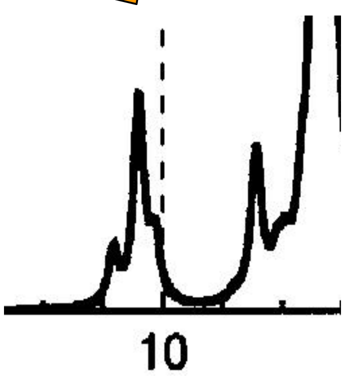
- **Giant Resonances are simple excitation modes to learn about nuclear structure and effective N-N interaction**
- **For GDR is on discussion how its strength function evolves when going from stable to exotic nuclei**
- **In neutron rich nuclei some GDR strength is shifted at low energy (Pygmy Resonance) and this has astrophysical implication**

γ-decay of the GDR in the Exotic Nucleus ^{68}Ni Excited via Coulomb Excitation

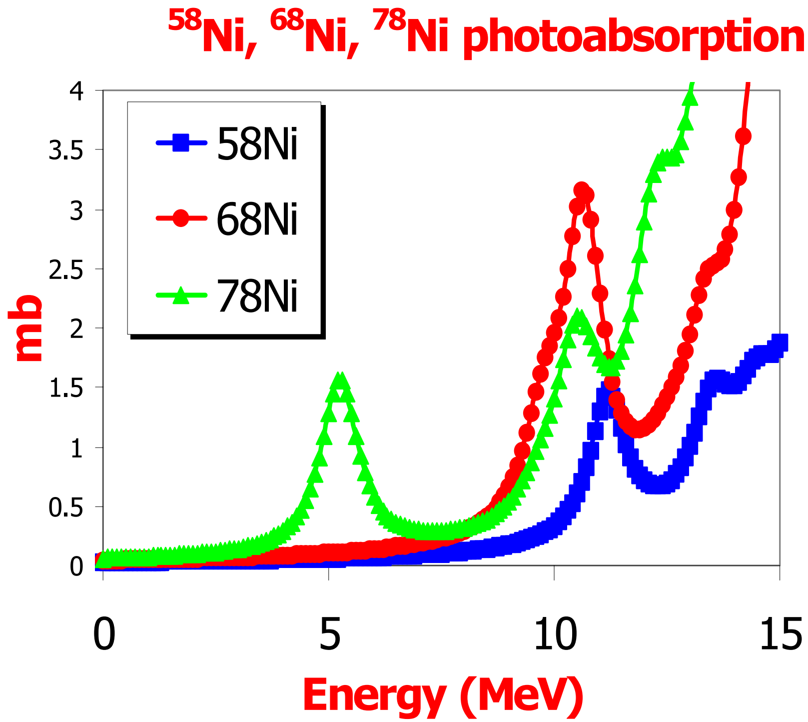


Relativistic RPA (Vretenar et al.)



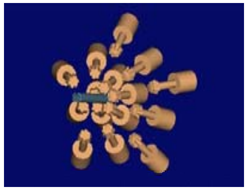


RPA (Colo' et al.)



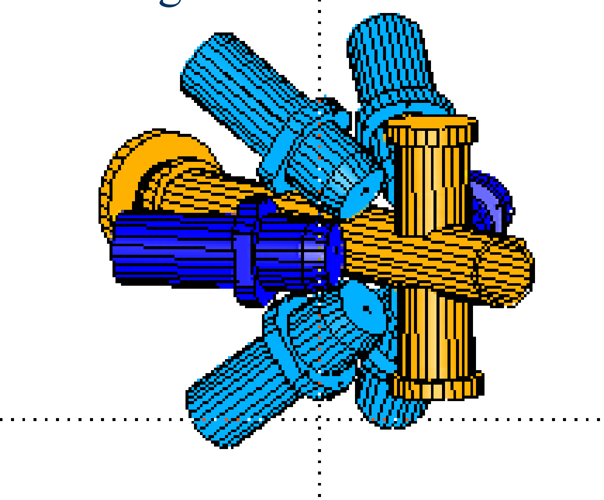
Both theories predict ≈ 10% of the strength function at ≈10 MeV for ^{68}Ni (Pygmy Resonance)

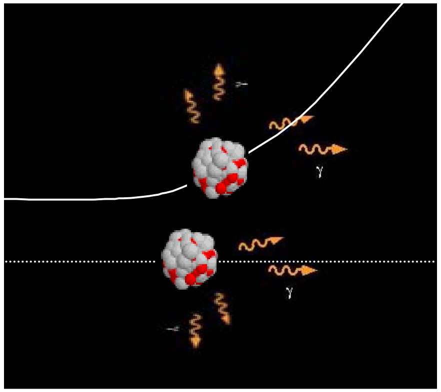
γ-decay of the GDR in the Exotic Nucleus ^{68}Ni Excited via Coulomb Excitation

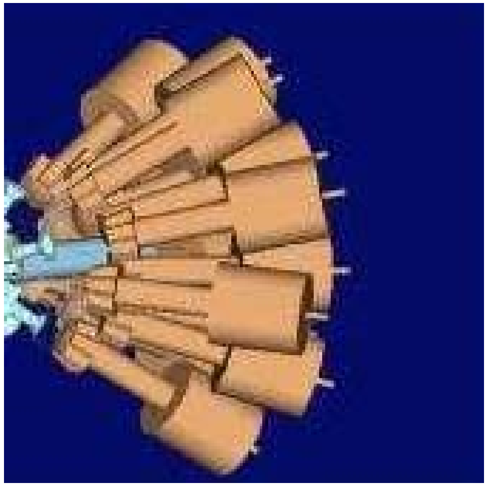


Experimental Details

BaF_2 for the whole GDR strength function

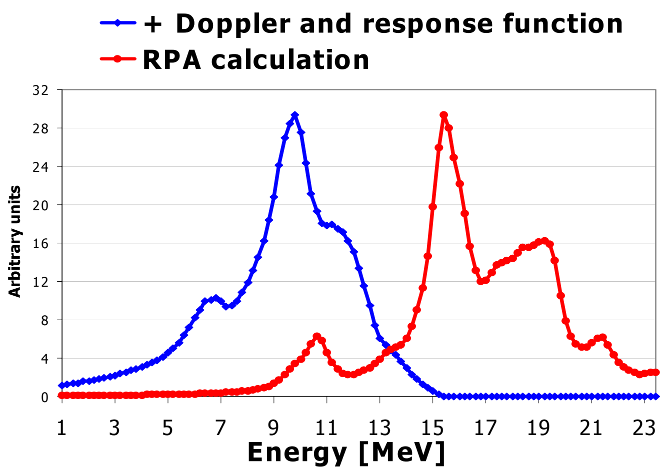




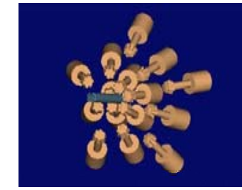


Rising for the Pygmy part

^{68}Ni (400 MeV/A) + ^{nat}Pb (2 g/cm^2)



The detector response for the ^{68}Ni GDR if BaF_2 are placed at backward angles is shifted by ≈5 MeV. This allows to separate target emission which is at rest and centered at 14 MeV γ-decay of the GDR in the Exotic Nucleus ^{68}Ni Excited via Coulomb Excitation



Count rate estimates

^{68}Ni beam from fragmentation of ^{86}Kr (10^{10} pps) on ^{9}Be $\Rightarrow$ **2.5 10^4 pps**

^{68}Ni (400 MeV/A) + ^{nat}Pb (2 g/cm^2)

σ_{coul} = 600 mb (E ≈ 15 MeV)
σ_{coul} = 150 mb (E ≈ 10 MeV)
ε_{BaF2} (10 MeV) = 1.1 %
ε_{Rising} (15 MeV) = 0.4 %
γ-decay branch = 2 %

BaF_2 : Cts/day (5-13 MeV) ≈ 2514 (60 in 0.2 MeV bins)

HpGe : Cts/day (15-17 MeV) ≈ 230

2^+ peak gated by the whole GDR: Cts/day ≈ 70

Concluding Remarks

- This experiment is complementary to the work done by the LAND group using the break-up fragment and neutrons (virtual photon absorption).

- The two methods are independent from each other and allow for a cross checking.

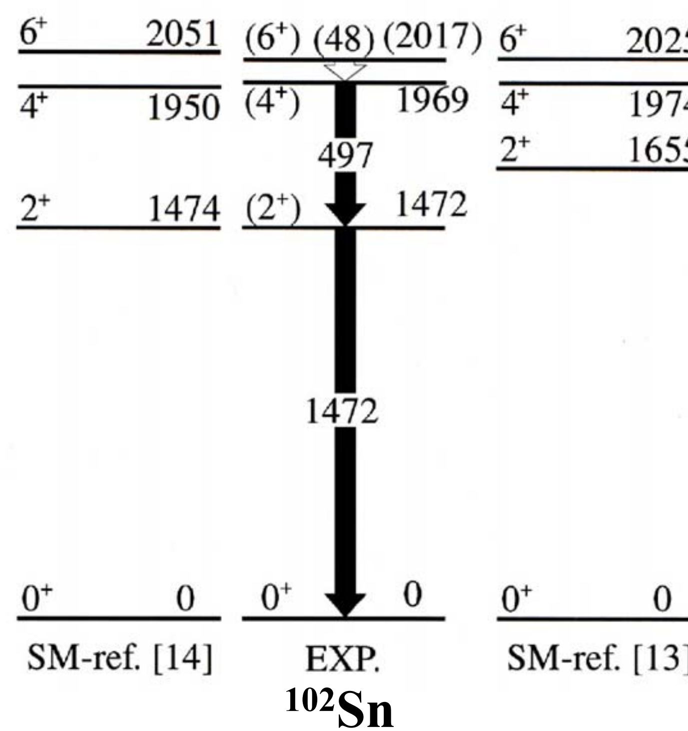
- The gamma measurement may provide a better resolution allowing to resolve fine structure.

Relativistic Coulomb Excitation of Nuclei Near ^{100}Sn

Collaboration: C. Fahlander et al. Lund University, M. Gorska et al. GSI, J. Nyberg et al. Uppsala University, B. Cederwall et al. Royal Institute of Technology, Stockholm, M. Benteley Keele University, G. de Angelis et al. LNL Italy, M. Palacz et al. Warsaw University, D. Sohler et al. Institute for Nuclear Research, Debrecen, P. Nolan et al. Liverpool University

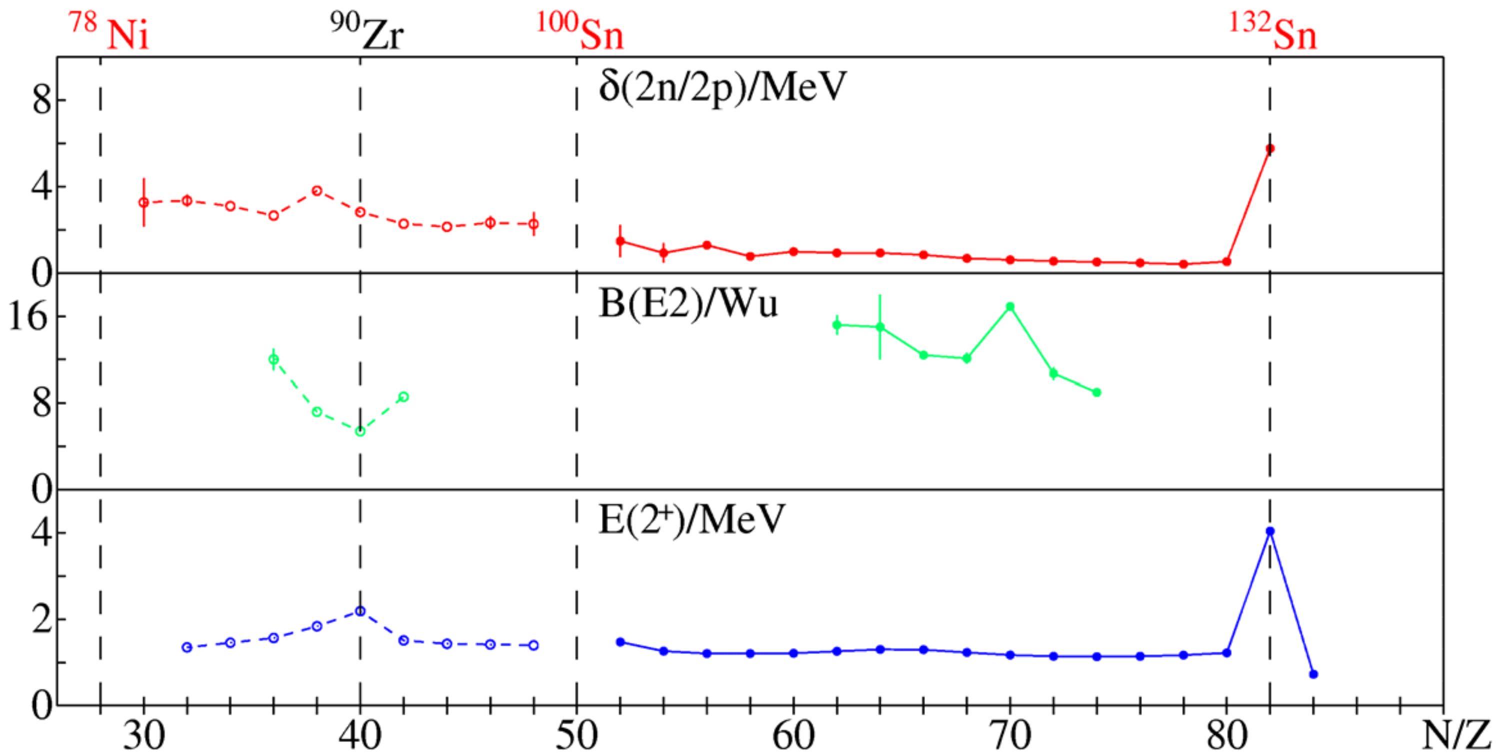
Spokesperson: **C. Fahlander, Lund University, M. Gorska, GSI**

- **Future experiments (next generation of RIB facility) will allow spectroscopy of ^{100}Sn.**
- **Closest neighbours to ^{100}Sn with measured excited states are ^{102}Sn and ^{98}Cd.**
- **Lifetimes and decay schemes of low-lying isomeric 6+ states in even Sn up to ^{102}Sn are known.**



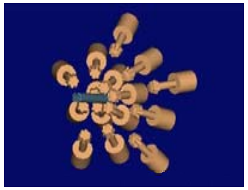
Lipoglavsek et al. PLB 440 (1998)246

Relativistic Coulomb Excitation of Nuclei Near ^{100}Sn



- $B(E2,2^+\text{->}0^+)$ values will provide sensitive measure of the E2 correlations related to core polarization.
- Lifetime measurements by Doppler methods are hampered by higher lying isomeric states.
- States decay too fast for electronic timing methods.
- Coulomb excitation is only way to obtain $B(E2,2^+\text{->}0^+)$ values

Relativistic Coulomb Excitation of Nuclei Near ^{100}Sn



Nuclei of interest:

Z=50 isotopes $^{104,106,108,110}Sn$

N=50 isotones ^{94}Ru, ^{96}Pd, ^{98}Cd

- Odd Sn isotopes -> stretched E2 transitions between $2d_{5/2}$ - $3s_{1/2}$ states.

Count rate estimates for ^{104}Sn

Coulomb excitation

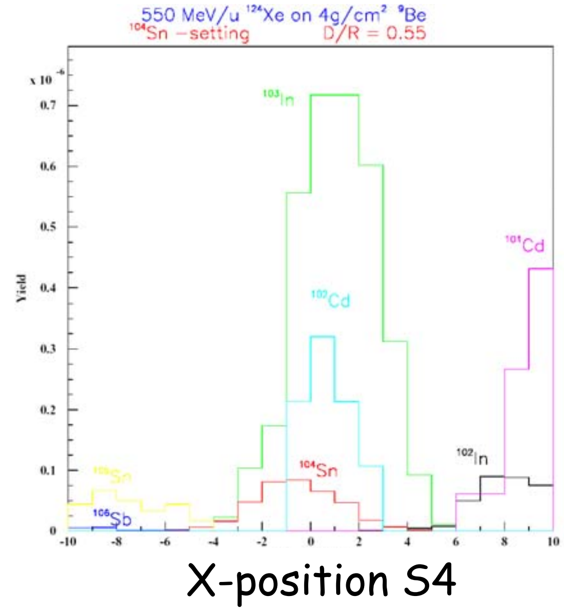
^{104}Sn (95 MeV/A) -> ^{208}Pb (200 mg/cm^2)

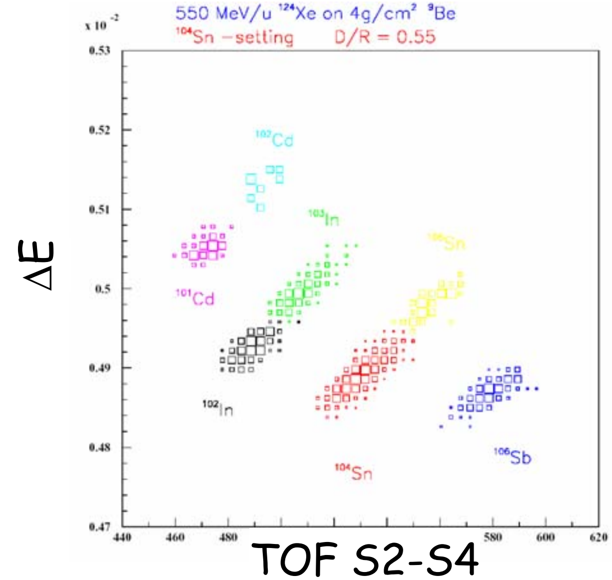
σ_{coul} = 200 mb (E ≈ 1.47 MeV)

ε_{Rising} = 3.0 % (E ≈ 1.3 MeV)

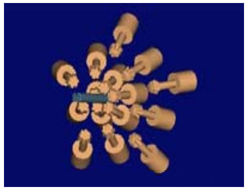
Yield of ^{104}Sn at S4: 370 pps

Estimated pγ rate for ^{104}Sn (2^+): 3/h





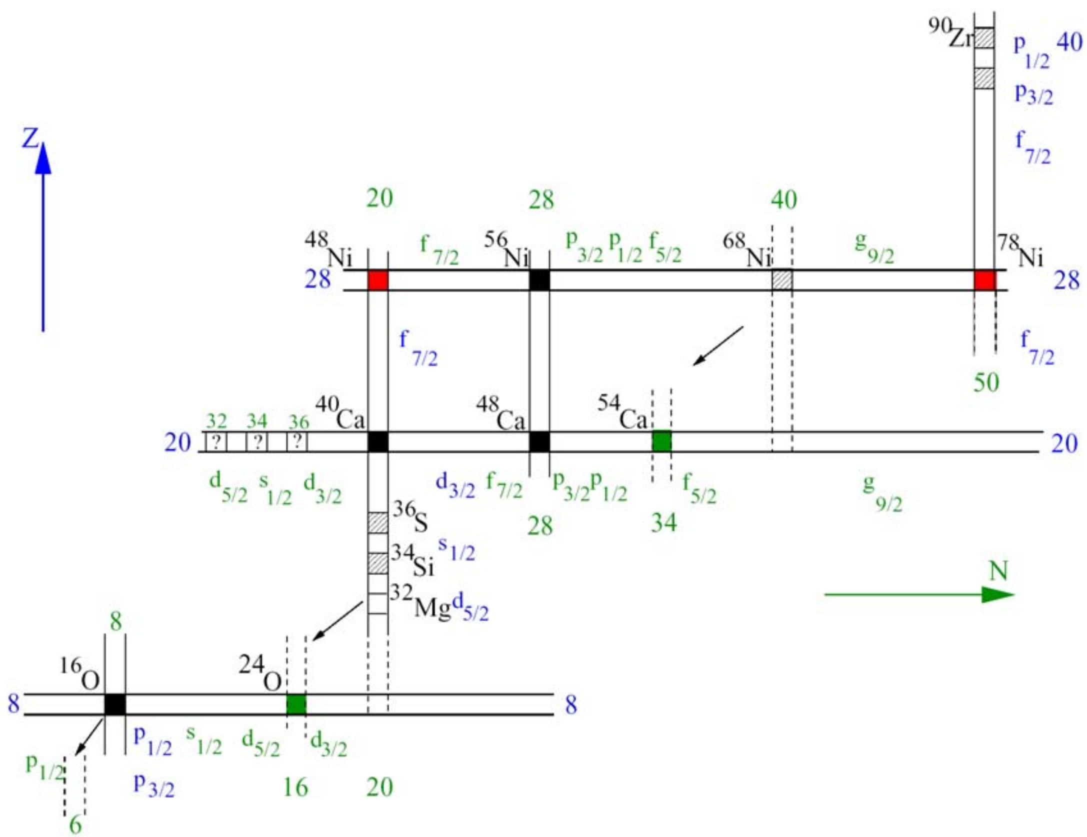
Relativistic Coulomb Excitation of Nuclei Near ^{100}Sn



Isotope	$\sigma(^{124}Xe)$ [mb]	$I_{p\gamma}$/h
^{104}Sn	$5.6\ 10^{-3}$	3
^{105}Sn	$5.0\ 10^{-2}$	27
^{106}Sn	0.3	161
^{107}Sn	1.3	170
^{108}Sn	3.7	490
^{109}Sn	7.4	~500
^{110}Sn	11.3	~500
^{112}Sn	12.4	~500
^{96}Pd	$6.4\ 10^{-2}$	30
^{94}Ru	2.9	~500

New Shell Structure at N>>Z – Relativistic Coulex in N=28-34, N=40-50 Nuclei

Collaboration:, H. Grawe, M. Gorska J. Döring, C. Plettner et al. GSI,
C. Fahlander et al. Lund University,
H. Hübel, A. Neusser, P. Bringel, A. Bürger, et al. Bonn University,
P. Reiter, et al. Cologne University
Spokesperson: **H. Grawe GSI, H. Hübel Bonn University,**
P. Reiter, Cologne University



- **N~50 isotones**
- **Ni isotopes N>68**

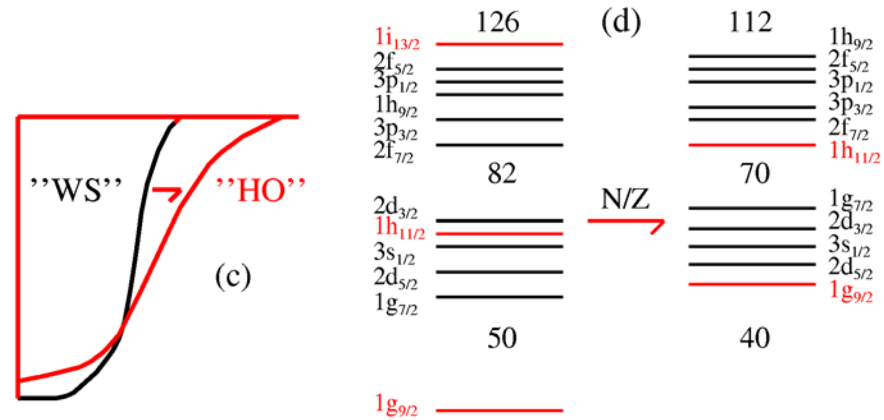
- **Ca isotopes, N~34**

New Shell Structure at N>>Z – Relativistic Coulex in N=28-34, N=40-50 Nuclei

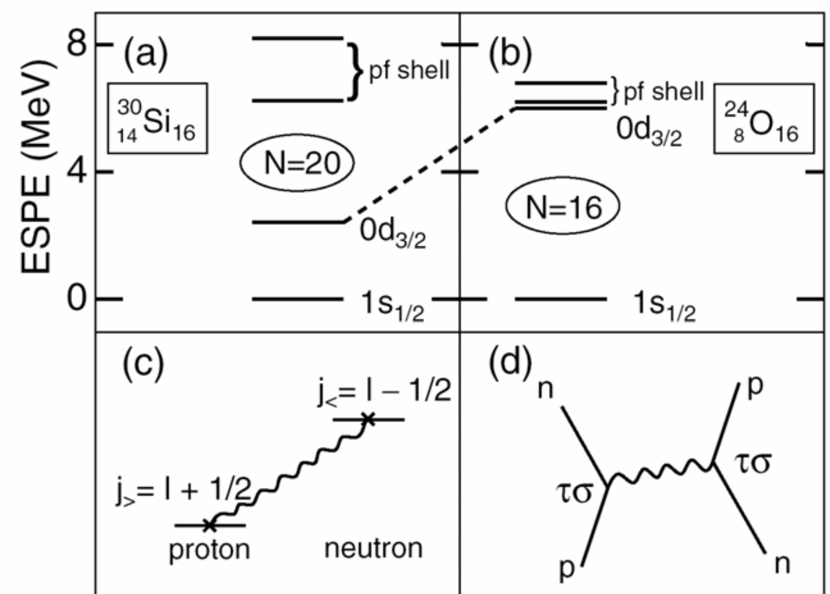
RISING

Reduced spin-orbit LS splitting:
- Neutron excess->Modified weaker surface slope of neutron potential.
- Woods-Saxon shape changes towards harmonic oscillator.
- LS splitting ~ potential slope harmonic oscillator magic numbers.

Increased spin-orbit LS splitting:
- Monopole part of nucleon-nucleon residual interaction strongest in the S=0 (spin-flip) and T=0 (isospin-flip, proton-neutron) channel of the two body interaction.
- Missing S=0 proton partners at N>>Z cause monopole shifts of neutron single particle orbits.
- New shell gaps



Dobaczewski et al. PRL 72 (1994) 981



Otsuka et al. PRL 87 (2001) 082502

New Shell Structure at N>>Z – Relativistic Coulex in N=28-34, N=40-50 Nuclei

Sub shell closure at N=32,34?

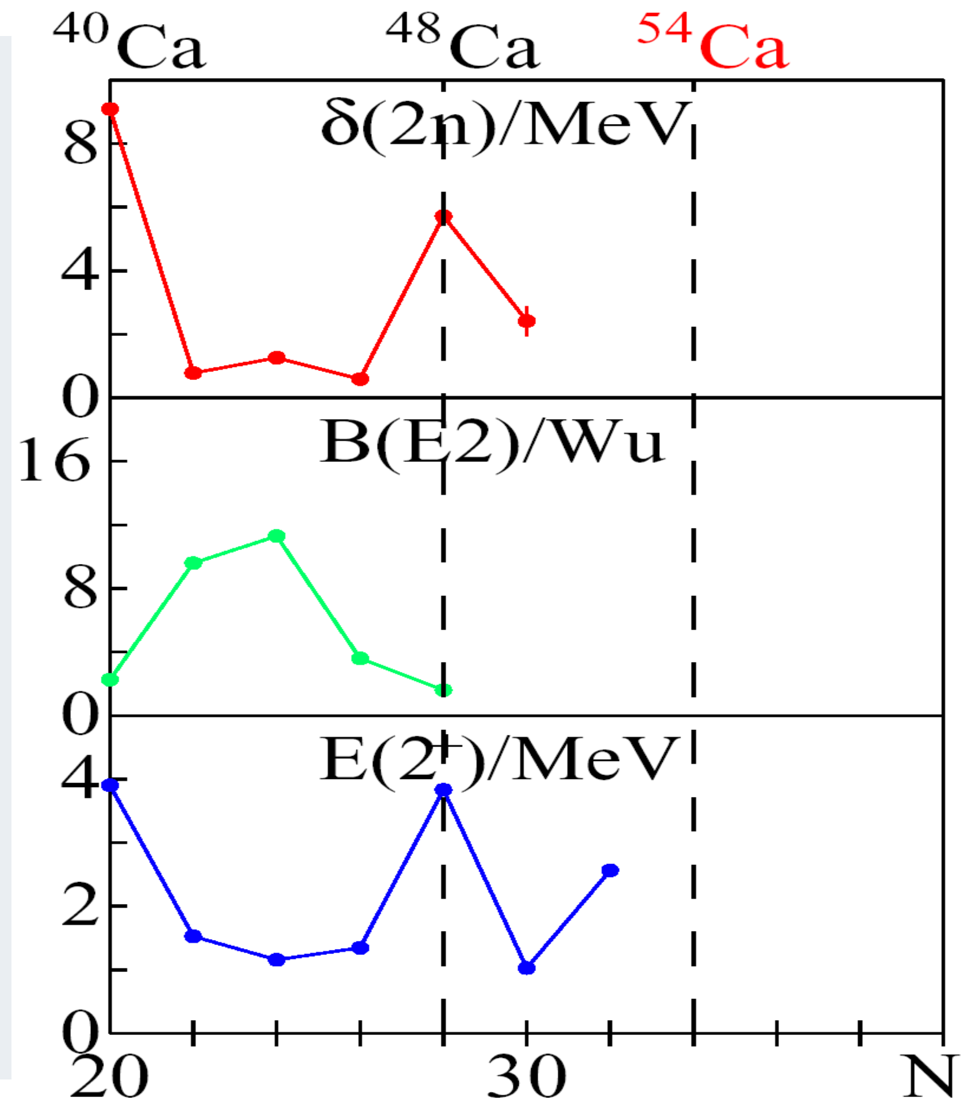
- Ca Isotopes: ^{52}Ca E(2⁺) energy

- Cr Isotopes: Maximum E(2⁺) energy at N=32

- N=34 isotones: increasing E(2⁺) energy from Fe to Cr

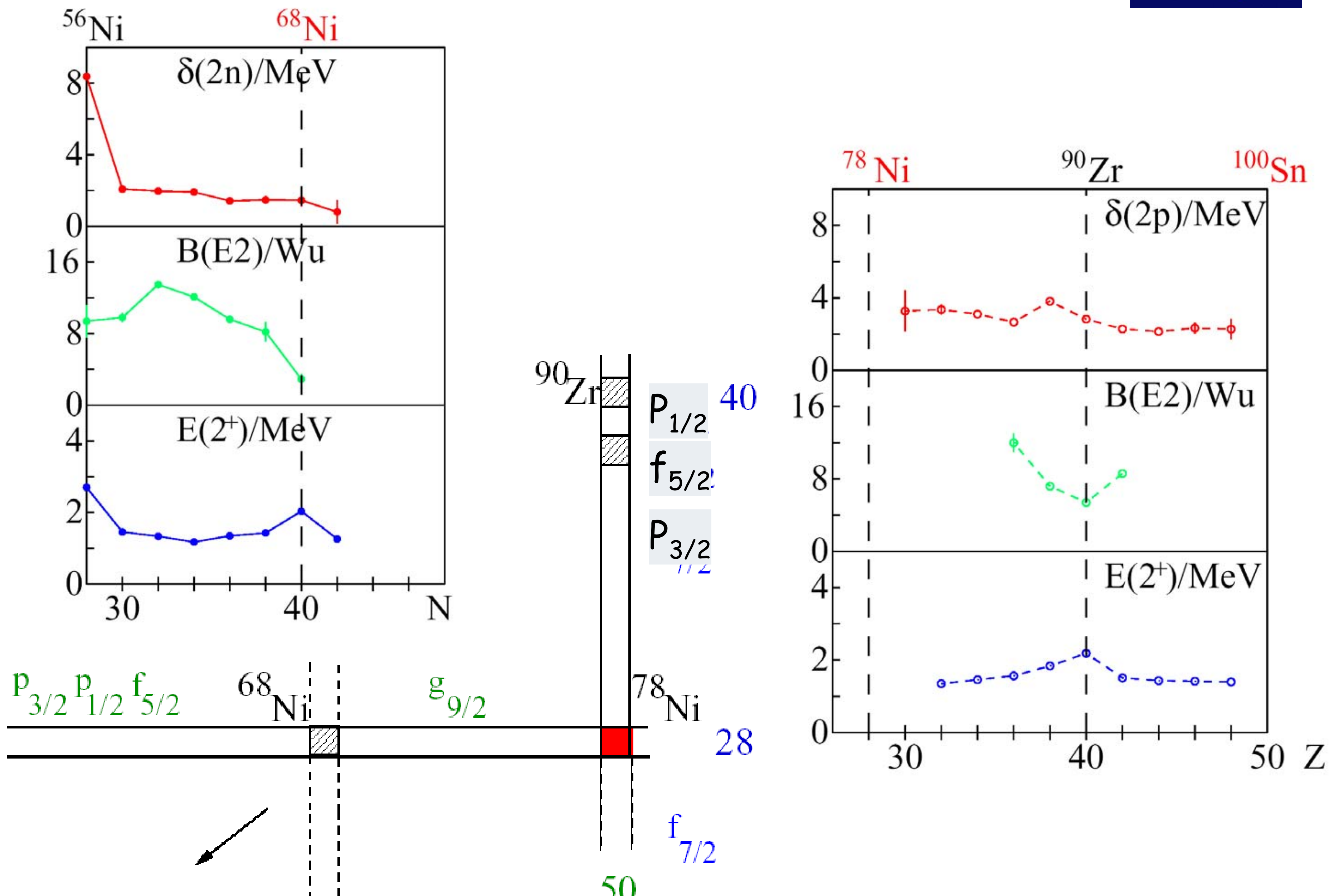
Experiments:
-Masses are challenging

-E(2⁺) energies, B(E2) values in N=30-34 nuclei of Ca, Cr, Ti



RISING

New Shell Structure at N>>Z – Relativistic Coulex in N=28-34, N=40-50 Nuclei



RISING

New Shell Structure at N>>Z – Relativistic Coulex in N=28-34, N=40-50 Nuclei

Count rate estimates:

- ^{50}Ca, N=30

^{50}Ca (108 MeV/A) -> ^{208}Pb (1000 mg/cm^2)

Yield of ^{50}Ca at S4: 263 pps

Estimated pγ rate for ^{50}Ca (2^+): 14/h

- ^{66}Fe, N=40

^{66}Fe (130 MeV/A) -> ^{208}Pb (1000 mg/cm^2)

Yield of ^{50}Ca at S4: 177 pps

Estimated pγ rate for ^{66}Fe (2^+): 34/h

- ^{82}Ge, N=50

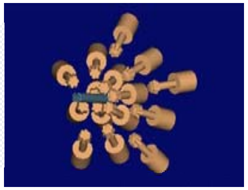
^{82}Ge (133 MeV/A) -> ^{208}Pb (200 mg/cm^2)

Yield of ^{82}Ge at S4: 620 pps

Estimated pγ rate for ^{82}Ge (2^+): 50/h

RISING

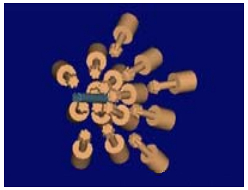
New Shell Structure at N>>Z – Relativistic Coulex in N=28-34, N=40-50 Nuclei



Count Rate Estimates

Isotope	$\sigma(^{82}Se)$ [b]	$\sigma(^{86}Kr)$ [b]	I_{RIB} [pps]	$I_{p\gamma}$/h	Priority/Comment
^{50}Ti	$2.3\ 10^{-3}$	$1.5\ 10^{-3}$	$2.5\ 10^{5}$	4500	I calibration
^{52}Ti	$3.2\ 10^{-4}$	$1.5\ 10^{-4}$	$2.5\ 10^{4}$	1540	I
^{54}Ti	$2.3\ 10^{-5}$	$8.2\ 10^{-6}$	1350	83	I
^{56}Ti	$1.0\ 10^{-6}$	$2.6\ 10^{-7}$	40	2	I difficult
^{82}Ge	-	$8.7\ 10^{-7}$	620	50	II
^{84}Se	-	$4.7\ 10^{-4}$	$3.3\ 10^{5}$	29	II
^{86}Kr	-	-	10^{6}	-	II calibration
^{58}Cr	$1.0\ 10^{-4}$	$3.7\ 10^{-5}$	8700	678	III
^{60}Fe	$2.7\ 10^{-3}$	$1.3\ 10^{-3}$	$3.5\ 10^{5}$	1380	III calibration
^{66}Fe	$2.8\ 10^{-6}$	$4.5\ 10^{-7}$	177	34	
^{68}Fe	$1.5\ 10^{-7}$	$1.4\ 10^{-8}$	5.5	1.1	not feasible
^{70}Ni	$4.0\ 10^{-5}$	$3.5\ 10^{-6}$	1380	130	GANIL?
^{72}Ni	$2.5\ 10^{-6}$	$1.8\ 10^{-7}$	83	9	III
^{74}Ni	$1.4\ 10^{-7}$	$8.7\ 10^{-9}$	4	0.4	not feasible
^{50}Ca	$4.5\ 10^{-6}$	$1.6\ 10^{-6}$	263	14	III
^{52}Ca	$1.4\ 10^{-7}$	$3.6\ 10^{-8}$	6	0.01	not feasible

Summary Fast beam Experiments



	Sec. beam	NoI	pγ coinc
Isospin Symmetry, Coulomb Effects Towards the Proton Drip-Line	^{46}Cr 1 10^{3} pps	^{45}Cr	18 h^{-1}
	^{46}Ti 2 10^{3} pps	^{45}Sc	440 h^{-1}
	^{54}Ni 8 10^{2} pps	^{53}Ni	10 h^{-1}
	^{54}Fe 2 10^{3} pps	^{53}Mn	580 h^{-1}
Relativistic Coulomb Excitation of Nuclei Near ^{100}Sn	^{108}Sn 4 10^{4} pps	^{108}Sn	490 h^{-1}
	^{104}Sn 4 10^{2} pps	^{104}Sn	3 h^{-1}
γ-decay of the GDR in ^{68}Ni Excited via Coulomb Excitation	^{68}Ni 2 10^{4} pps	^{68}Ni	6 h^{-1}
		pBaF:	64 h^{-1}
New Shell Structure at N>>Z Relativistic Coulex in N=28-34 and N=40-50 Nuclei	^{50}Ca 263 pps	^{50}Ca	14 h^{-1}
	^{66}Fe 177 pps	^{66}Fe	34 h^{-1}
	^{82}Ge 620 pps	^{82}Ge	50 h^{-1}