



# Gamma-ray spectroscopy with Hyperball2

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# Collaborators

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## E566 collaboration

KEK

Osaka Electro-Communication University

Kyoto University

Osaka University

Seoul National University

GSI

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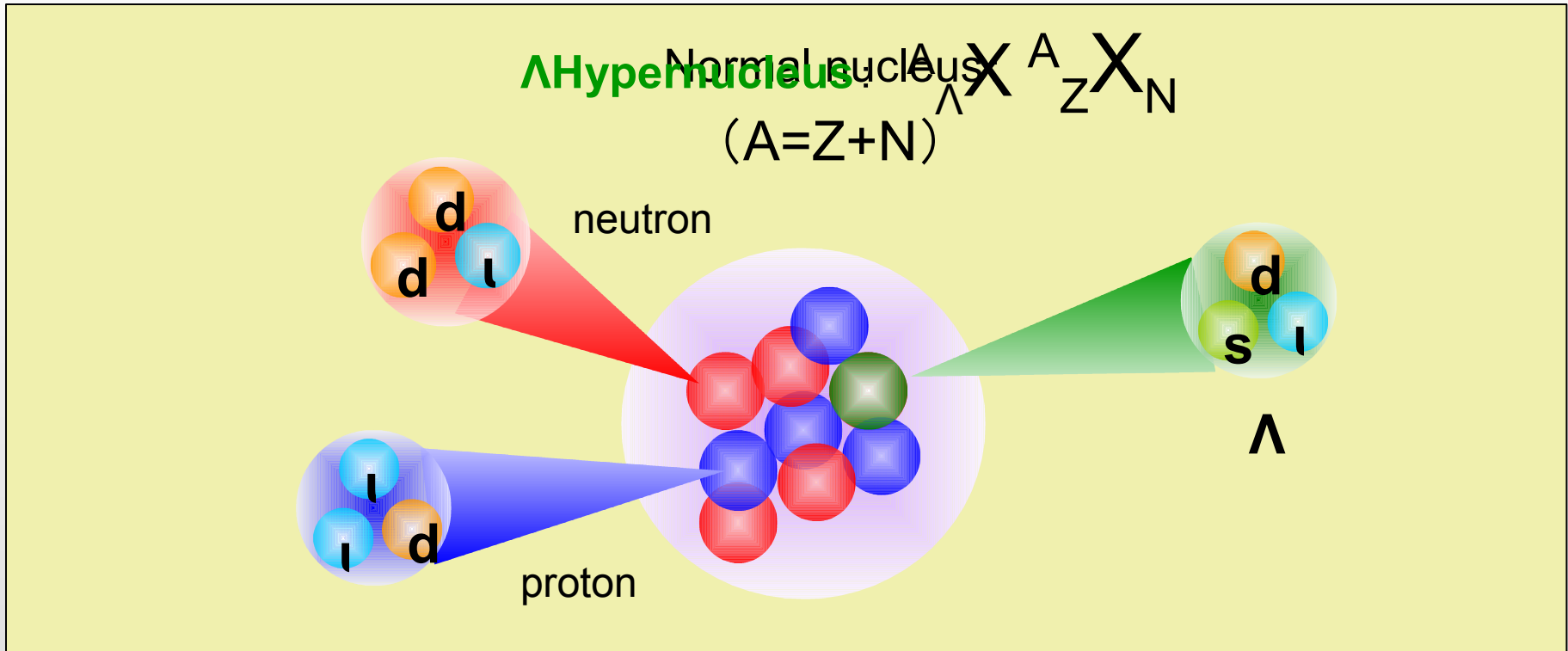
University of York, U.K  
P.Joshi

ATOMKI, Hungary  
J.Timar

CIAE, China  
Y.Y.Fu, S.H.Zhou



# Nuclei with strangeness: Hypernuclei



Up quark



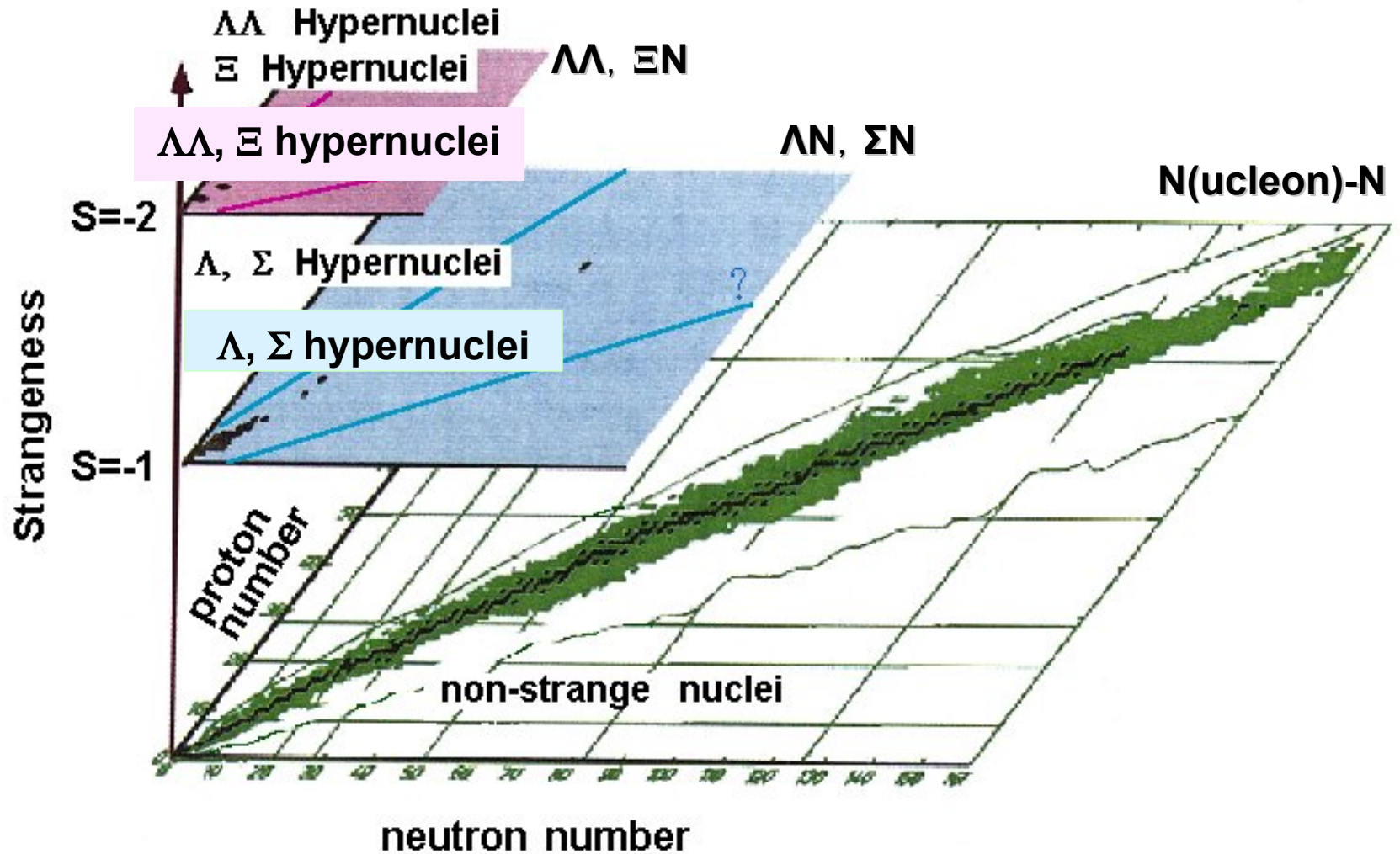
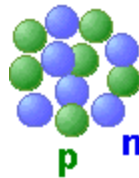
Down quark



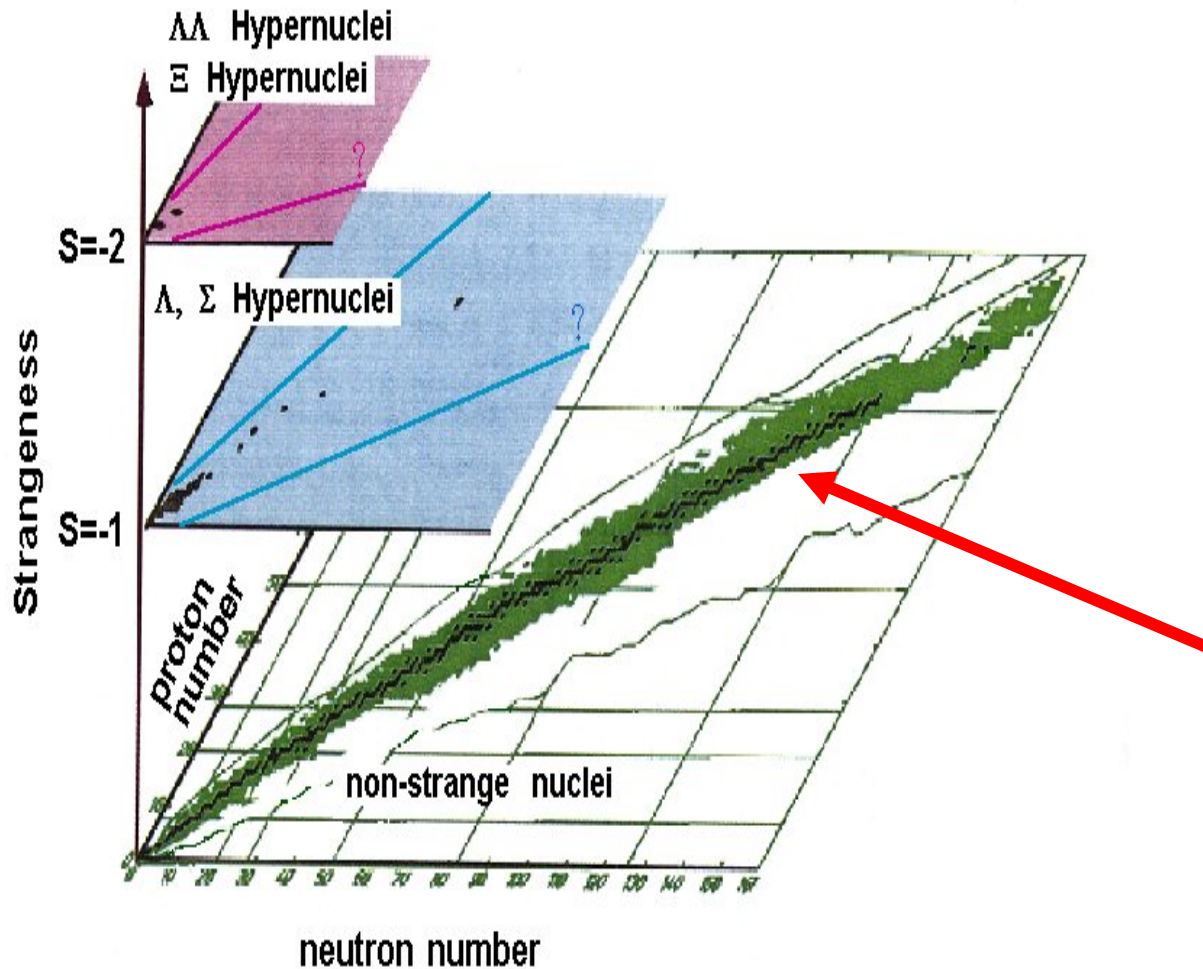
Strange quark

Baryons with strangeness = **Hyperon**  
 ( $\Lambda$ ,  $\Sigma^0$ ,  $\Sigma^+$ ,  $\Sigma^-$ ,  $\Xi^0$ ,  $\Xi^-$ )  
 → nuclei with strangeness = **Hypernuclei**

# 3D Nuclear Chart



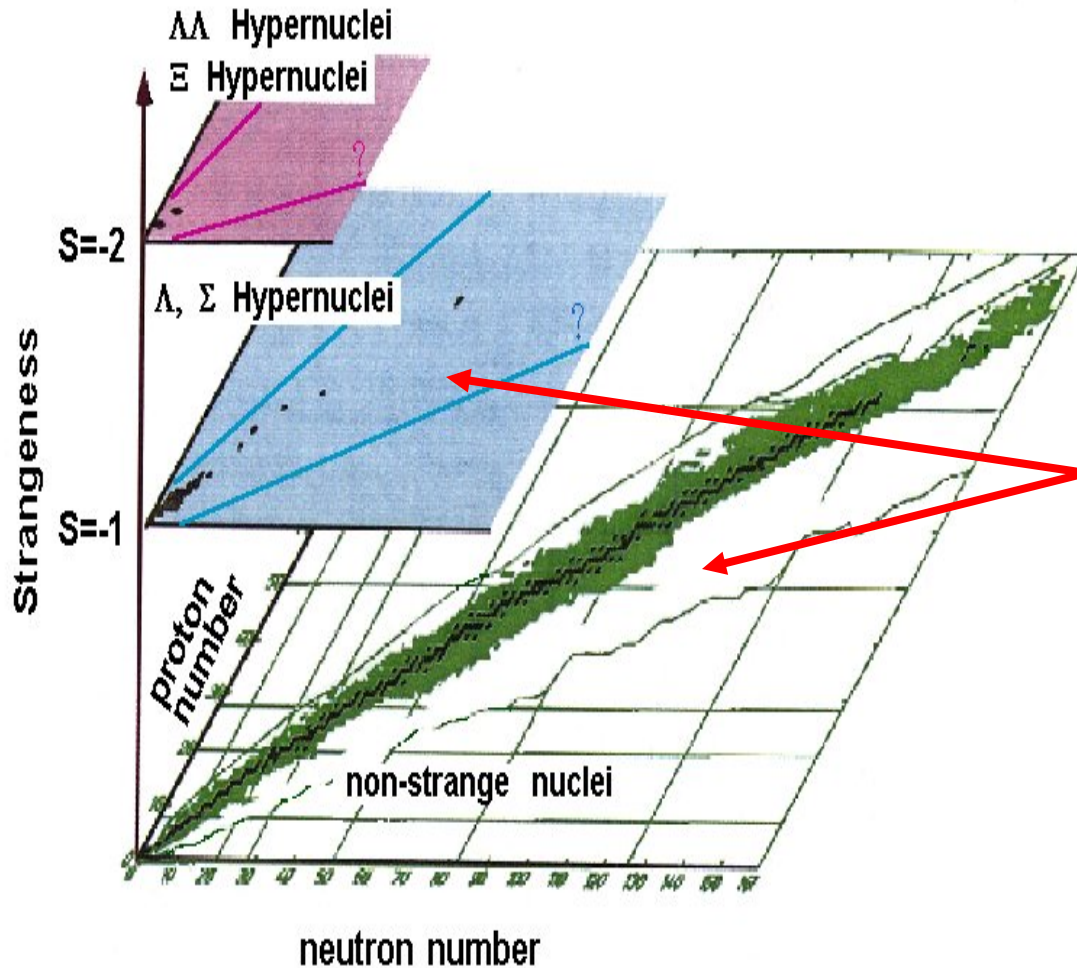
# $\gamma$ -ray spectroscopy



- A powerful probe for precise measurements of nuclear bound states  
( $\sim 2$  keV for 1 MeV  $\gamma$ -ray with **HpGe** detectors)
- Has been limited to normal nuclear studies due to technical challenges

# Hyperball2: a unique $\gamma$ -ray spectrometer

Hyperball2 (& Hyperball)



- Functional in the 3D nuclear chart
  - ❖ Event by event reaction tagging with dipole magnet spectrometer (SKS)
  - ❖ Electronics for extremely high counting rates with a huge background environment

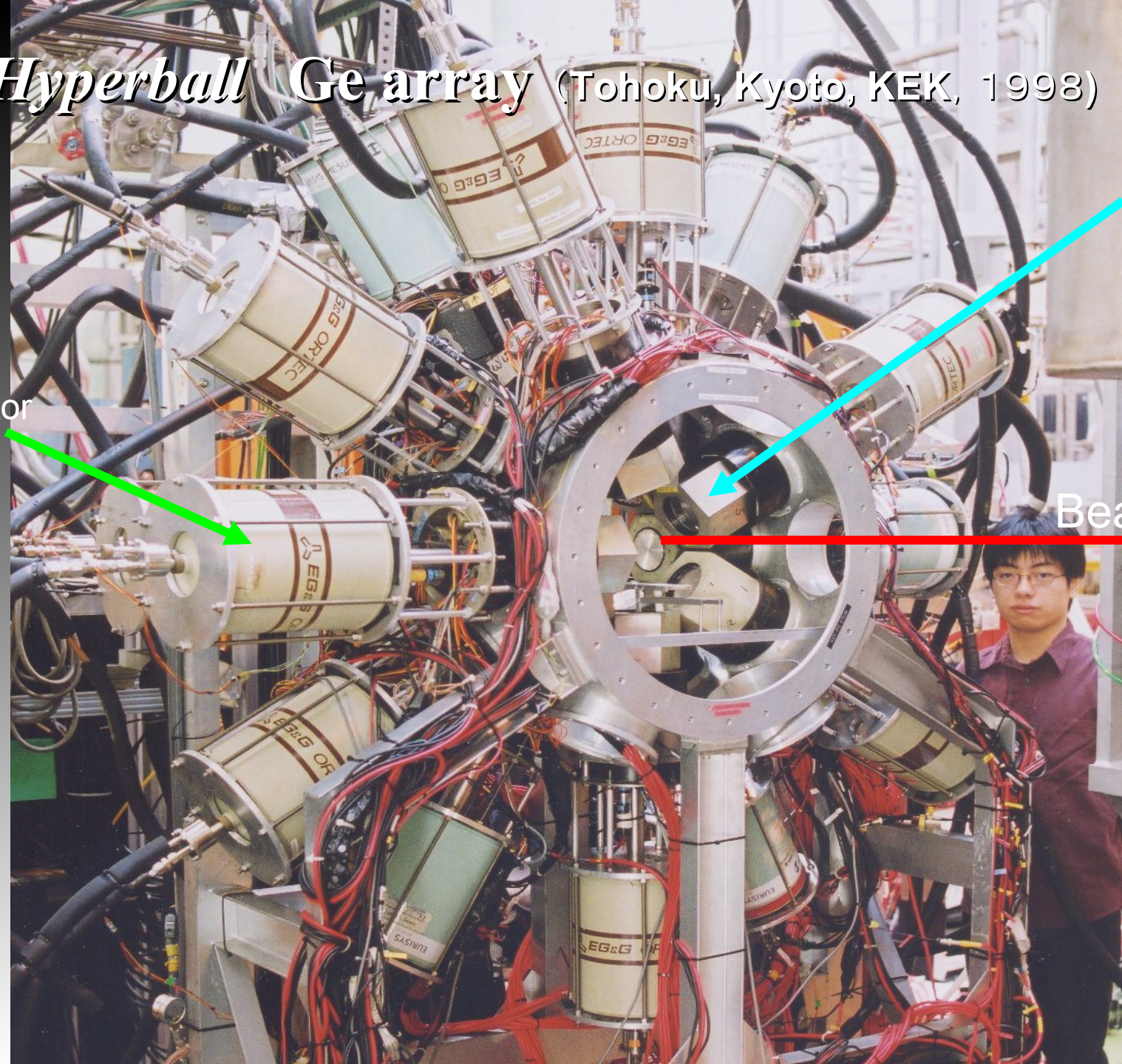


# Hyperball Ge array (Tohoku, Kyoto, KEK, 1998)

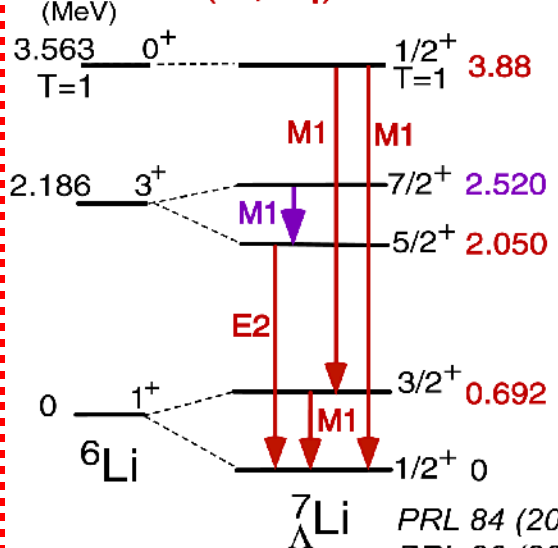
Ge detector

BGO

Beam

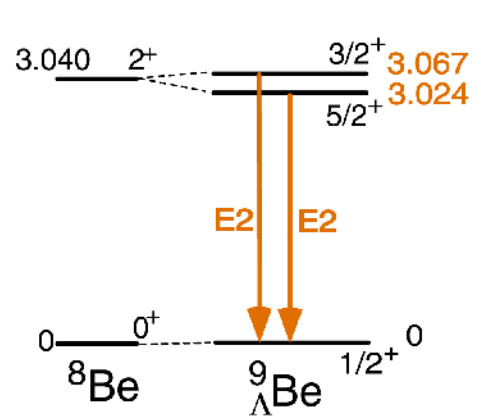


**${}^7\text{Li} (\pi^+, K^+\gamma)$  KEK E419**



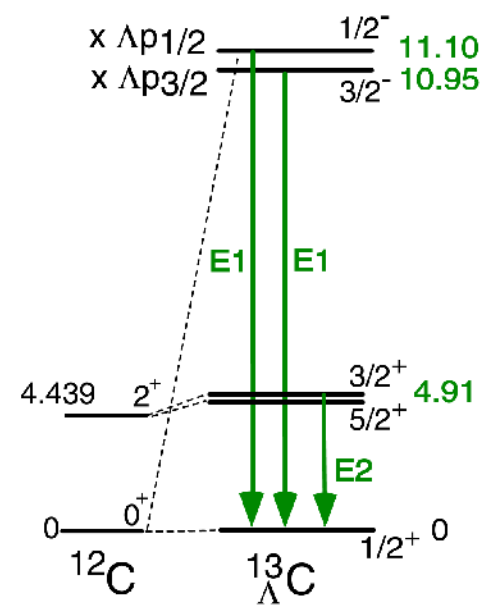
PLB 579 (2004) 258  
 Phys. Rev. C 73, 012501(R) (2006)  
 PRL 84 (2000) 5963  
 PRL 86 (2001) 1982

**${}^9\text{Be} (K^-, \pi^-\gamma)$  BNL E930-1**



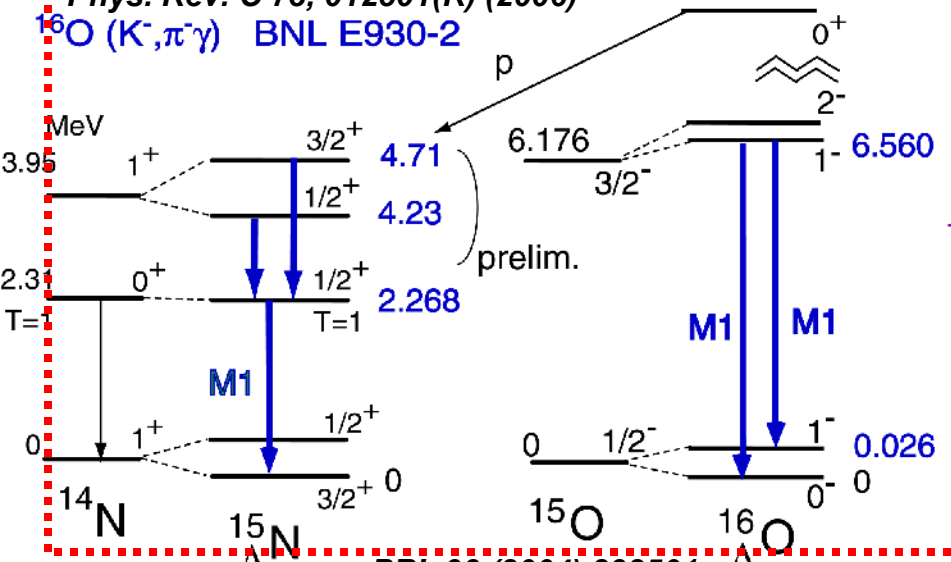
PRL 88 (2002) 082501

**${}^{13}\text{C} (K^-, \pi^-\gamma)$  BNL E929 (NaI)**



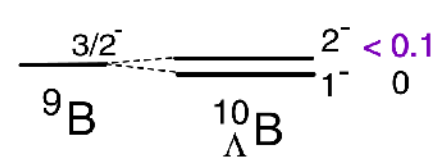
PRL 86 (2001) 4255

**${}^{16}\text{O} (K^-, \pi^-\gamma)$  BNL E930-2**

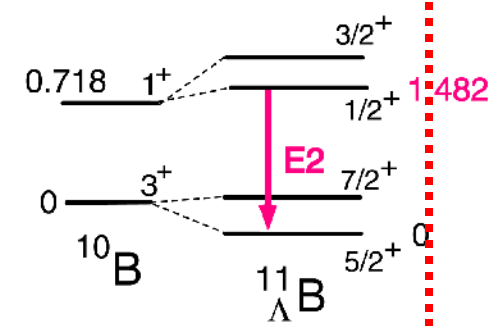


PRL 93 (2004) 232501

**${}^{10}\text{B} (K^-, \pi^-\gamma)$  BNL E930-2**



**${}^7\text{Li} (\pi^+, K^+\gamma)$  KEK E518**





# 2nd Generation Ge array: Hyperball2 (operational since 2005)

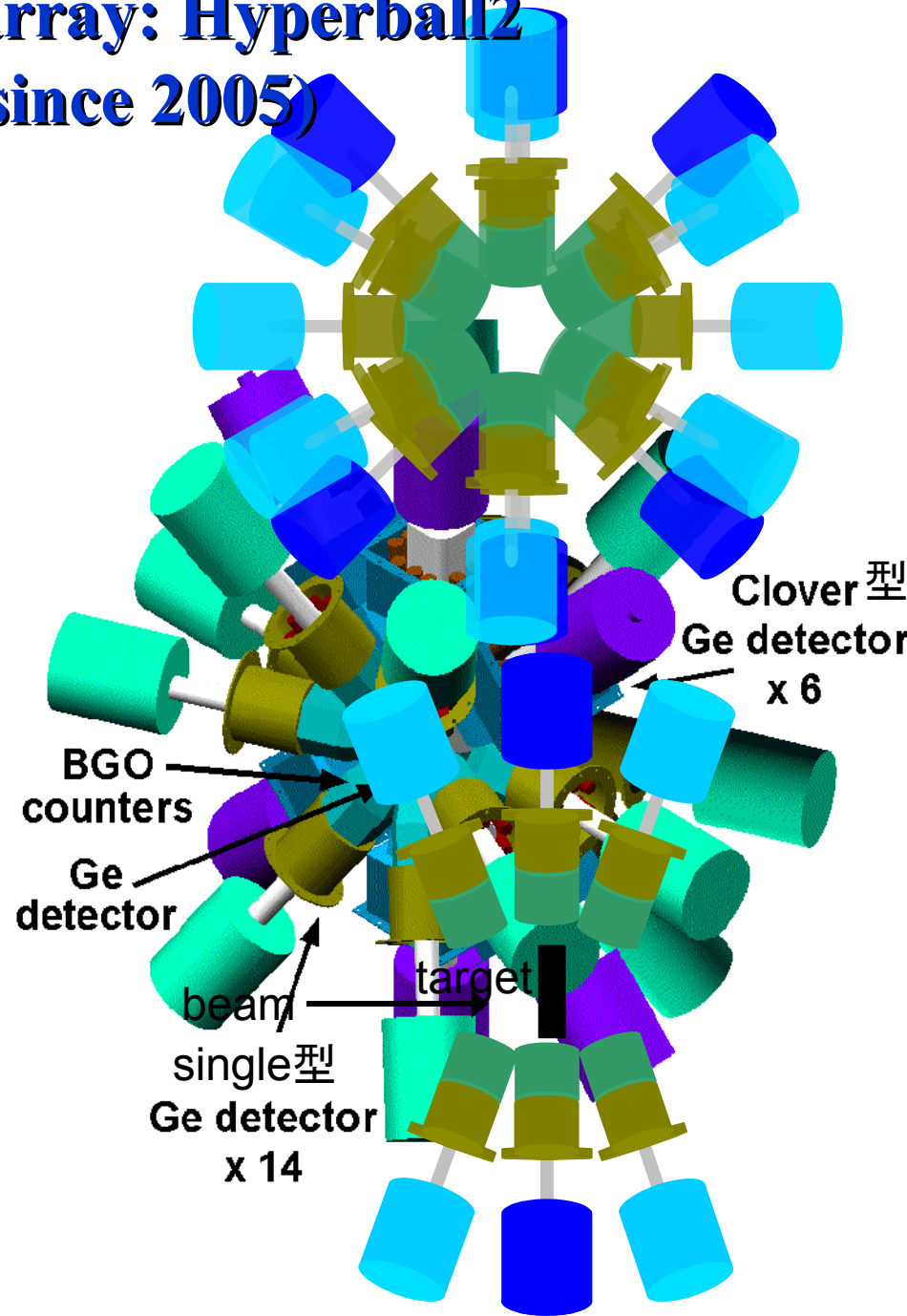
[single crystal Ge detector + BGO] × 14  
+  
[clover Ge detector + BGO] × 6

Photo peak efficiency ~5% at 1MeV  
⇒ Twice that of Hyperball  
→ 2<sup>3</sup> times for triple  $\gamma$  coincidence  
(multi-fold  $\gamma$  cascade decay event)

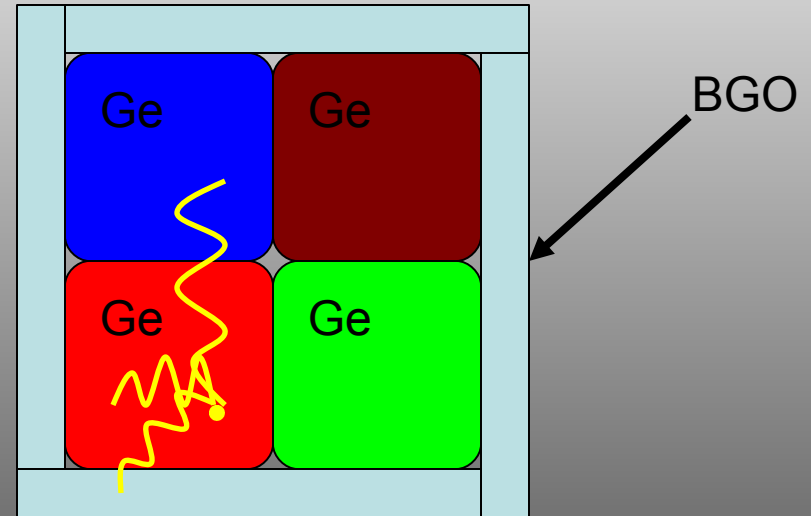
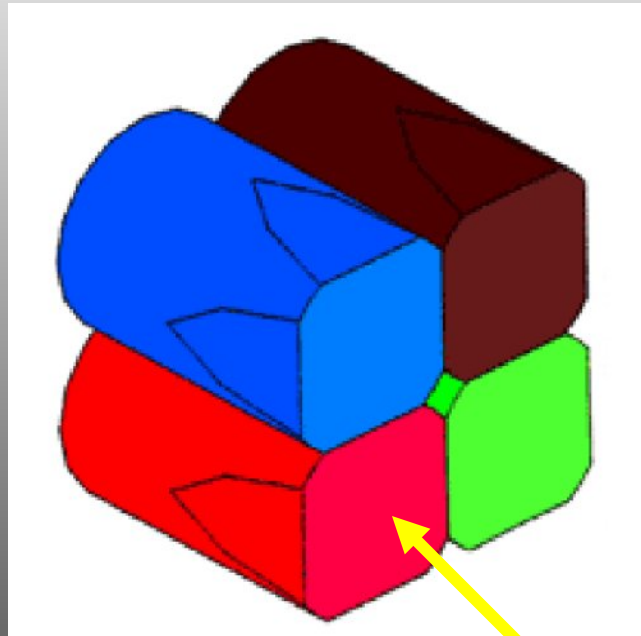
Electronics for high counting rate  
~50kHz/detector or  
~0.5TeV/ s/detector energy deposit



Hypernuclear  $\gamma$ -ray spectroscopy



# Clover detectors

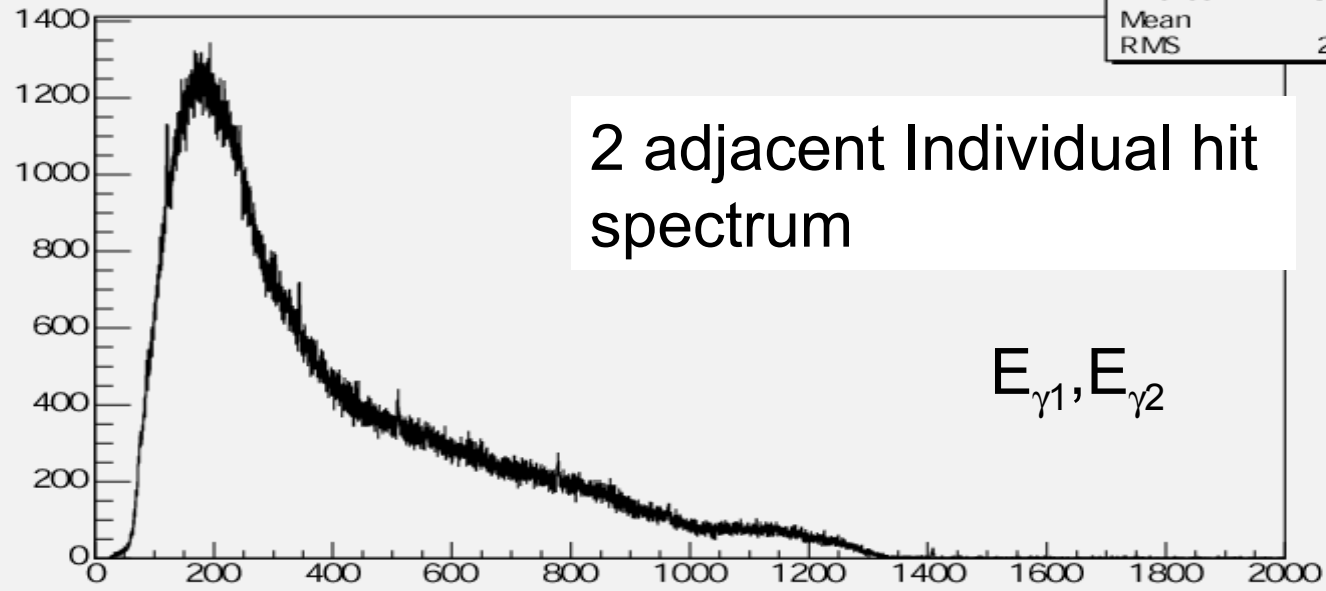


- (1) Fully absorbed → Good event
- (2) Compton escape → Rejected event
- (3) Scatter to adjacent crystal (add-back) → Good event



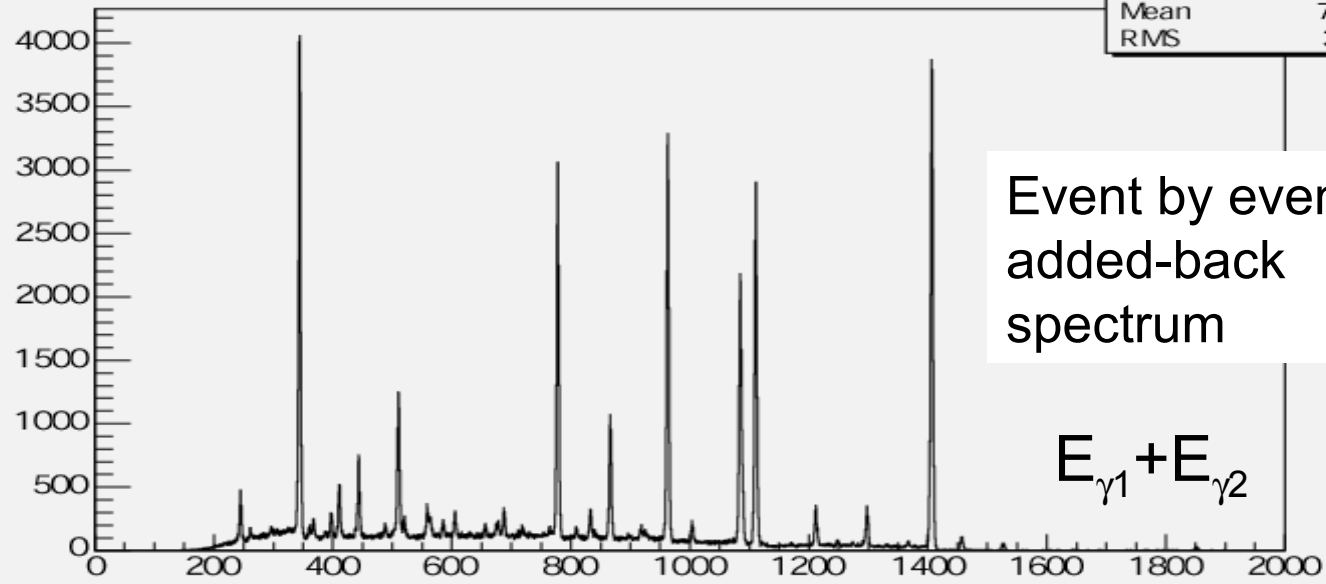
$^{152}\text{Eu}$

Case 2 hits



hit2	
Entries	1780018
Mean	400
RMS	277.8

Case 2 hits (Added back)



hit2ab	
Entries	890009
Mean	796.6
RMS	352.1

Energy (keV)

# Exploring 3D nuclear chart with Hyperball2



- $\Lambda\text{N}$  interaction
  - spin-dependent interactions: spin-spin, spin-orbit, tensor
- Nuclear medium effect on  $\Lambda$ 
  - measurement of magnetic moment of  $\Lambda$  in nucleus

- Spontaneous formation of chirality
  - chiral doublet (twin) bands
- Stable triaxial nuclear deformation

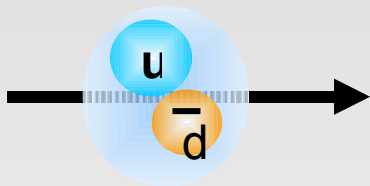


# Hyperball2

## @KEK E566

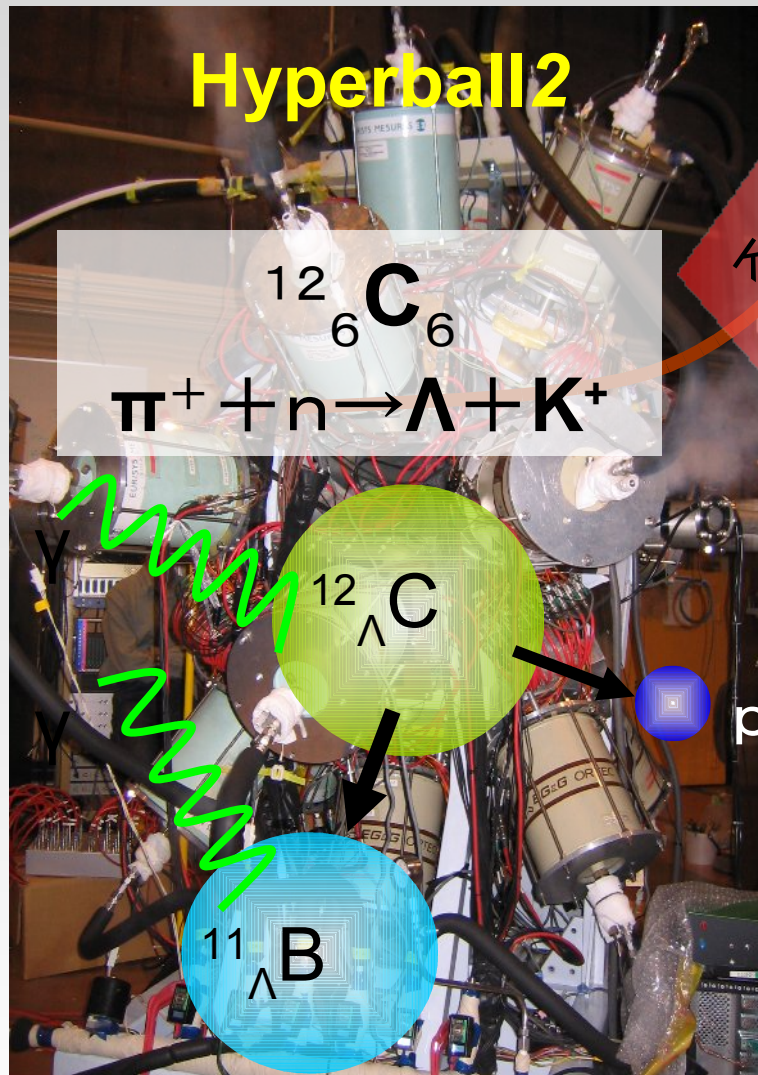
(September, 2005)

$\pi^+$  meson

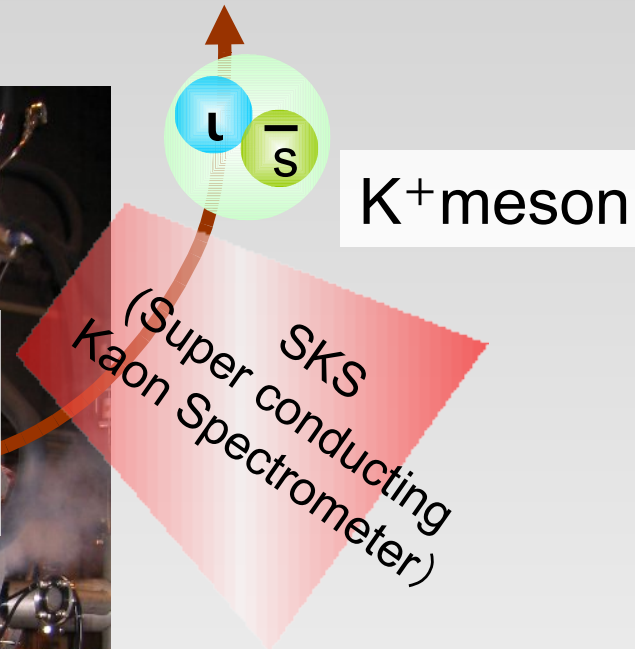


$\pi^+$  momentum  
 $P_{\pi^+} = 1.05 \text{ GeV}/c$

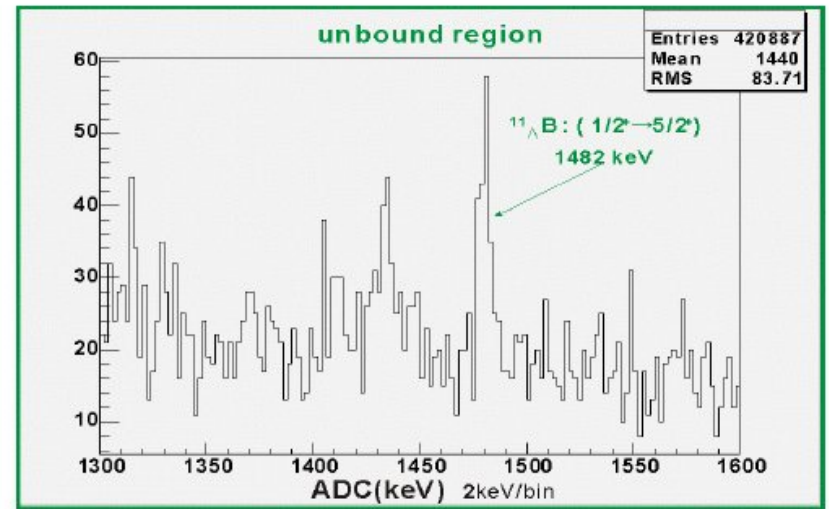
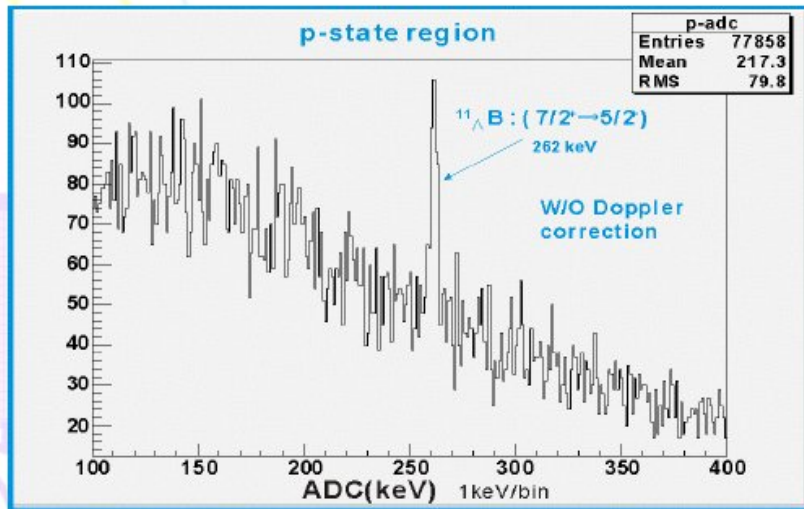
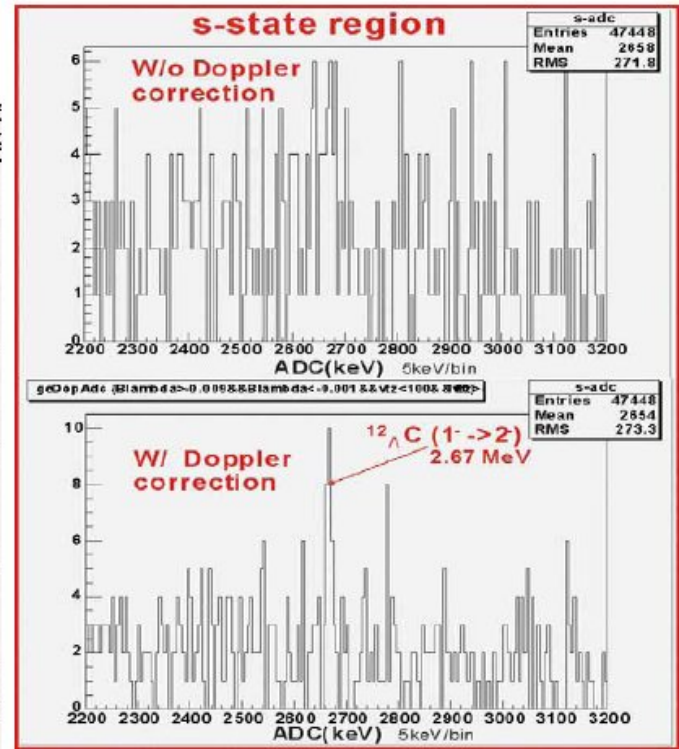
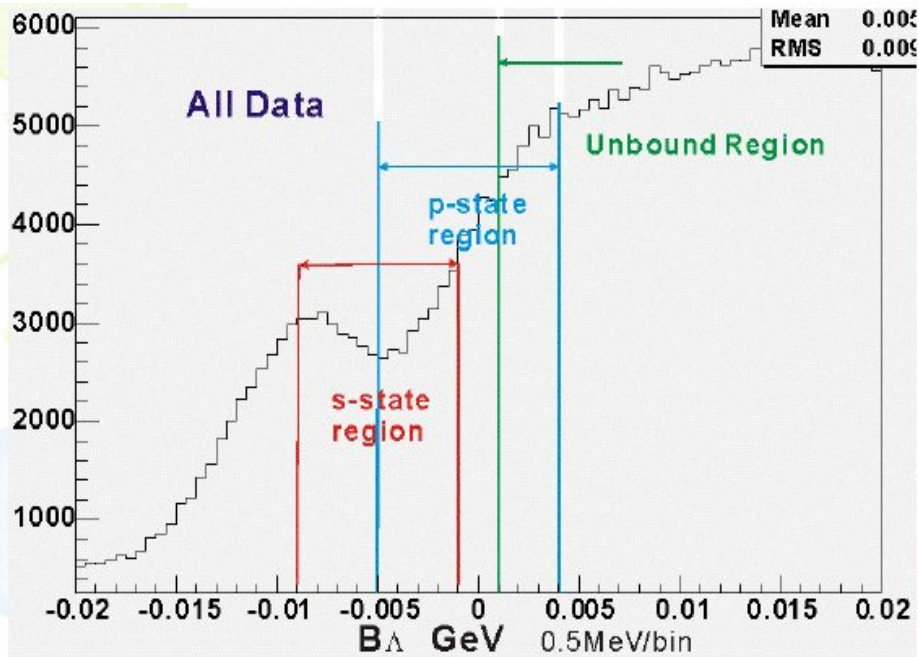
12 GeV  
 Proton Synchrotron



$\text{K}^+$  momentum =  $P_{\text{K}^+}$

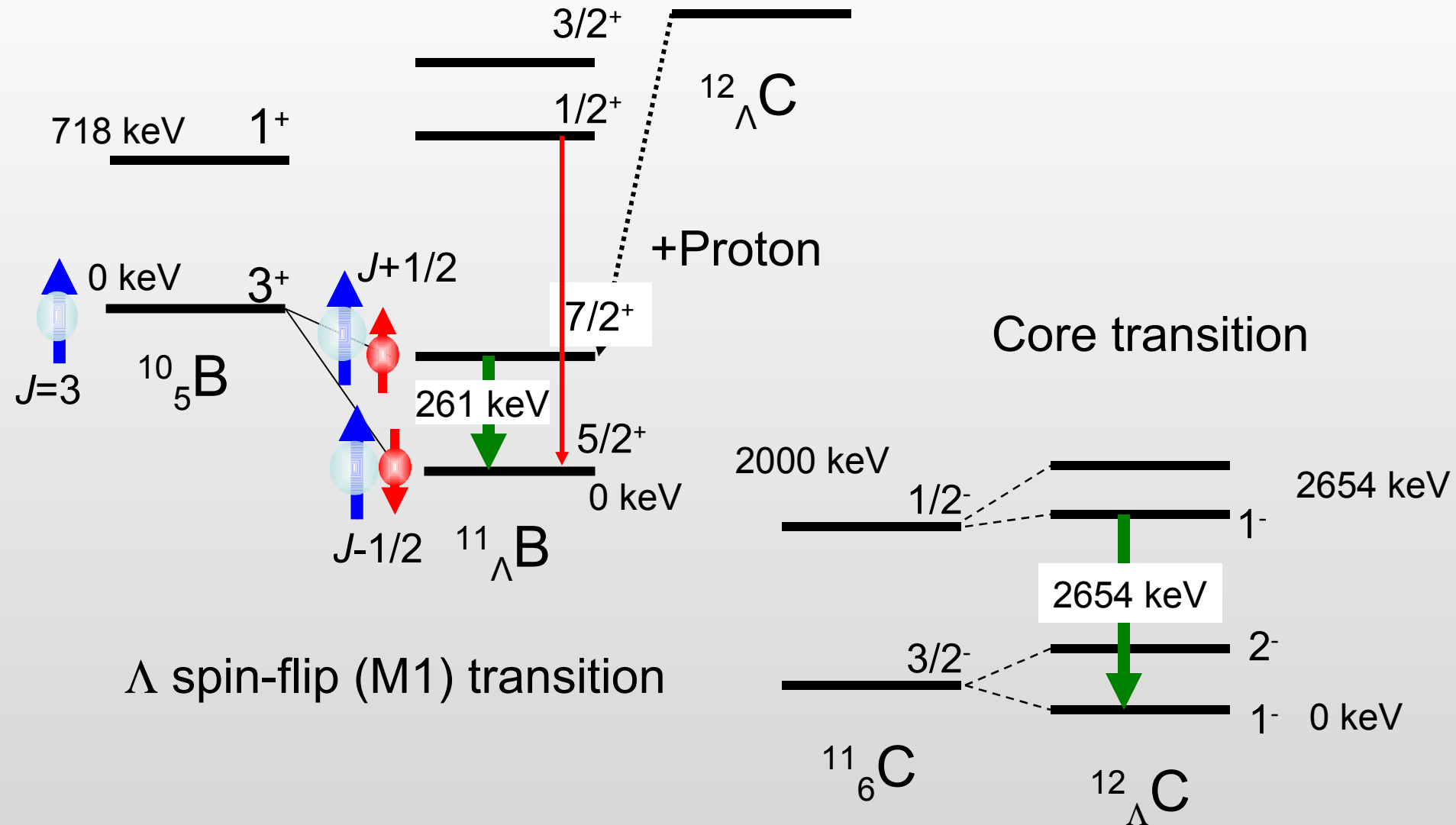


# Preliminary results from E566 data analysis by Ma et. al.





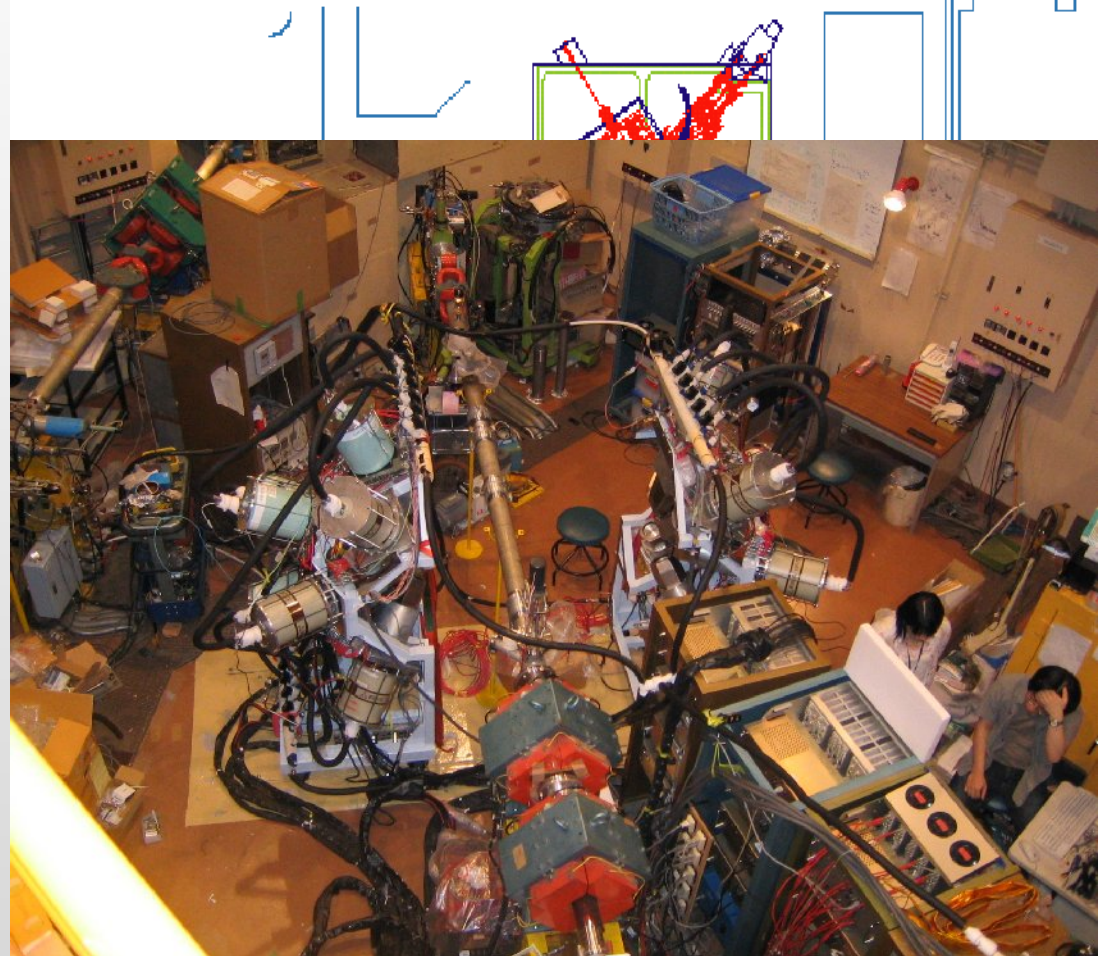
# Level Scheme from E566





# In-beam $\gamma$ -ray spectroscopy with Hyperball2 at CYRIC, Tohoku University 930 Cyclotron K=110

- Chiral doublet search in  $A \sim 80$  region (June & July, 2005; March, July, 2006)
  - $^{70}\text{Zn}(^{13}\text{C}, 4n)^{79}\text{Kr}$  @ 65 MeV
  - $^{70}\text{Zn}(^{13}\text{C}, p2n)^{80}\text{Br}$  @ 53 MeV
- High-spin Isomer in  $N=83$  isotones:  $^{151}\text{Er}$  (Feb., 2006)
  - $^{116}\text{Sn}(^{40}\text{Ar}, 5n)^{151}\text{Er}$  @ 195 MeV
- Triple coincidence



# Chiral geometry in rotating nuclei

## Perpendicular Coupling of three angular momenta

$|IL\rangle$

$|IR\rangle$

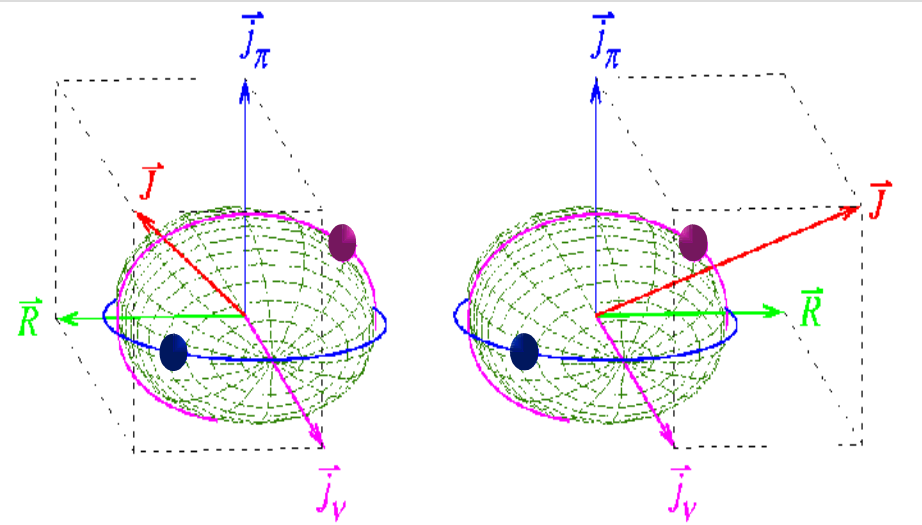
$I \gg 1$

$$\langle IL | E2 | IR \rangle \approx 0$$

$$\langle IL | M1 | IR \rangle \approx 0$$

$$B(EM; I_i^+ \rightarrow I_f^+) \approx B(EM; I_i^- \rightarrow I_f^-)$$

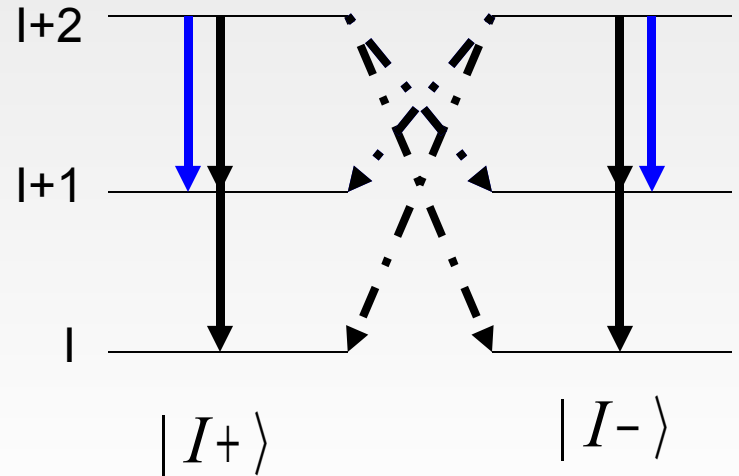
$$B(EM; I_i^+ \rightarrow I_f^-) \approx B(EM; I_i^- \rightarrow I_f^+)$$



*K.Starosta et. al., Phys. Rev. Lett. 86, 971 (2001).*

$$|I+\rangle = \frac{1}{\sqrt{2}} (|IL\rangle_+ + |IR\rangle)$$

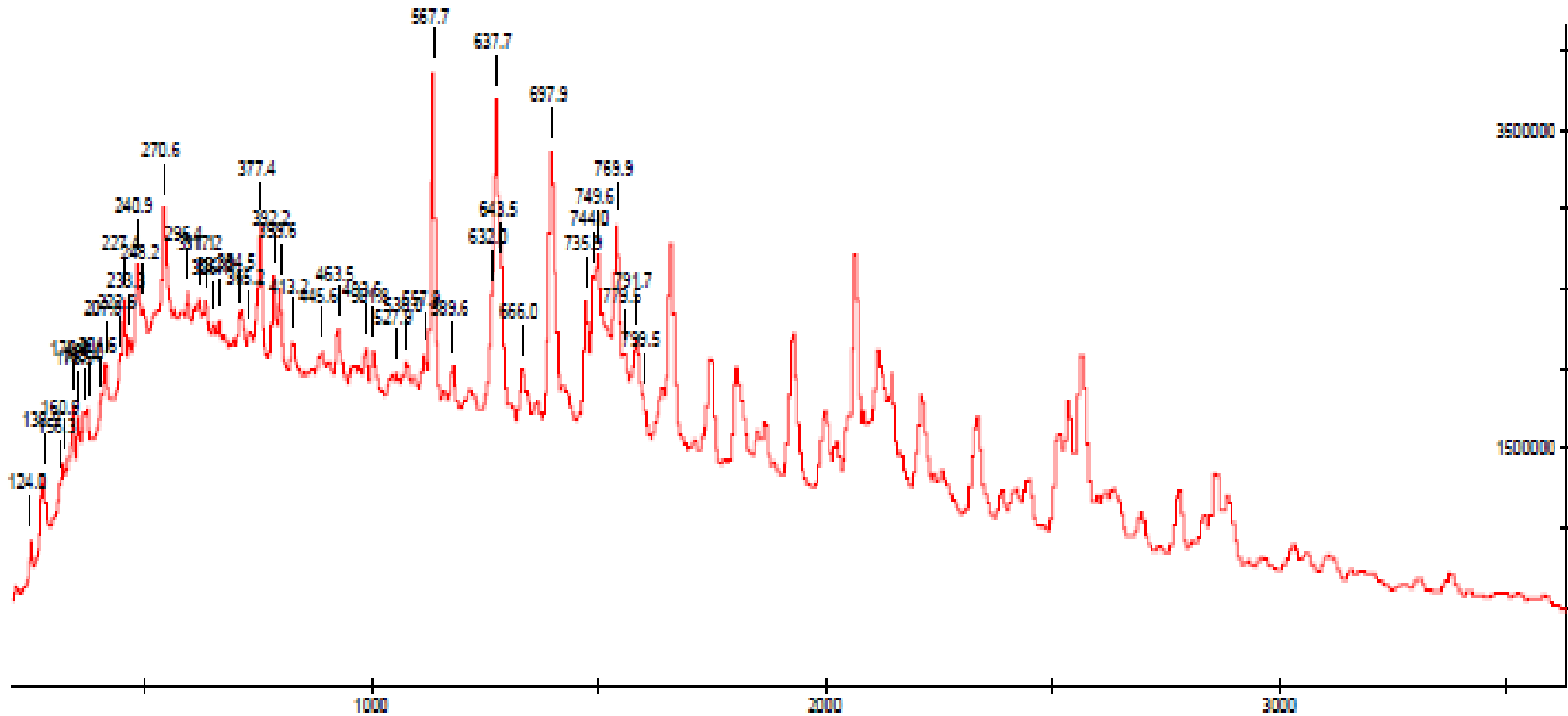
$$|I-\rangle = \frac{i}{\sqrt{2}} (|IL\rangle_- - |IR\rangle)$$





# $^{70}\text{Zn}(^{13}\text{C},xnp\gamma)@ 65\text{MeV}$

Triple coincidence total spectrum



$E_\gamma$

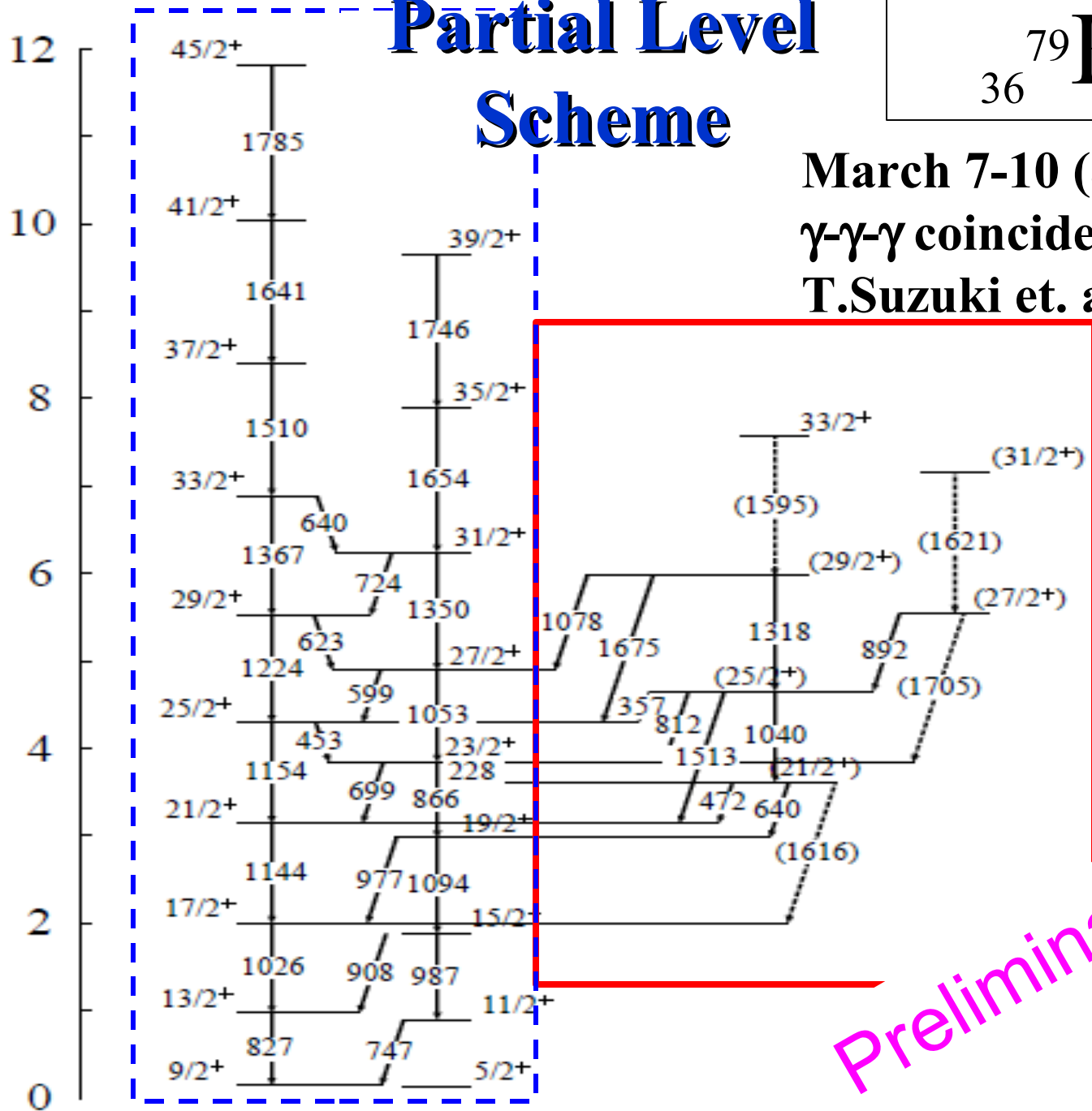
(0.5keV/Channel)

# Partial Level Scheme



March 7-10 (80hours)  
 $\gamma$ - $\gamma$ - $\gamma$  coincidence  
T.Suzuki et. al.

Excitation Energy (MeV)



Preliminary

# Summary

- Hyperball2 is a unique Ge  $\gamma$ -ray spectrometer capable of exploring the 3D nuclear chart.
- KEK experiment in September, 2005
  - $^{12}_{\Lambda}\text{C}$  and  $^{11}_{\Lambda}\text{B}$
- CYRIC experiment still ongoing
  - $^{79}_{36}\text{Kr}$  and  $^{80}_{35}\text{Br}$



Thank you

