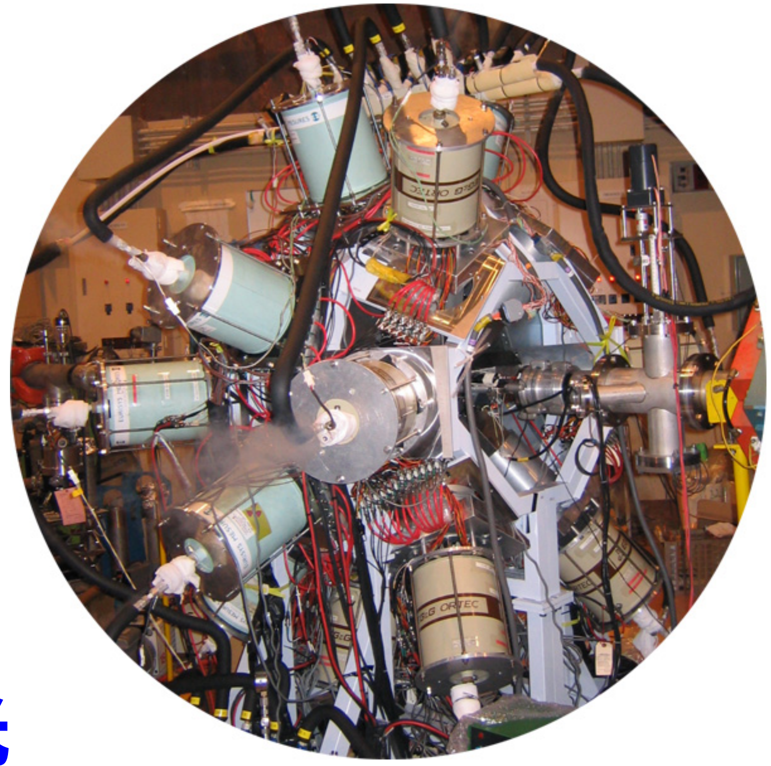


東北大サイクロにおけるγ線核分光

東北大学サイクロトロンRIセンター
東北大学大学院理学研究科
鈴木 智和

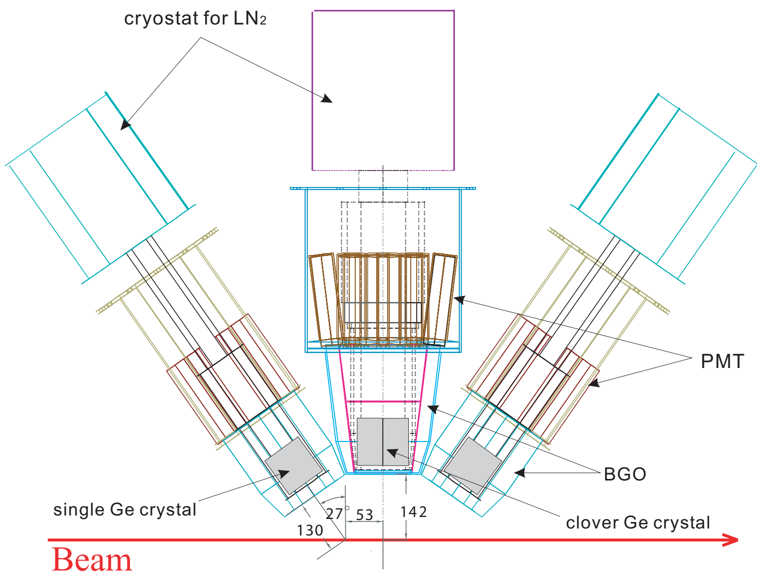
February 19-20, 2006

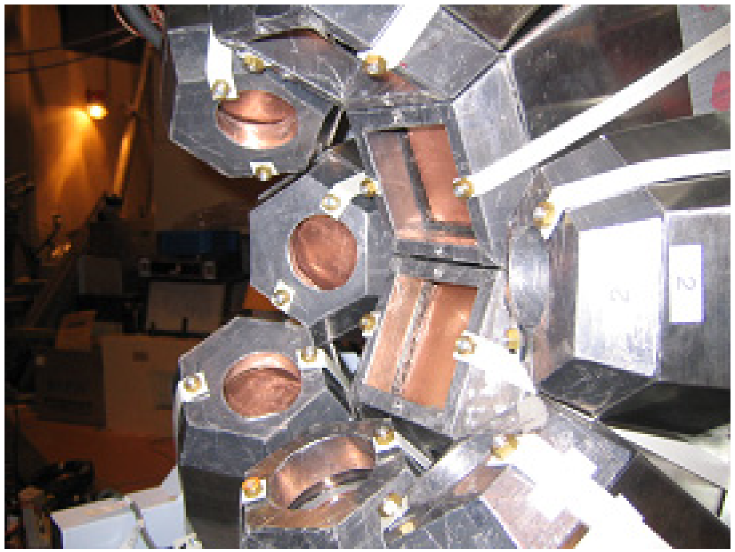
Contents

1. Hyperball-2
   - Detectors, Advantages, Disadvantages
   - BGO anti-Compton supressor
   - FERA-VME DAQ system
2. Nuclear Chirality
   - Criteria for Nuclear Chirality
   - Lifetime Measurements in the $A \sim$130 region
   - Chiral Candidates and Possible Existance in the $A \sim$100 region
3. Experiments with Hyperball-2
   - Spectra, Linear Polarization
   - Experiment Result
4. Possible experiments for nuclear chirality in RCNP

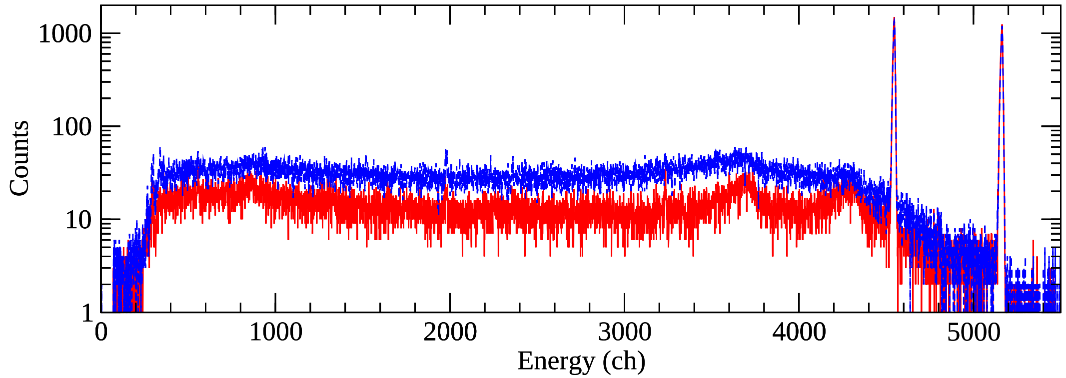
Hyperball-2

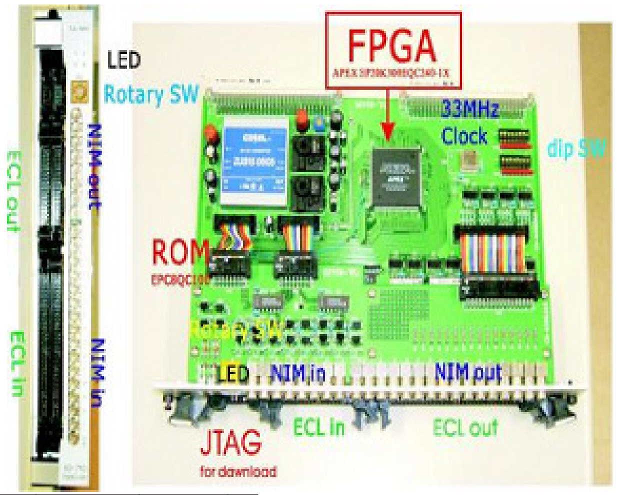
- Total of 20 detectors
  - Photo peak efficiency ∼4% at 1MeV
    - ∗ Eurisys Coaxial Ge + BGO (R.E. 60%, ×4)
    - ∗ ORTEC Coaxial Ge + BGO (R.E. 60%, ×10)
    - ∗ Eurisys Clover Ge + BGO (R.E. 20%×4,125% with addback ×4)
- Advantages
  - Large total photo peak efficiency (γ-γ-γ coincidence measurement)
  - Possible to use with high intensity (∼10pnA) beam (high counting rate).
- Disadvantages
  - Few angles
    - ∗ Detectors placed mostly around 90°. (lower angular correlation sensitivity)
  - Detectors in upper and lower ring point off center





BGO anti-Compton suppressor



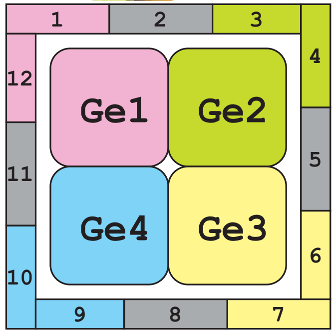


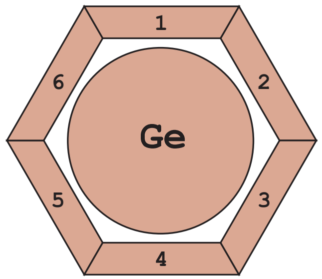
Ge-1 $\times$ $\overline{\text{BGO1} \cup \text{BGO2} \cup \text{BGO11} \cup \text{BGO12}}$

Ge-2 $\times$ $\overline{\text{BGO2} \cup \text{BGO3} \cup \text{BGO4} \cup \text{BGO5}}$

Ge-3 $\times$ $\overline{\text{BGO5} \cup \text{BGO6} \cup \text{BGO7} \cup \text{BGO8}}$

Ge-4 $\times$ $\overline{\text{BGO8} \cup \text{BGO9} \cup \text{BGO10} \cup \text{BGO11}}$





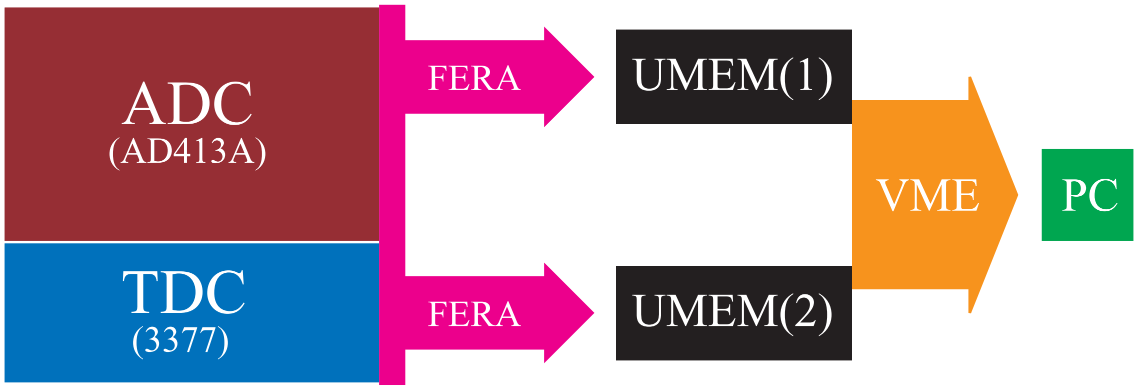
12 BGO + 1 Ge = 13 TUL IN channels
$\longrightarrow$ 78 TUL IN channels for 6 Clovers

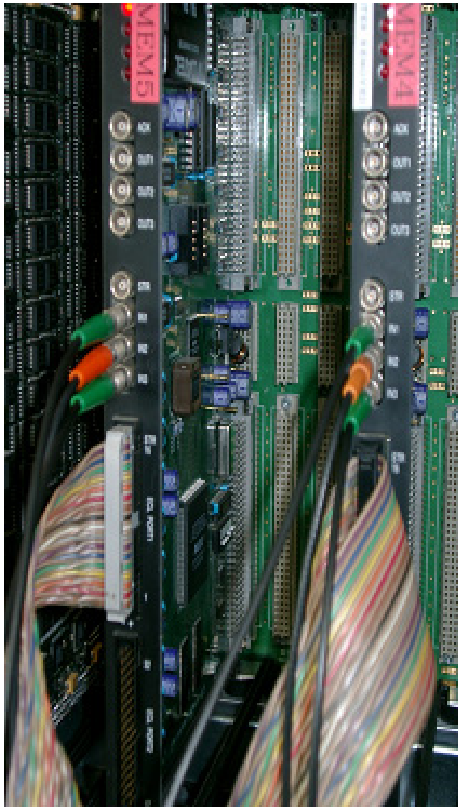
32 ECL IN + 16 NIM IN = 48 IN per TUL

Peak/Total	BGO OFF	BGO ON
Normal type	~18%	~32%
Clover(individual)	~10%	~15%
Clover(add-back)	~20%	~30%

FERA-VME Double Buffer Data Taking System

- Switching of two memory modules controled by TUL
  - No dead time for data transfer from ADC/TDC to UMEM
    (VME universal memory module developed by Osaka Univ.)
  - For 1 event data size = 100byte
  - FERA ADC,TDC $\longrightarrow$ UMEM   29μsec/event
    - $*$ Conversion time of ADC   24μsec/event
    - $*$ data transfer(20Mbyte/sec)   5μsec/event
  - UMEM $\longrightarrow$ PC (5Mbyte/sec)   20μsec/event



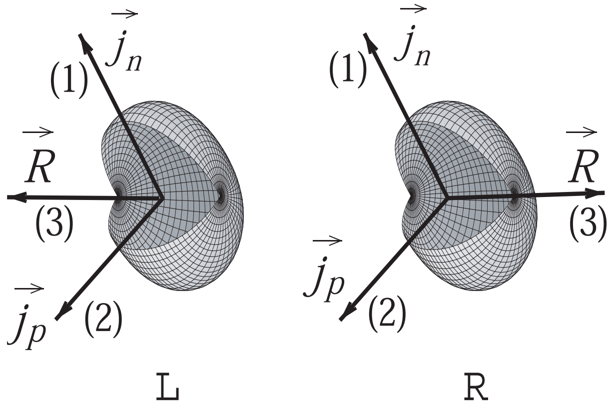


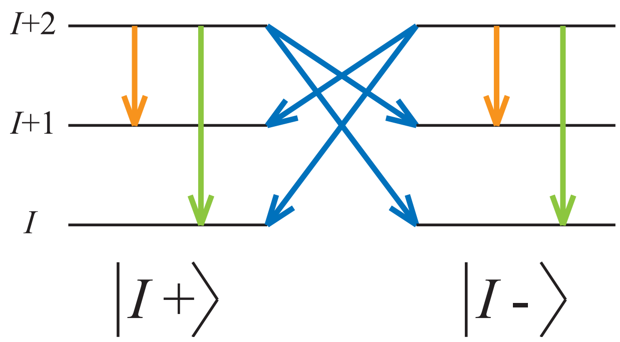
Nuclear Chirality

- For mass 80 region $(\pi g_{9/2} \otimes \nu g_{9/2}^{-1})$

  1. 1-axis: longest axis of the triaxial shape
     j_n; neutron-hole in a high-j_n shell
  2. 2-axis: shortest axis
     j_p; proton-particle in a high-j_p shell
  3. 3-axis : intermediate axis of the triaxial shape
     R; core rotation

- Three perpendicular angular momentum can be formed into two systems of handedness, the right-handed or the left-handed system





$$[O, H] = 0$$

$$O = TR(\pi)$$

$$H\,|IR\rangle = \epsilon_R\,|IR\rangle\,, \quad H\,|IL\rangle = \epsilon_L\,|IL\rangle$$

$$O\,|IR\rangle = |IL\rangle\,, \quad O\,|IL\rangle = |IR\rangle$$

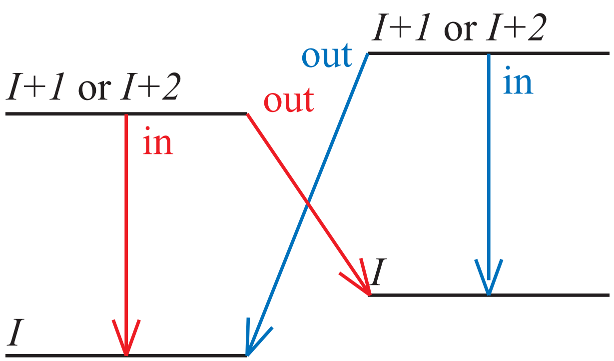
$$\epsilon_R = \epsilon_L$$

$$\begin{cases} |IM+\rangle = \frac{1}{\sqrt{2}}(|L\rangle + |R\rangle) \\ |IM-\rangle = -\frac{i}{\sqrt{2}}(|L\rangle - |R\rangle) \end{cases}$$

Criteria for Nuclear Chirality

- Nearly degenerate $\Delta I = 1$ twin bands with the same parity
  - observed in some odd-odd and odd-A nuclei in A ~130 region (proton $h_{11/2}$ particle and neutron $h_{11/2}$ hole configuration)
    - ^{124,126,128,130,132}Cs, ^{130,132,134}La, ^{132,134}Pr, ^{136}Pm, ^{138,140}Eu, ^{135}Nd, ^{135}Ce
  - observed in some odd-odd and odd-A nuclei in A ~100 region (proton $g_{9/2}$ hole and neutron $h_{11/2}$ particle configuration)
    - ^{107}Ag, ^{102,103,104,105,106}Rh, ^{100}Tc

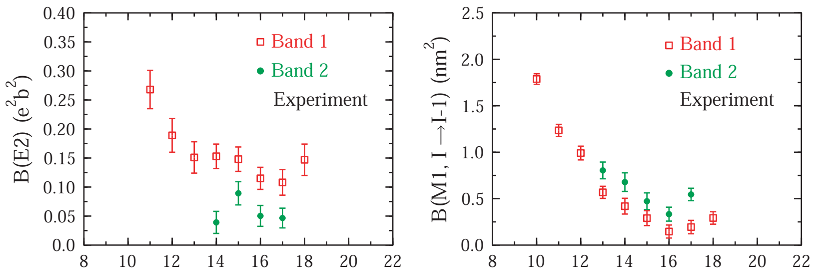
- $B(E2 : I \rightarrow I-2)_{\text{in,out}}$ and $B(M1 : I \rightarrow I-2)_{\text{in,out}}$ values are the same or similar between both bands.
  - lifetime measurements are required.
    - measured in ^{134}Pr, ^{132}La, and ^{128}Cs
    - GS plus plunger experiment done for ^{103,104}Rh (RDDS; Recoil Distance Doppler shit Method)



Lifetime measurements in the mass 130 region

Lifetime measurement in ^{134}Pr

- Euroball IV + Cologne plunger device
- RDDS/DSAM

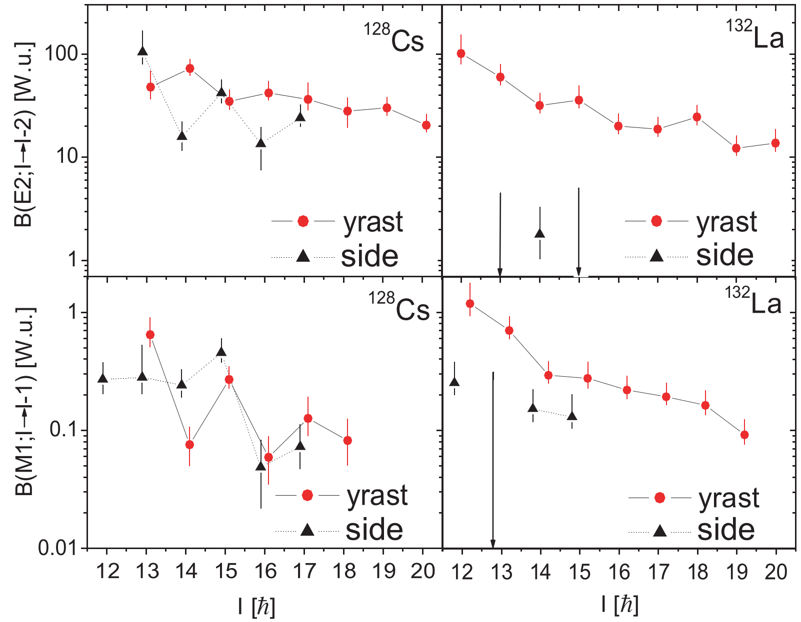


From D. Tonev et. al. Phys Rev. Lett. 96 (2006) 052501

^{128}Cs is best chiral cadidates!

Lifetime measurement in ^{128}Cs, ^{132}La

- OSIRIS II (Warsaw)
- DSAM

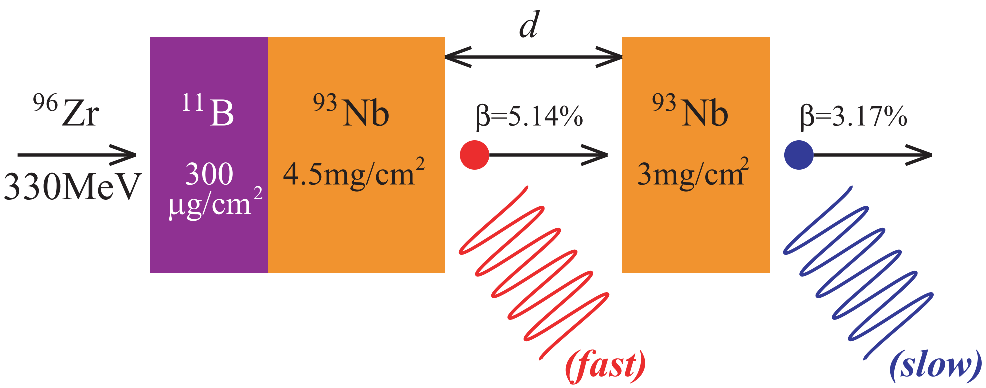


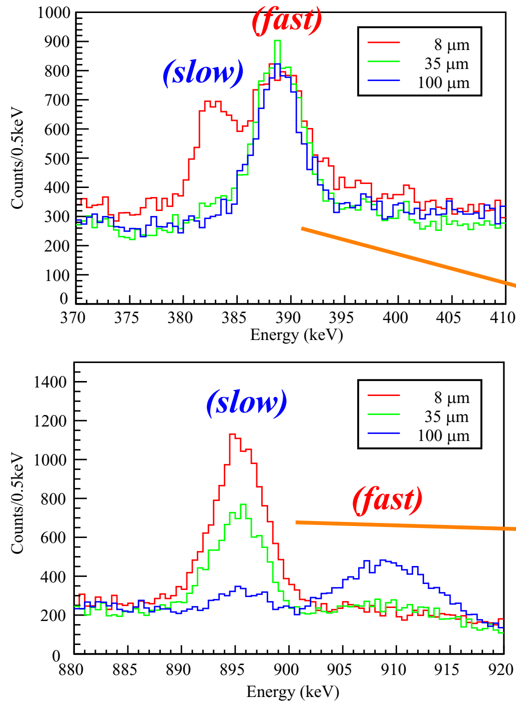
From E. Grodner et. al. Phys Rev. Lett. 97 (2006) 172501

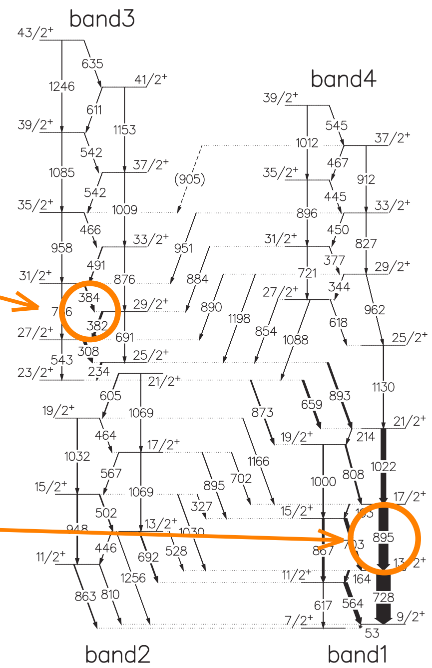
GAMMASPHERE GSFMA169

Lifetime measurement of candidates chiral members in the $A \sim 100$ region

- Recoil Distance Doppler Shift Method (RDDS)
  - GAMMASPHERE Ge detectors array (Total 17-rings, 110 detectors with BGO-ACS)
  - Cologne univ. plunger device
- Inverse Kinematics Reaction
  - ^{11}B(^{96}Zr,xn)^{104,103}Rh (x=3,4)
  - E(^{96}Zr) = 330MeV from ATLAS accelerator at ANL
  - 7 distances (8,15,23,35,50,75,100 μm)

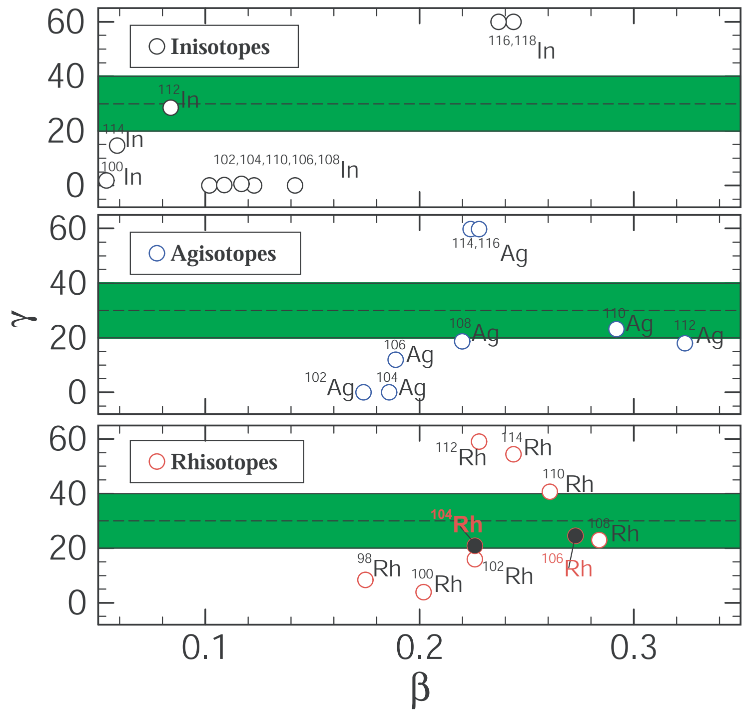






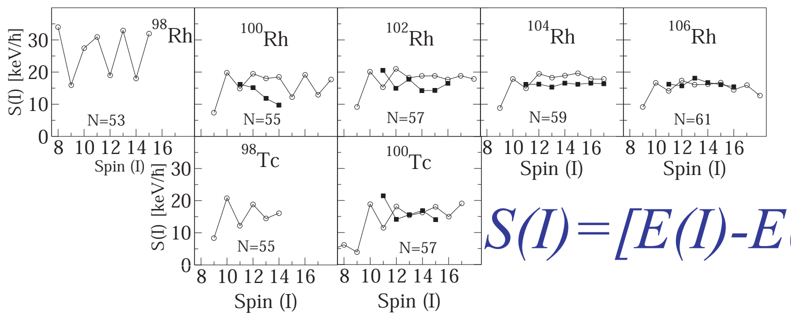
From J. Timar et. al. Phys Rev C 73 (2006) 011301

Chiral Candidates and possible existence in the $A \sim 100$ region



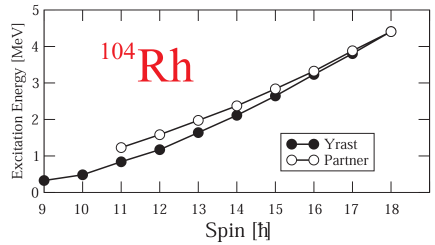
^{104}In	^{105}In	^{106}In	^{107}In	^{108}In	^{109}In	^{110}In	^{111}In	^{112}In	^{113}In	^{114}In	^{115}In	^{116}In	49
^{103}Cd	^{104}Cd	^{105}Cd	^{106}Cd	^{107}Cd	^{108}Cd	^{109}Cd	^{110}Cd	^{111}Cd	^{112}Cd	^{113}Cd	^{114}Cd	^{115}Cd	48
^{102}Ag	^{103}Ag	^{104}Ag	^{105}Ag	^{106}Ag	^{107}Ag	^{108}Ag	^{109}Ag	^{110}Ag	^{111}Ag	^{112}Ag	^{113}Ag	^{114}Ag	47
^{101}Pd	^{102}Pd	^{103}Pd	^{104}Pd	^{105}Pd	^{106}Pd	^{107}Pd	^{108}Pd	^{109}Pd	^{110}Pd	^{111}Pd	^{112}Pd	^{113}Pd	46
^{100}Rh	^{101}Rh	^{102}Rh	^{103}Rh	^{104}Rh	^{105}Rh	^{106}Rh	^{107}Rh	^{108}Rh	^{109}Rh	^{110}Rh	^{111}Rh	^{112}Rh	45
^{99}Ru	^{100}Ru	^{101}Ru	^{102}Ru	^{103}Ru	^{104}Ru	^{105}Ru	^{106}Ru	^{107}Ru	^{108}Ru	^{109}Ru	^{110}Ru	^{111}Ru	44
^{98}Tc	^{99}Tc	^{100}Tc	^{101}Tc	^{102}Tc	^{103}Tc	^{104}Tc	^{105}Tc	^{106}Tc	^{107}Tc	^{108}Tc	^{109}Tc	^{110}Tc	43
55	56	57	58	59	60	61	62	63	64	65	66	67	

From J. Meng et. al. Phys. Rev. C 73 (2006) 037303



S(I)=[E(I)-E(I-2)]/2I

From P. Joshi et. al. J. Phys. Nucl. Part. Phys. 31 (2005) S1895-S1898



From C. Vaman et. al. Phys. Rev. Lett. 92 (2004) 032501

Nuclear Chirality in the A ~80 region

- proton $h_{11/2}$ particle and neutron $h_{11/2}$ hole configuration

$$\Updownarrow \text{ similar mechanism}$$

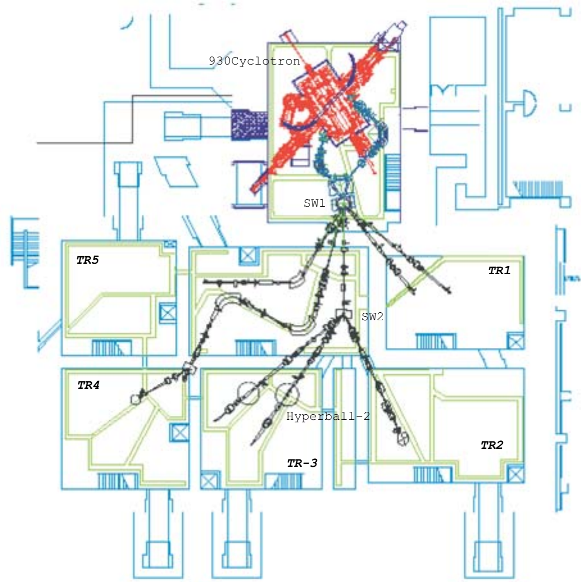
- proton $g_{9/2}$ particle and neutron $g_{9/2}$ hole configuration

Search for chiral doublet in the new mass region

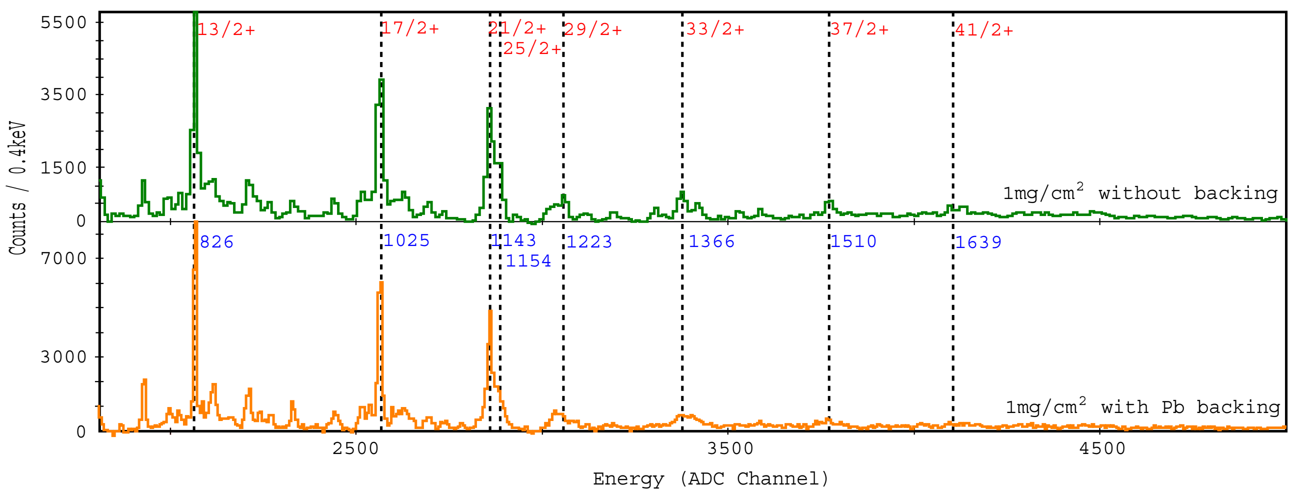
- ^{79}Kr (odd-A, $\pi g_{9/2}^2 \otimes \nu g_{9/2}^{-1}$)
- ^{80}Br (odd-odd, $\pi g_{9/2} \otimes \nu g_{9/2}^{-1}$)

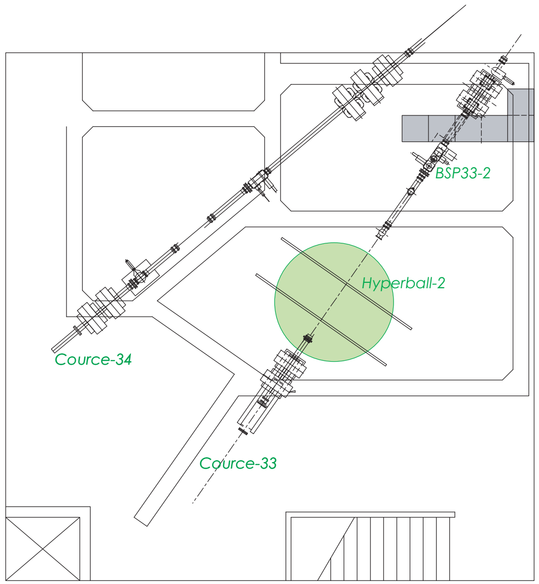
Experiment with Hyperball-2 in CYRIC

- Course 33 at CYRIC, Tohoku University
- Reaction and target
  - ^{70}Zn(^{13}C,4n)^{79}Kr
    - ∗ Beam: $^{13}C^{3+}$ @ 65MeV from 930 cyclotron
    - ∗ Target: 500μg/cm^2 $\times$ 2 70% enriched ^{70}Zn (self-supporting, stacked)
  - ^{70}Zn(^{13}C,p2n)^{80}Br
    - ∗ Beam: $^{13}C^{3+}$ @ 53MeV from 930 cyclotron
    - ∗ Target: 1mg/cm^2 70% enriched ^{70}Zn (Pb backing, 10mg/cm^2)

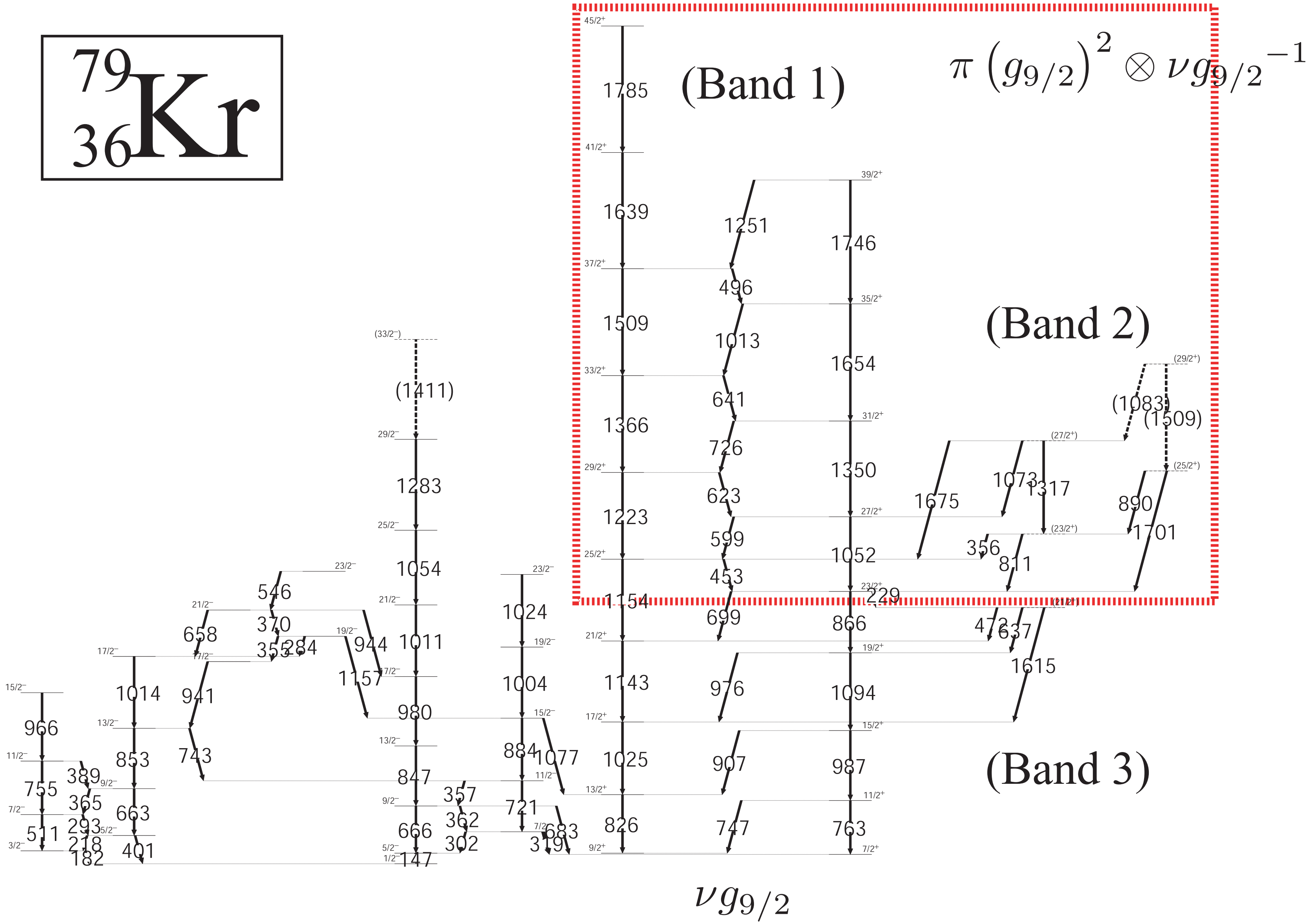


- HPGe array: Hyperball-2 for γ ray detection
- trigger: γ-γ-γ (triple coincidence)

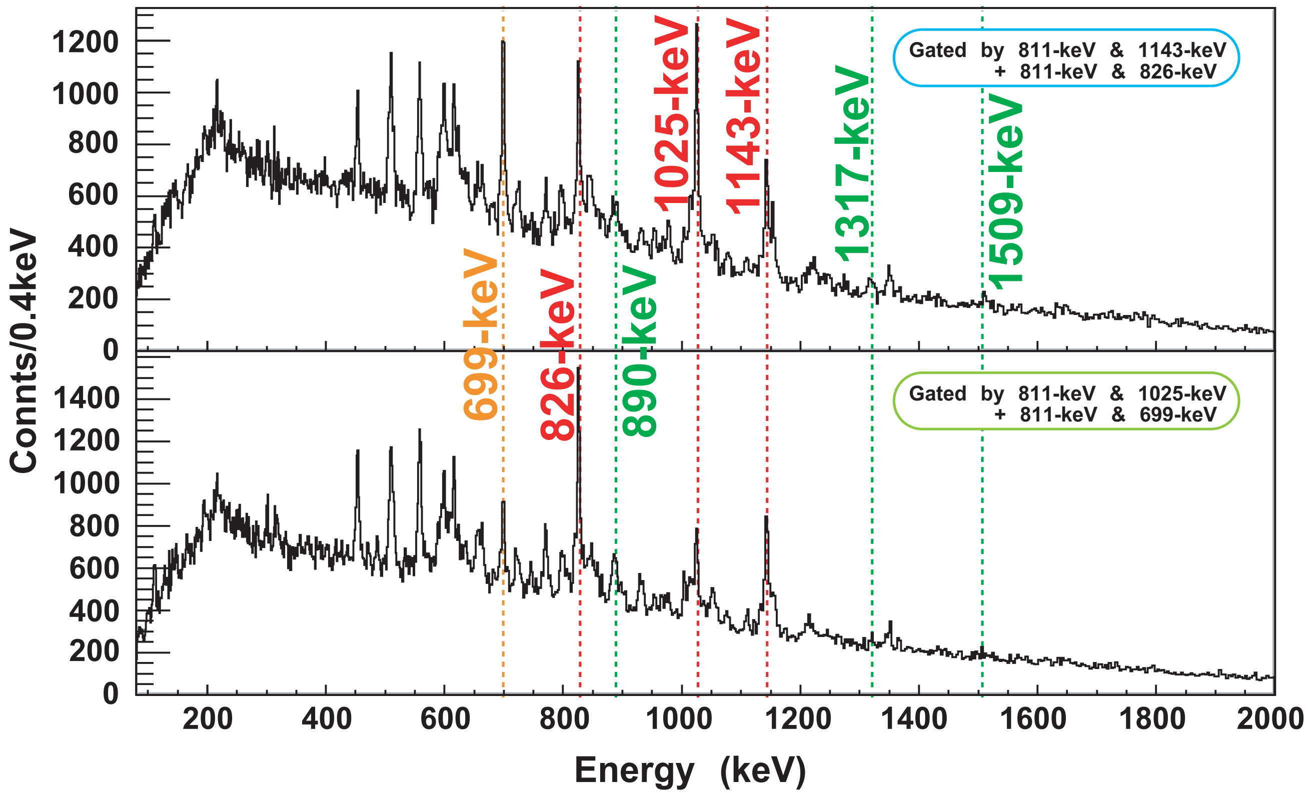


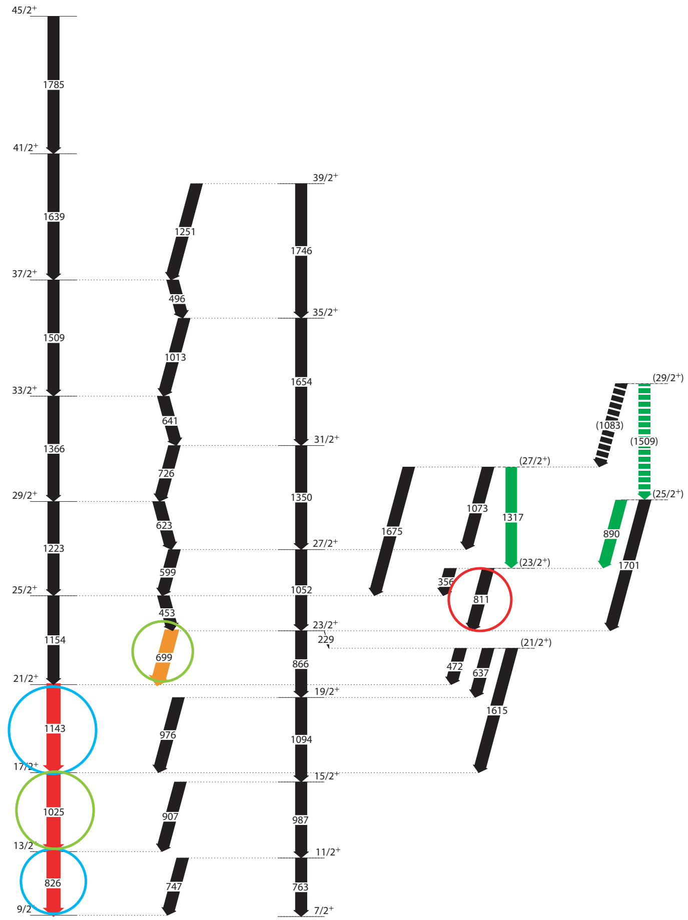


Deduced Level Scheme



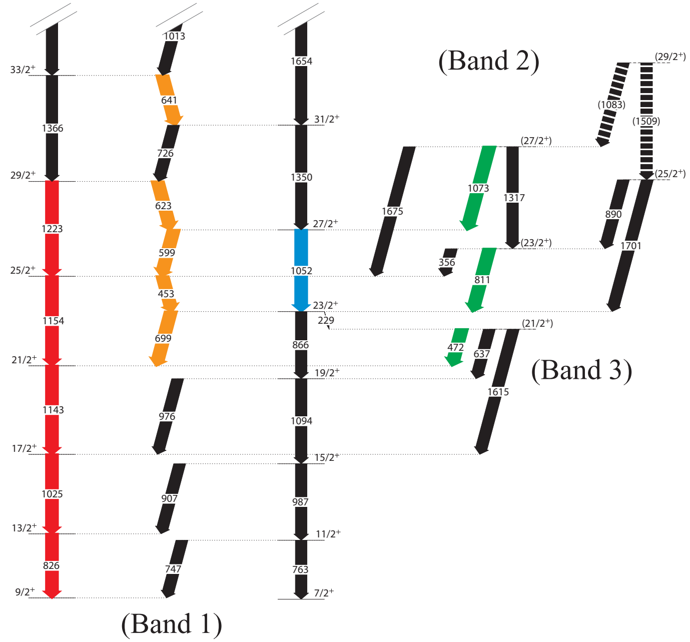
γ-γ-γ spectra


Gated by 811-keV & 1143-keV
+ 811-keV & 826-keV
Gated by 811-keV & 1025-keV
+ 811-keV & 699-keV
699-keV
826-keV
890-keV
1025-keV
1143-keV
1317-keV
1509-keV
Conts/0.4keV
Energy (keV)

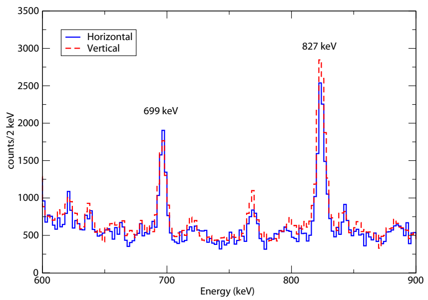


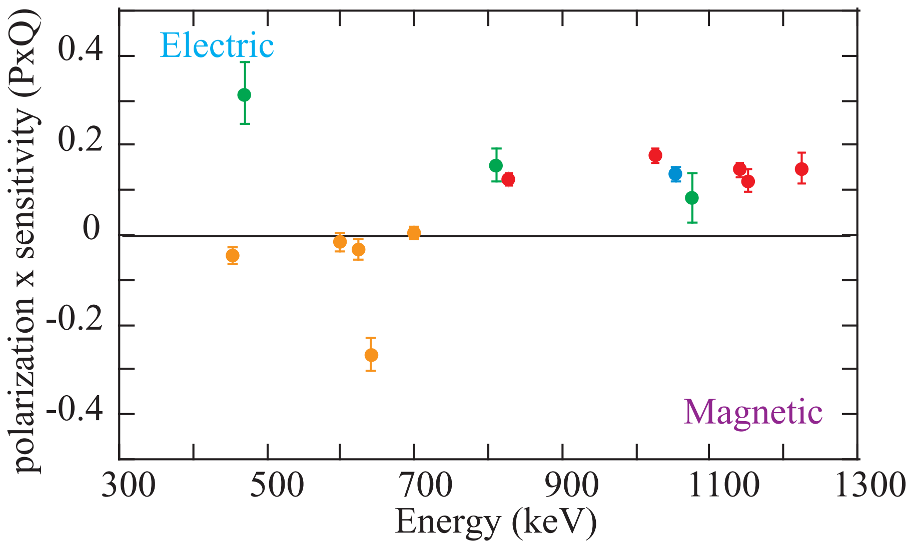
Relative spin-parity assignment

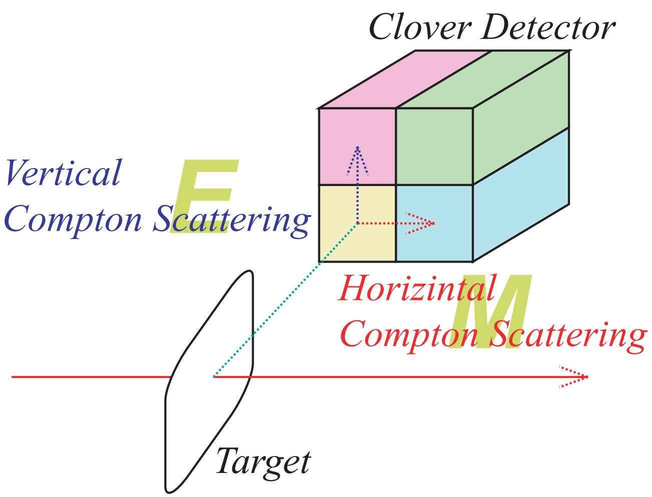
- Linear polarization can be extracted with clover detectors to infer relative spin and parity.
  - Sign of P can be known without knowing sensitivity $Q(E)$.

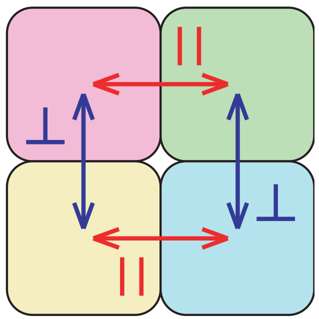


$$P = \frac{1}{Q}\frac{N_\perp - N_\parallel}{N_\perp + N_\parallel}$$

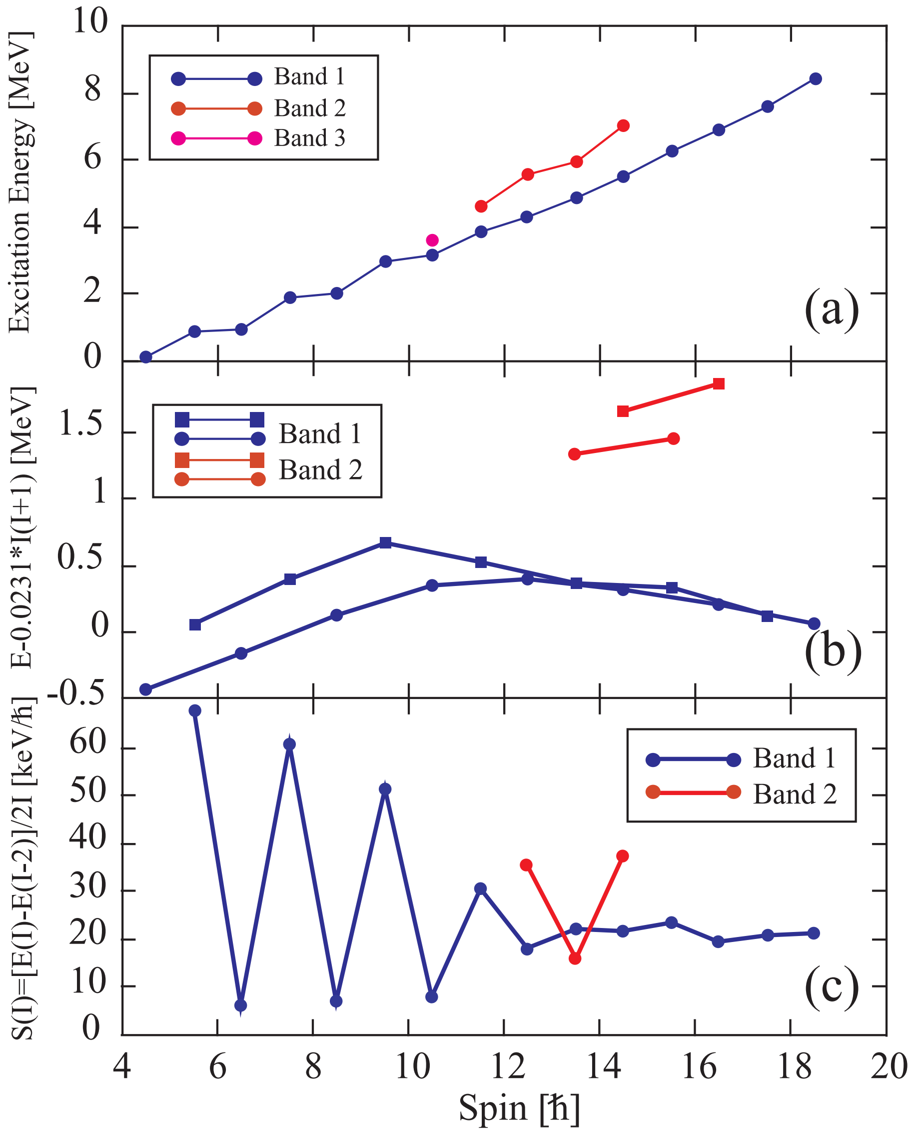








Discussion of result: ^{79}Kr

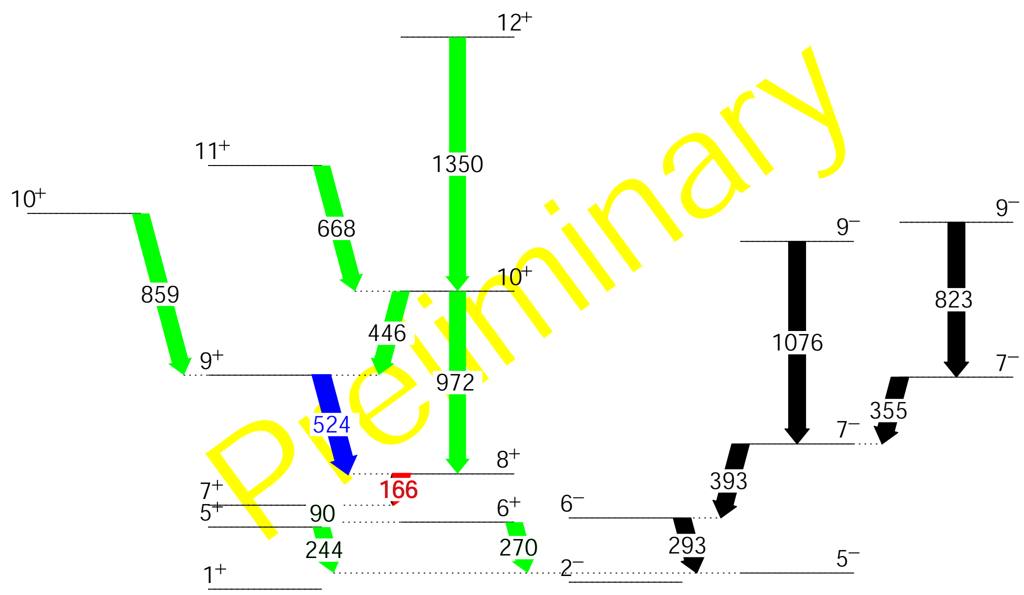


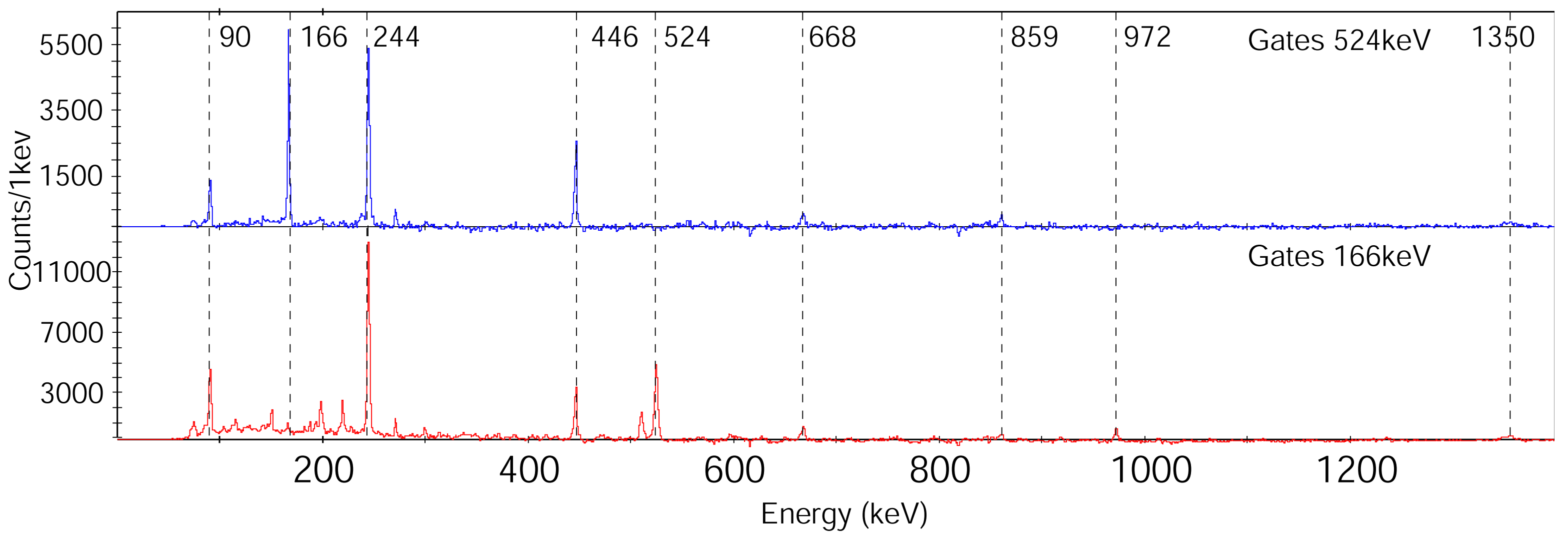
I	27/2	29/2	31/2	33/2
$E(I)_P - E(I)_Y$ in keV	811	1247	1079	1532

- If two bands are chiral partners...
  - Nearly degenerate between two bands.
  - Single particle states should be the same
  - $S(I) = [E(I) - E(I-2)]/2I$ should be smoothly varying.

The Current Result shows that the side band structures are of non chiral.

^{80}Br; ^{70}Zn(^{13}C,p2n)@54MeV





Possible experiments in RCNP

^{104}In	^{105}In	^{106}In	^{107}In	^{108}In	^{109}In	^{110}In	^{111}In	^{112}In	^{113}In	^{114}In	^{115}In	^{116}In	49
^{103}Cd	^{104}Cd	^{105}Cd	^{106}Cd	^{107}Cd	^{108}Cd	^{109}Cd	^{110}Cd	^{111}Cd	^{112}Cd	^{113}Cd	^{114}Cd	^{115}Cd	48
^{102}Ag	^{103}Ag	^{104}Ag	^{105}Ag	^{106}Ag	^{107}Ag	^{108}Ag	^{109}Ag	^{110}Ag	^{111}Ag	^{112}Ag	^{113}Ag	^{114}Ag	47
^{101}Pd	^{102}Pd	^{103}Pd	^{104}Pd	^{105}Pd	^{106}Pd	^{107}Pd	^{108}Pd	^{109}Pd	^{110}Pd	^{111}Pd	^{112}Pd	^{113}Pd	46
^{100}Rh	^{101}Rh	^{102}Rh	^{103}Rh	^{104}Rh	^{105}Rh	^{106}Rh	^{107}Rh	^{108}Rh	^{109}Rh	^{110}Rh	^{111}Rh	^{112}Rh	45
^{99}Ru	^{100}Ru	^{101}Ru	^{102}Ru	^{103}Ru	^{104}Ru	^{105}Ru	^{106}Ru	^{107}Ru	^{108}Ru	^{109}Ru	^{110}Ru	^{111}Ru	44
^{98}Tc	^{99}Tc	^{100}Tc	^{101}Tc	^{102}Tc	^{103}Tc	^{104}Tc	^{105}Tc	^{106}Tc	^{107}Tc	^{108}Tc	^{109}Tc	^{110}Tc	43
55	56	57	58	59	60	61	62	63	64	65	66	67	

1. RCNP can provide various heavy ion beam.
2. The germanium detectors array will be installed in EN cource.
   - 15 detectors
     $\Longleftrightarrow$ γ-γ-γ coincidence
   - 4 angles
     $\Longleftrightarrow$ determine transition multipolarity with angular distribution (DCO ratio).
   - The segmented detector is placed 90°.
     $\Longleftrightarrow$ determine electric or magnetic transition with leniar polarization.
   - Lifetime measurement with DSAM method for higher spin states.

- ^{112}In
  - ^{110}Cd(α,pn). . . M. Eibert et.al. J. Phys. G: Nucl. Phys. 2 (1976) L203
  - ^{96}Zr(^{22}Ne,p5n)
  - ^{70}Zn(^{48}Ca,p5n)
- ^{108}Ag (^{109}Ag,^{110}Ag)
  - ^{100}Mo(^{11}B,3n). . . F.R. Espinoza-Quiñones et. al. Phys. Rev. C 52 (1995)
  - ^{96}Zr(^{15}N,3n)
  - ^{96}Zr(^{18}O,p5n)

$E_{\mathrm{beam}} \sim$4MeV/u

Summary

1. Hyperball-2

2. Nuclear Chirality

    - Criteria for Nuclear Chirality
    - Lifetime Measurements
    - Chiral Candidates and Possible Existance in the A ~100 region

3. Experiments with Hyperball-2

    - γ-γ-γ coincidence, Linear Polarization
    - The observed side band structures in ^{79}Kr are of non chiral.

4. ^{112}In is best idea for Chiral doublet search in RCNP.

Nuclear Chart in the A ∼100 region

^{96}In	^{97}In	^{98}In	^{99}In	^{100}In	^{101}In	^{102}In	^{103}In	^{104}In	^{105}In	^{106}In	^{107}In	^{108}In	^{109}In	^{110}In	^{111}In	^{112}In	**^{113}In**	^{114}In	**^{115}In**	^{116}In	49
^{95}Cd	^{96}Cd	^{97}Cd	^{98}Cd	^{99}Cd	^{100}Cd	^{101}Cd	^{102}Cd	^{103}Cd	^{104}Cd	^{105}Cd	**^{106}Cd**	^{107}Cd	**^{108}Cd**	^{109}Cd	**^{110}Cd**	**^{111}Cd**	**^{112}Cd**	**^{113}Cd**	**^{114}Cd**	**^{115}Cd**	48
^{94}Ag	^{95}Ag	^{96}Ag	^{97}Ag	^{98}Ag	^{99}Ag	^{100}Ag	^{101}Ag	^{102}Ag	^{103}Ag	^{104}Ag	^{105}Ag	^{106}Ag	**^{107}Ag**	^{108}Ag	**^{109}Ag**	^{110}Ag	^{111}Ag	^{112}Ag	^{113}Ag	^{114}Ag	47
^{93}Pd	^{94}Pd	^{95}Pd	^{96}Pd	^{97}Pd	^{98}Pd	^{99}Pd	^{100}Pd	^{101}Pd	**^{102}Pd**	^{103}Pd	**^{104}Pd**	**^{105}Pd**	**^{106}Pd**	^{107}Pd	**^{108}Pd**	^{109}Pd	**^{110}Pd**	^{111}Pd	^{112}Pd	^{113}Pd	46
^{92}Rh	^{93}Rh	^{94}Rh	^{95}Rh	^{96}Rh	^{97}Rh	^{98}Rh	^{99}Rh	^{100}Rh	**^{101}Rh**	^{102}Rh	**^{103}Rh**	^{104}Rh	^{105}Rh	^{106}Rh	^{107}Rh	^{108}Rh	^{109}Rh	^{110}Rh	^{111}Rh	^{112}Rh	45
^{91}Ru	^{92}Ru	^{93}Ru	^{94}Ru	^{95}Ru	**^{96}Ru**	^{97}Ru	**^{98}Ru**	**^{99}Ru**	**^{100}Ru**	**^{101}Ru**	**^{102}Ru**	^{103}Ru	**^{104}Ru**	^{105}Ru	^{106}Ru	^{107}Ru	^{108}Ru	^{109}Ru	^{110}Ru	^{111}Ru	44
^{90}Tc	^{91}Tc	^{92}Tc	^{93}Tc	^{94}Tc	^{95}Tc	^{96}Tc	^{97}Tc	^{98}Tc	^{99}Tc	^{100}Tc	^{101}Tc	^{102}Tc	^{103}Tc	^{104}Tc	^{105}Tc	^{106}Tc	^{107}Tc	^{108}Tc	^{109}Tc	^{110}Tc	43
^{89}Mo	^{90}Mo	^{91}Mo	**^{92}Mo**	^{93}Mo	**^{94}Mo**	**^{95}Mo**	**^{96}Mo**	**^{97}Mo**	**^{98}Mo**	^{99}Mo	**^{100}Mo**	^{101}Mo	^{102}Mo	^{103}Mo	^{104}Mo	^{105}Mo	^{106}Mo	^{107}Mo	^{108}Mo	^{109}Mo	42
^{88}Nb	^{89}Nb	^{90}Nb	^{91}Nb	^{92}Nb	**^{93}Nb**	^{94}Nb	^{95}Nb	^{96}Nb	^{97}Nb	^{98}Nb	^{99}Nb	^{100}Nb	^{101}Nb	^{102}Nb	^{103}Nb	^{104}Nb	^{105}Nb	^{106}Nb	^{107}Nb	^{108}Nb	41
^{87}Zr	^{88}Zr	^{89}Zr	**^{90}Zr**	**^{91}Zr**	**^{92}Zr**	^{93}Zr	**^{94}Zr**	^{95}Zr	**^{96}Zr**	^{97}Zr	^{98}Zr	^{99}Zr	^{100}Zr	^{101}Zr	^{102}Zr	^{103}Zr	^{104}Zr	^{105}Zr	^{106}Zr	^{107}Zr	40
^{86}Y	^{87}Y	^{88}Y	**^{89}Y**	^{90}Y	^{91}Y	^{92}Y	^{93}Y	^{94}Y	^{95}Y	^{96}Y	^{97}Y	^{98}Y	^{99}Y	^{100}Y	^{101}Y	^{102}Y	^{103}Y	^{104}Y	^{105}Y	^{106}Y	39
^{85}Sr	**^{86}Sr**	**^{87}Sr**	**^{88}Sr**	^{89}Sr	^{90}Sr	^{91}Sr	^{92}Sr	^{93}Sr	^{94}Sr	^{95}Sr	^{96}Sr	^{97}Sr	^{98}Sr	^{99}Sr	^{100}Sr	^{101}Sr	^{102}Sr	^{103}Sr	^{104}Sr	^{105}Sr	38
^{84}Rb	**^{85}Rb**	^{86}Rb	**^{87}Rb**	^{88}Rb	^{89}Rb	^{90}Rb	^{91}Rb	^{92}Rb	^{93}Rb	^{94}Rb	^{95}Rb	^{96}Rb	^{97}Rb	^{98}Rb	^{99}Rb	^{100}Rb	^{101}Rb	^{102}Rb	^{103}Rb	^{104}Rb	37
^{83}Kr	**^{84}Kr**	^{85}Kr	**^{86}Kr**	^{87}Kr	^{88}Kr	^{89}Kr	^{90}Kr	^{91}Kr	^{92}Kr	^{93}Kr	^{94}Kr	^{95}Kr	^{96}Kr	^{97}Kr	^{98}Kr	^{99}Kr	^{100}Kr	^{101}Kr	^{102}Kr	^{103}Kr	36
^{82}Br	^{83}Br	^{84}Br	^{85}Br	^{86}Br	^{87}Br	^{88}Br	^{89}Br	^{90}Br	^{91}Br	^{92}Br	^{93}Br	^{94}Br	^{95}Br	^{96}Br	^{97}Br	^{98}Br	^{99}Br	^{100}Kr	^{101}Kr	^{102}Kr	35
47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	