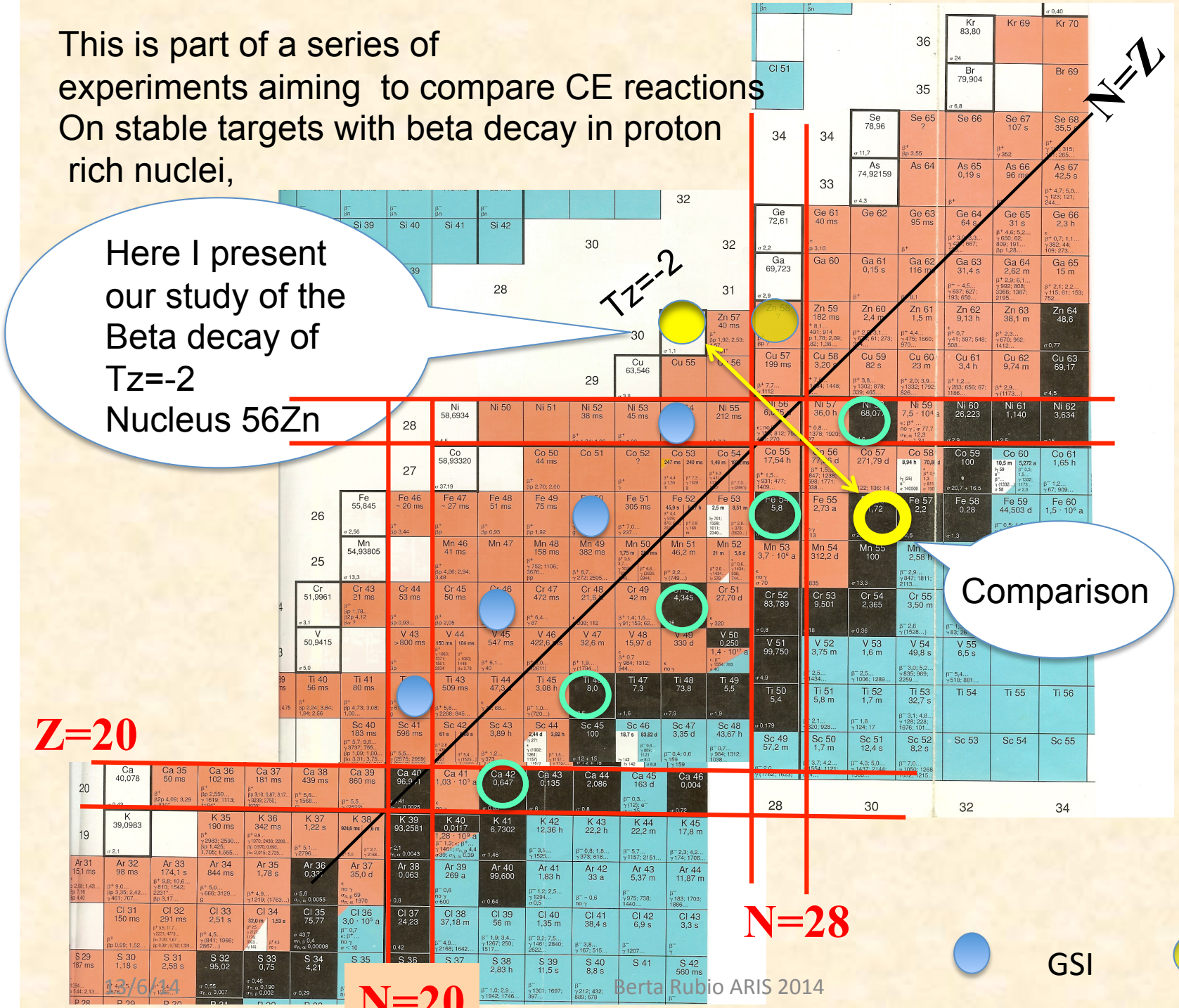
The first observation of the exotic beta-delayed gamma-proton decay in the *fp* shell
The Beta Decay of the T_Z = -2, ^{56}Zn Nucleus

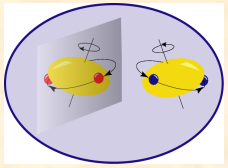
(Phys. Rev. Lett accepted)

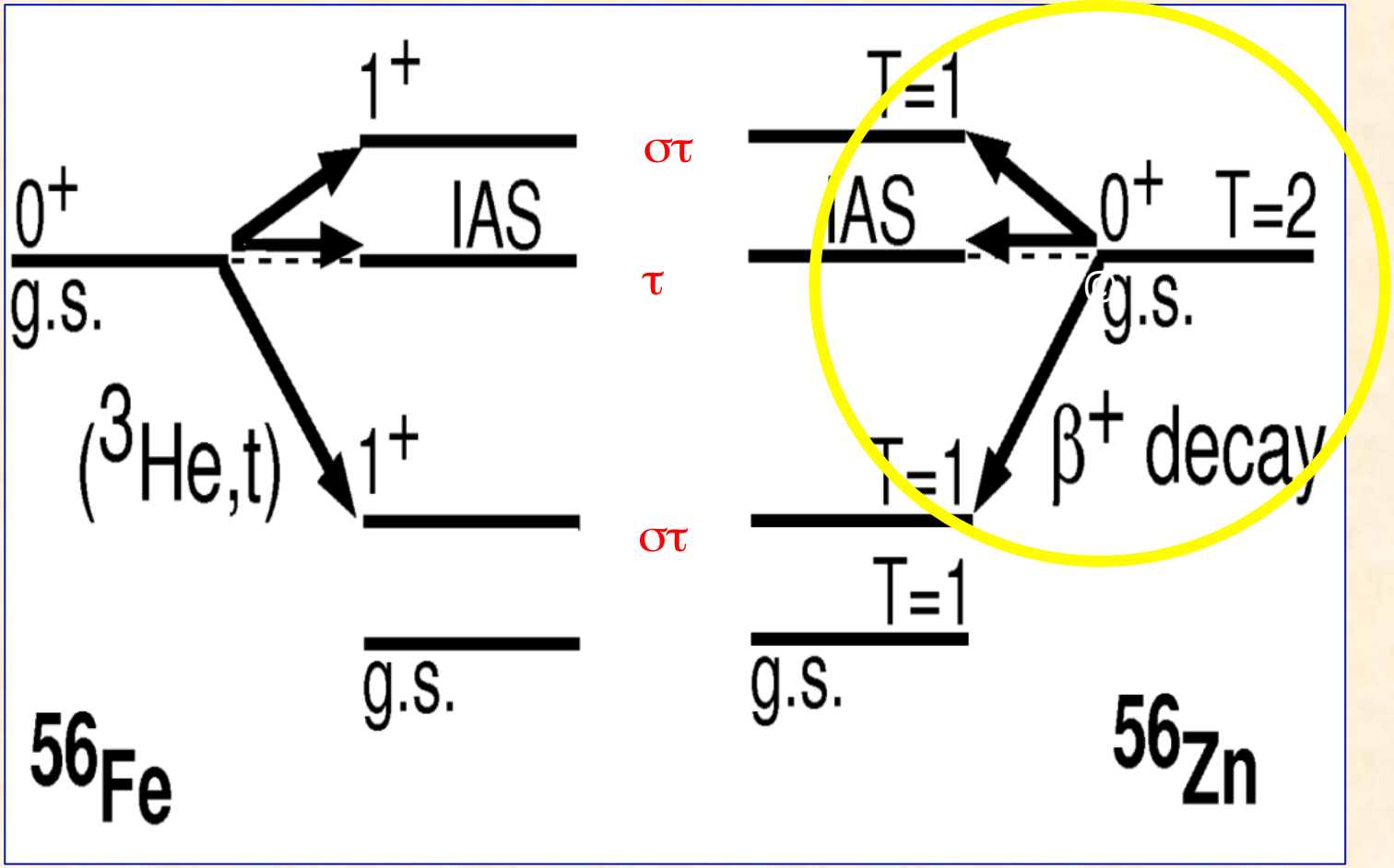
S.E.A. Orrigo, B. Rubio, Y. Fujita, B. Blank, W. Gelletly et al
(Valencia-Osaka-Bordeaux-Surrey-Istanbul-GANIL-Santiago de Chile-Gent-Argonne)
For the GANIL E556a colaboration

This is part of a series of experiments aiming to compare CE reactions On stable targets with beta decay in proton rich nuclei,



If isospin symmetry exists, mirror nuclei should populate the same states with the same probability, in the daughter nucleus, in the two mirror processes





Theoretically

$$B(GT) = \left| \frac{1}{\sqrt{2}} \langle \psi_f | \sum_{\mu} \sum_{k} \sigma_k^{\mu} \tau_k^{\pm} | \psi_i \rangle \right|^2$$

$$B(F) = \left| \frac{1}{\sqrt{2}} \langle \psi_f | \tau^{\pm} | \psi_i \rangle \right|^2$$

Experimentally
Charge Exchange

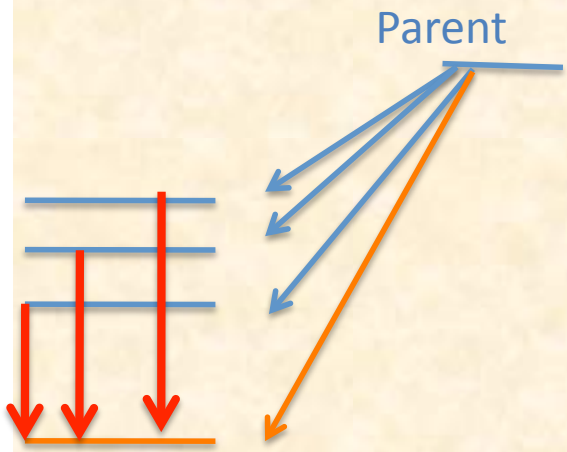
$$B(GT,F)^{CE} \propto \frac{d\sigma}{d\Omega}(0^\circ)$$

Experimentally
Beta-decay

Beta feeding to states
in the daughter nucleus

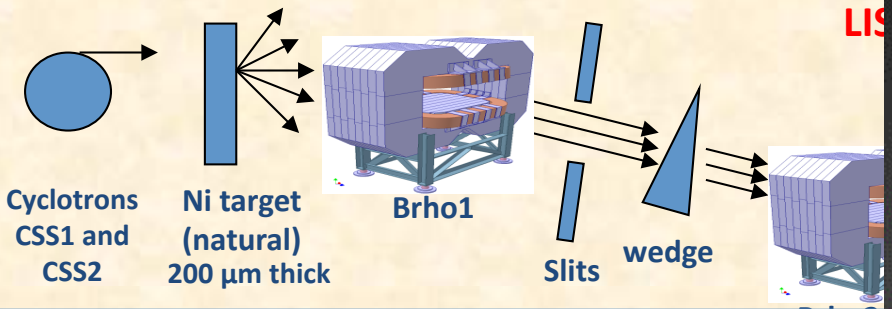
$$B(GT,F)^{\beta} \propto \frac{I_\beta(E)}{f(Q_\beta - E, Z)T_{1/2}}$$

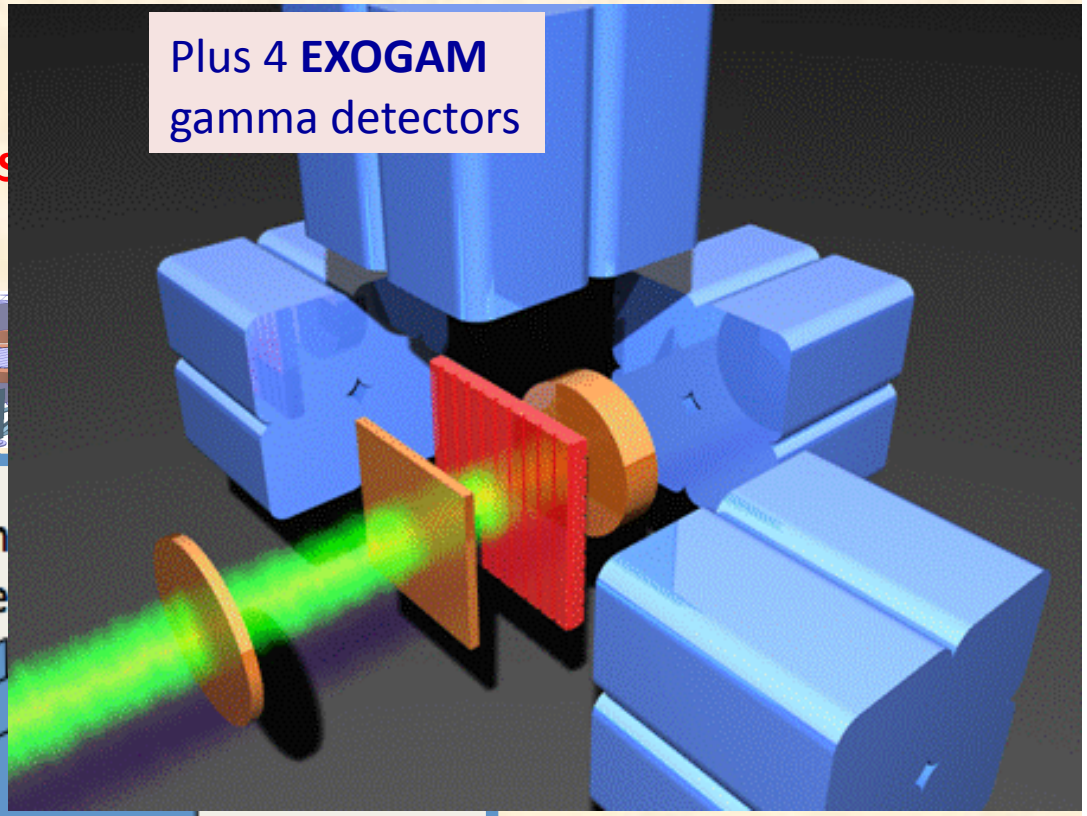
Parent beta half life

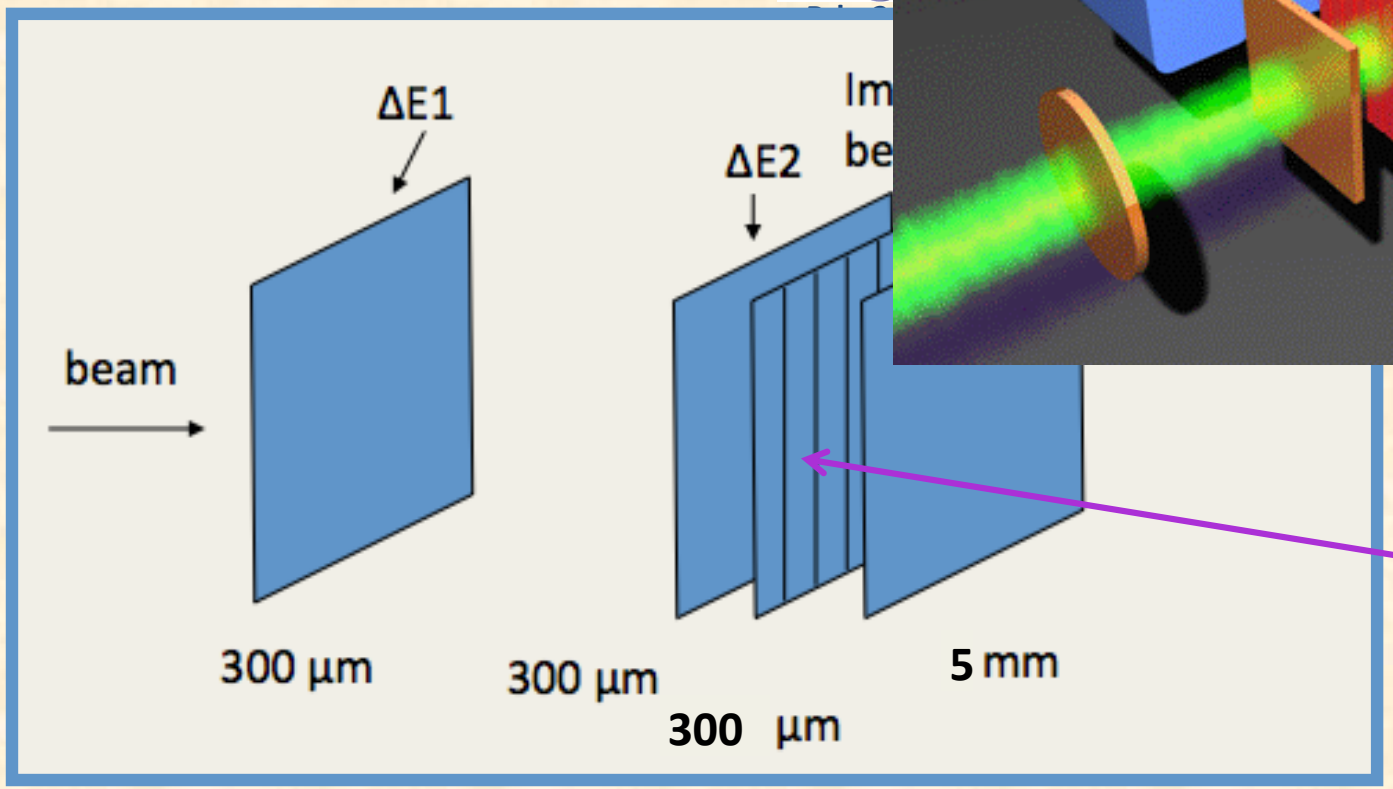


$^{58}Ni^{26+}$ (74.5 AMeV) + ^{nat}Ni @ GANIL 2010

74.5 MeV / nucleon
Incoming $^{58}Ni^{26+}$ 3.7 eμA intensity







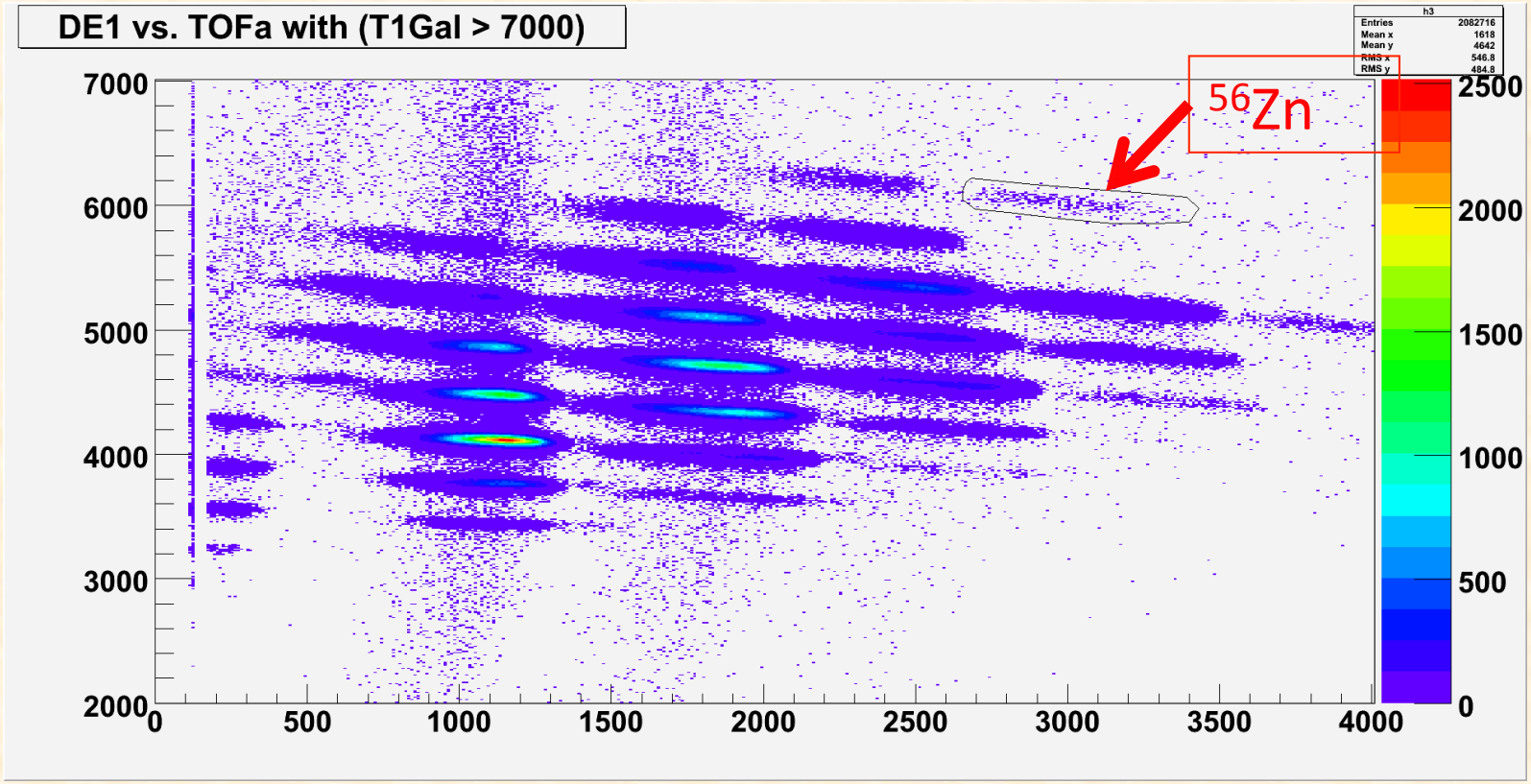
DSSSD detector
Implantation and decay (β, p)
- ✓ 16 strips X and 16 strips Y
- ✓300 μm thick
- ✓ 3 mm pitch

As expected, the statistics is limited:

In 3 days:

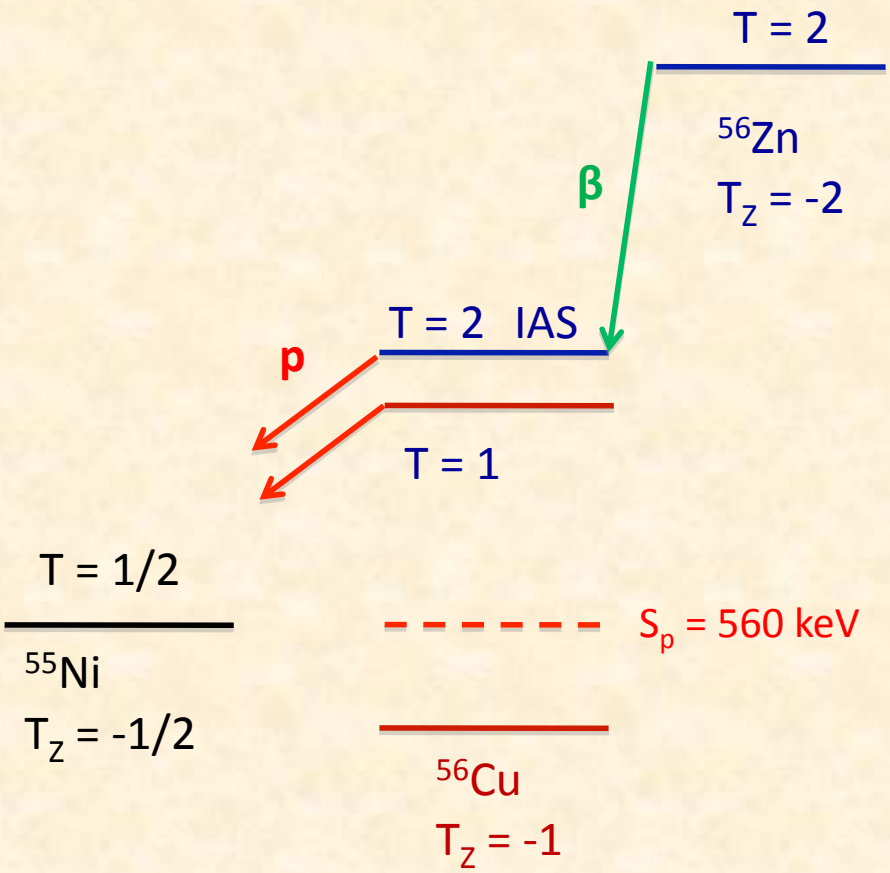
Total ^{56}Zn implantations = 8861

0.033 imp/s

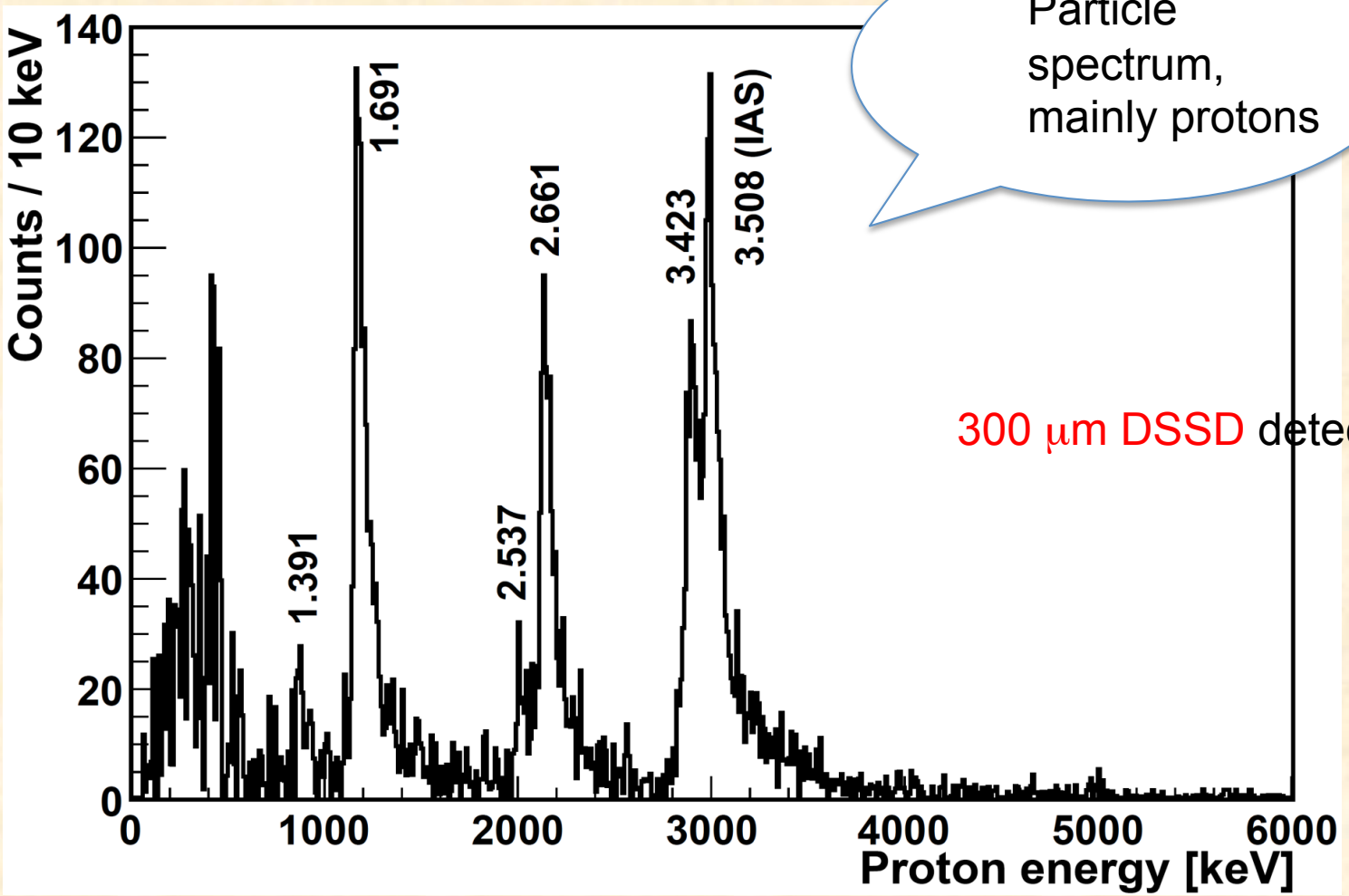


Expected beta decay of 56Zn

Because the Sp is only 560 keV we expect most of the decay to proceed by proton emission



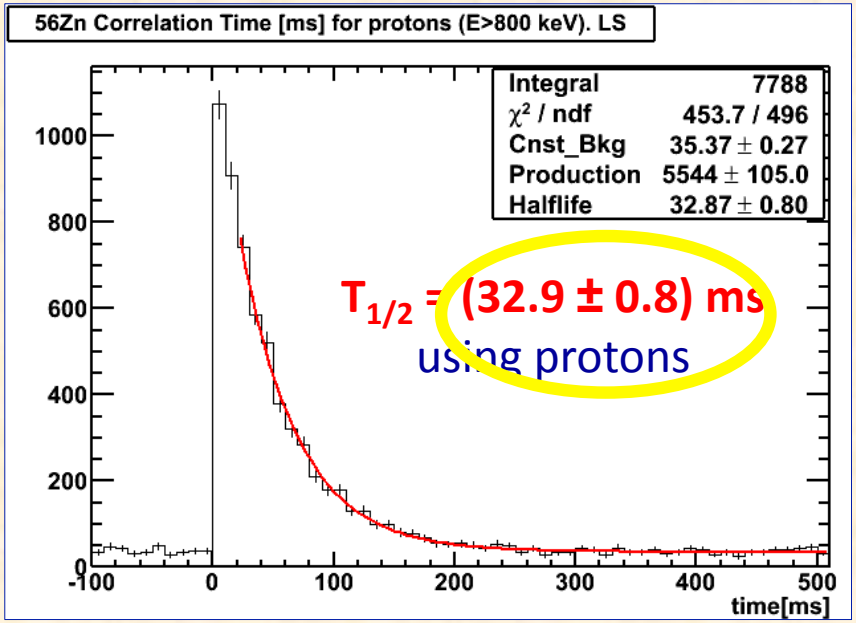
This is indeed what we saw

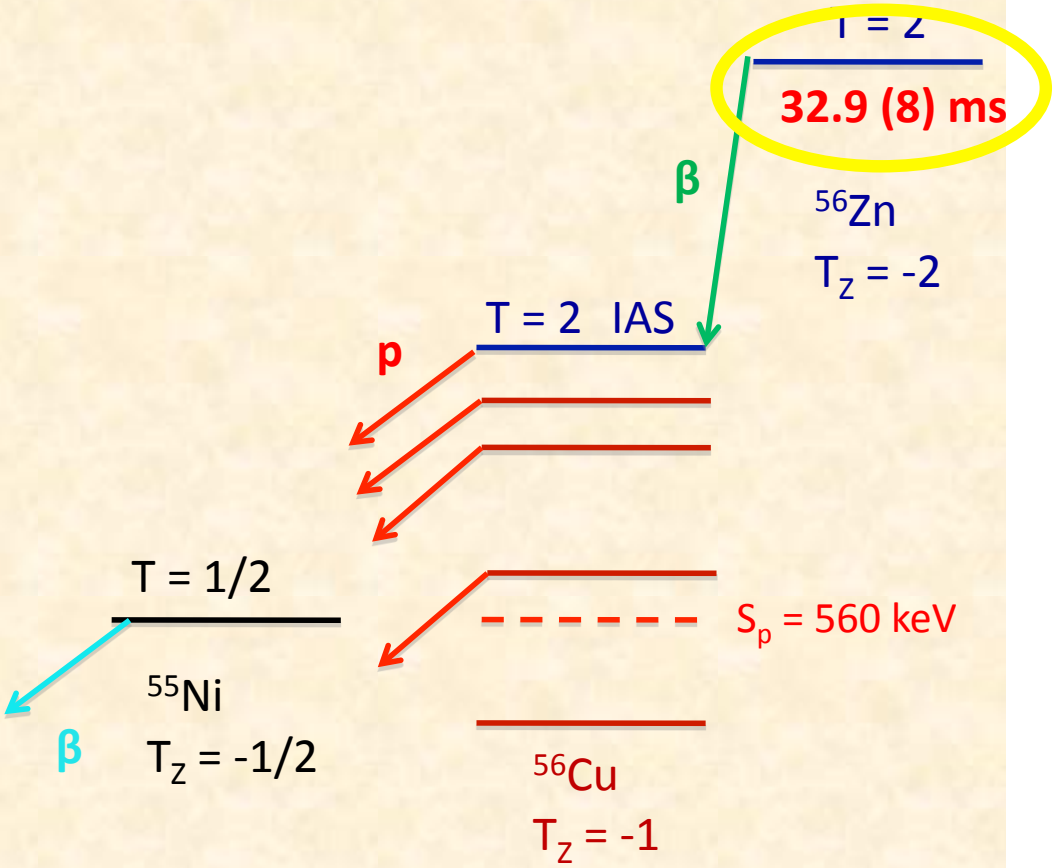


Particle spectrum, mainly protons

300 μm DSSD detector

Half-life analysis for ^{56}Zn (T_Z = -2) using beta delayed protons

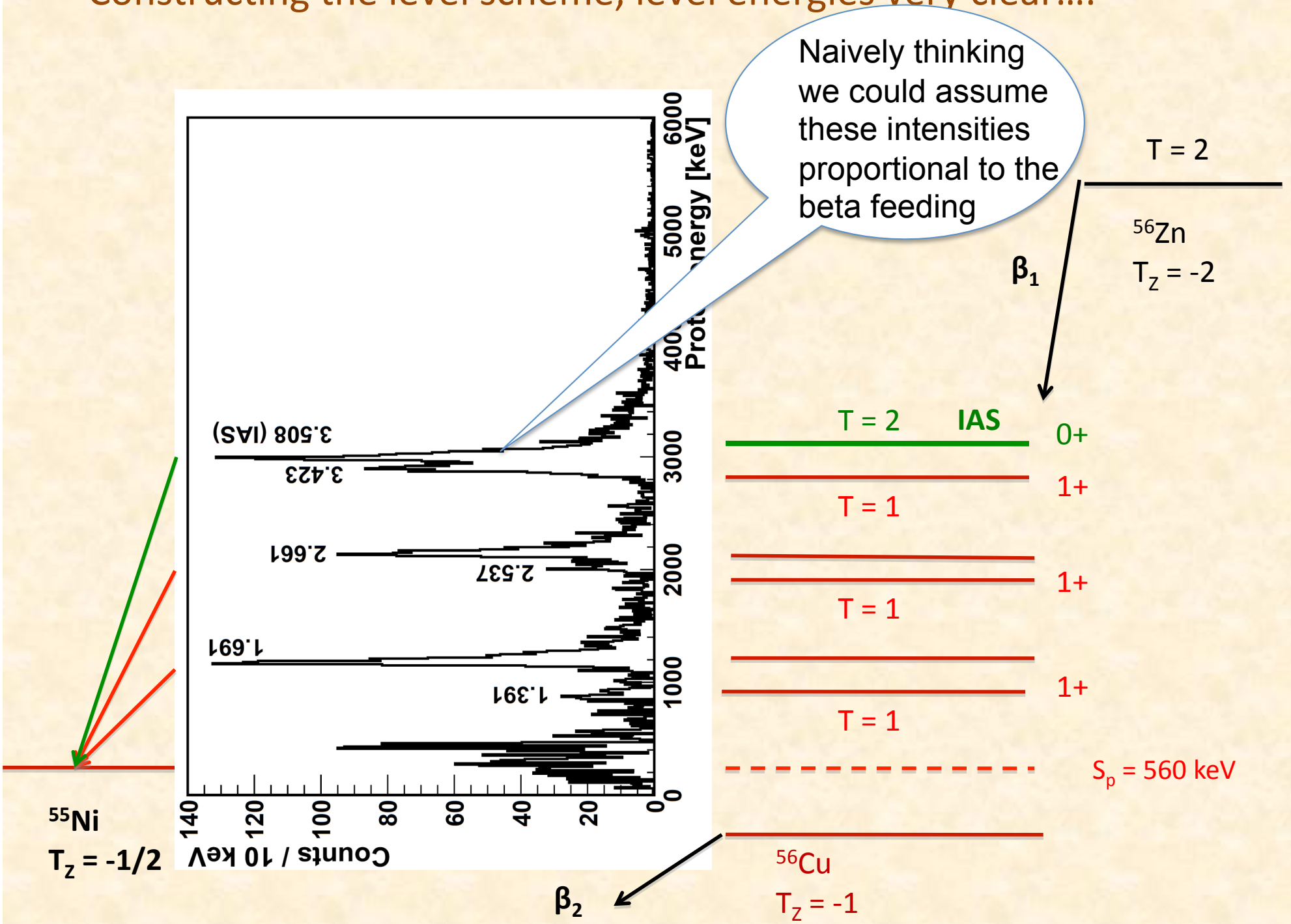




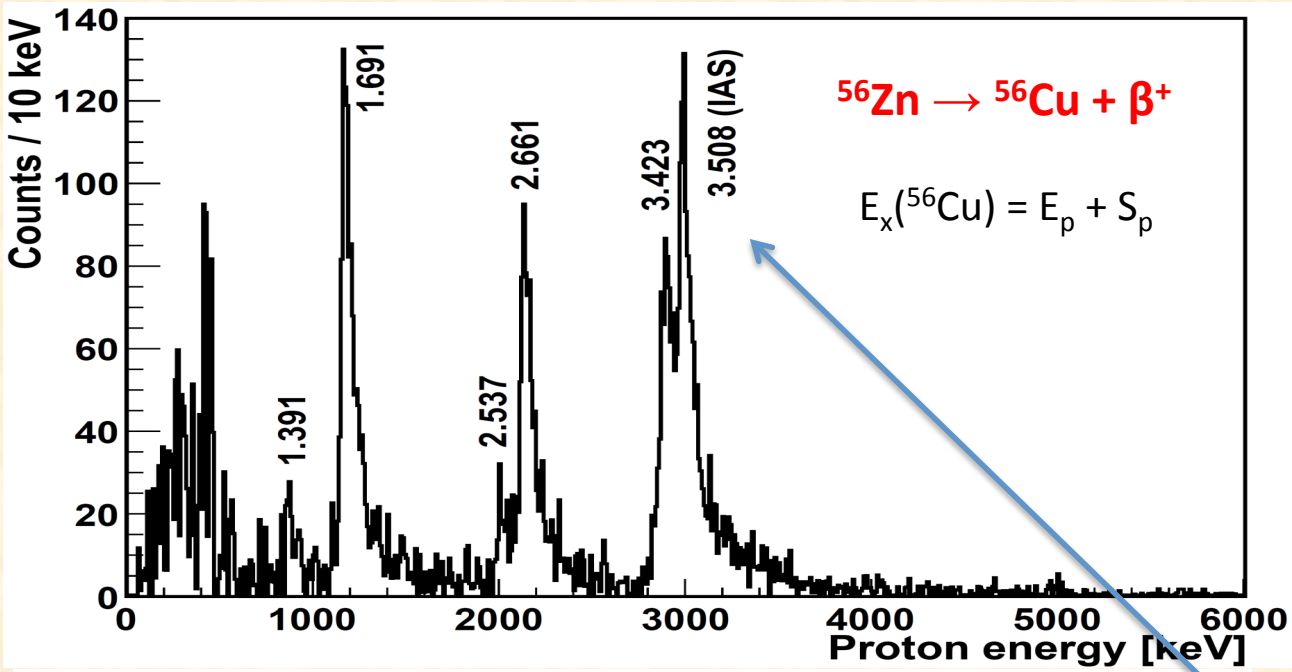
Literature:

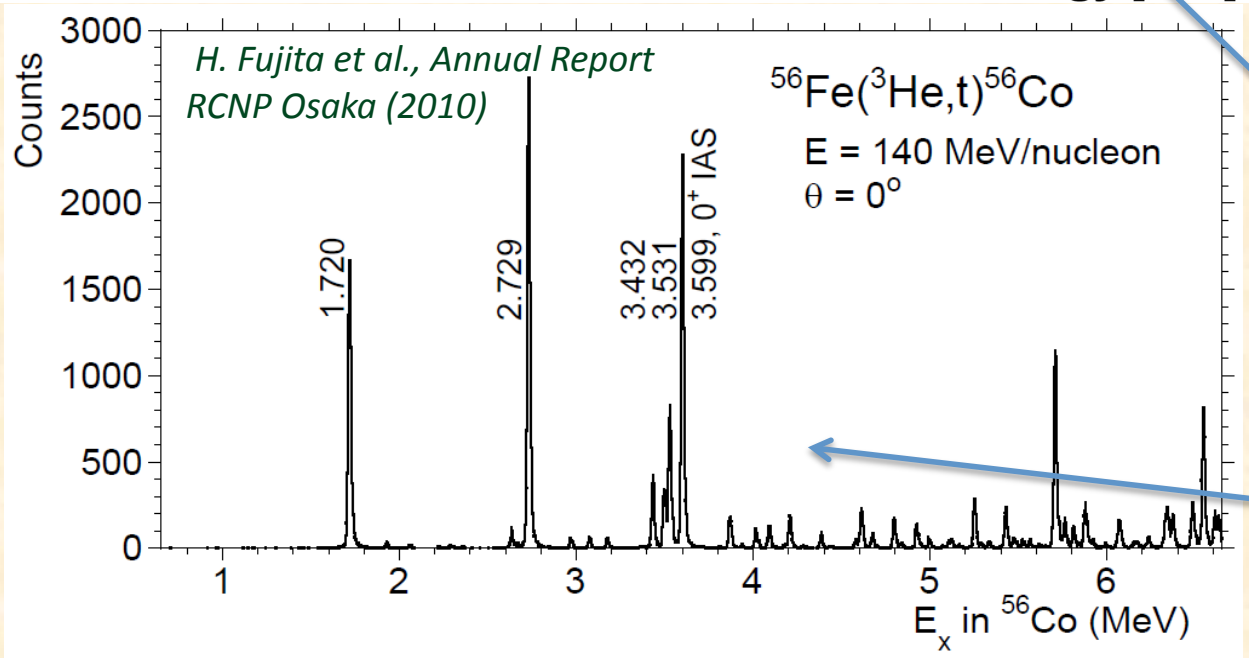
$T_{1/2}$ = 30 ± 1.7 ms (*C. Dossat et al., NPA 792(2007)18*)

Constructing the level scheme, level energies very clear….



Comparison of mirror transitions for A = 56

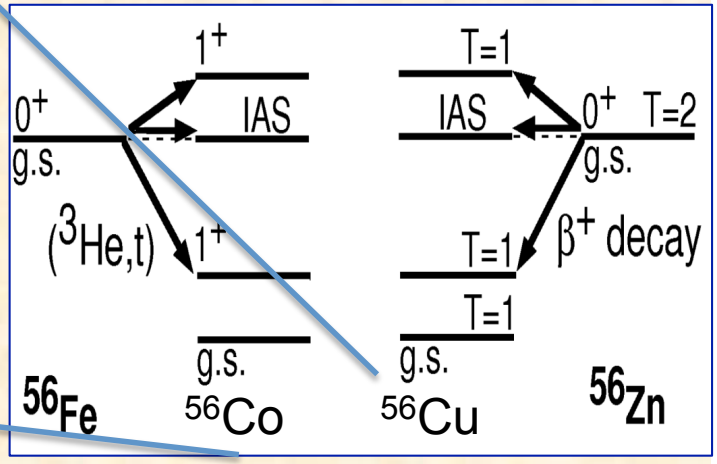




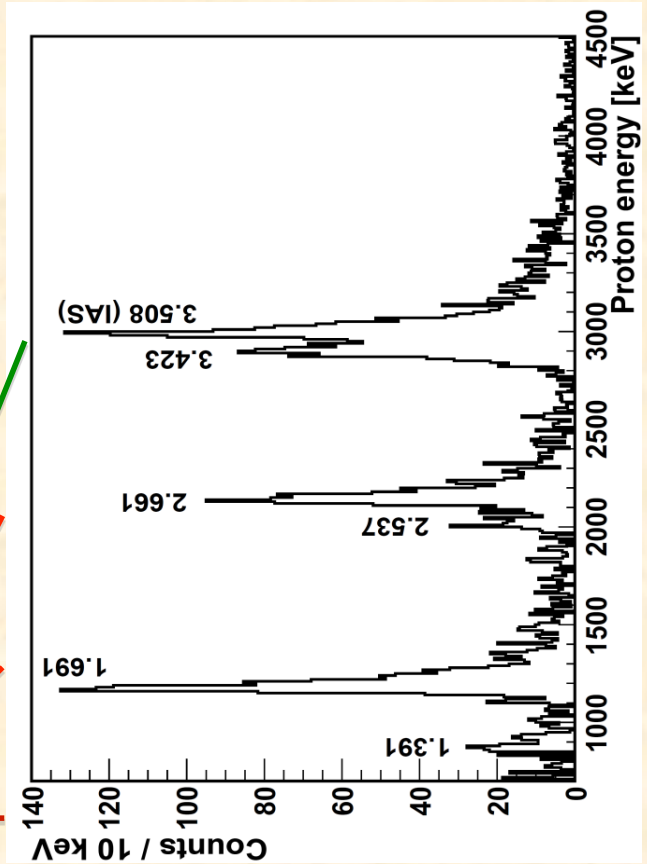
The **Isobaric Analog State (IAS)** is clearly identified in both spectra (In agreement with previous data *(C. Dossat et al., NPA 792(2007)18)*

Isospin symmetry holds well !

All the dominant transitions are observed in both β decay and CE starting from mirror nuclei



Constructing the ^{56}Zn decay scheme…



p (T =1/ 2)

^{55}Ni

T_z = -1/2

T=1/2

The p-decay of the IAS is isospin forbidden

T = 2

0+

^{56}Zn

T_z = -2

β

T = 2 IAS

0+

1+

T = 1

γ ??

1+

T = 1

1+

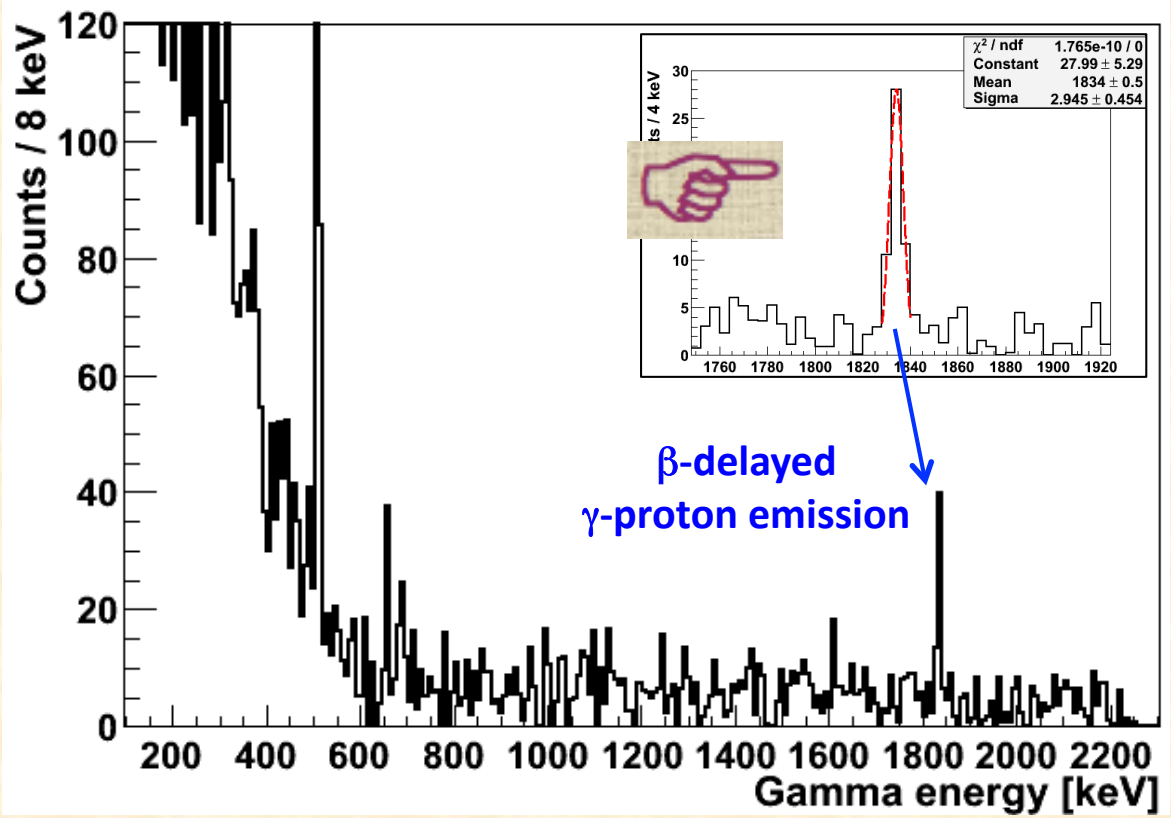
T = 1

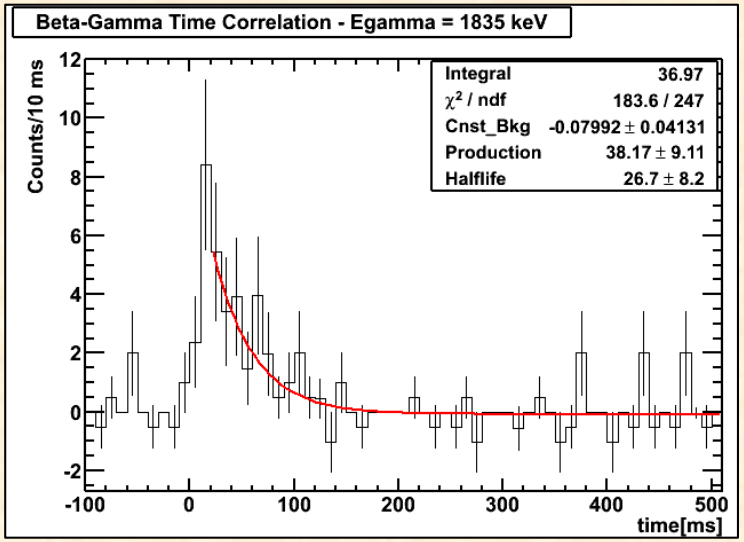
S_p = 560 keV

^{56}Cu

T_z = -1

Indeed we observed the gamma transition deexciting the IAS





A γ ray at 1834.5 ± 1.0 keV is observed in the ^{56}Zn-correlated γ-spectrum corresponding to the de-excitation of the IAS

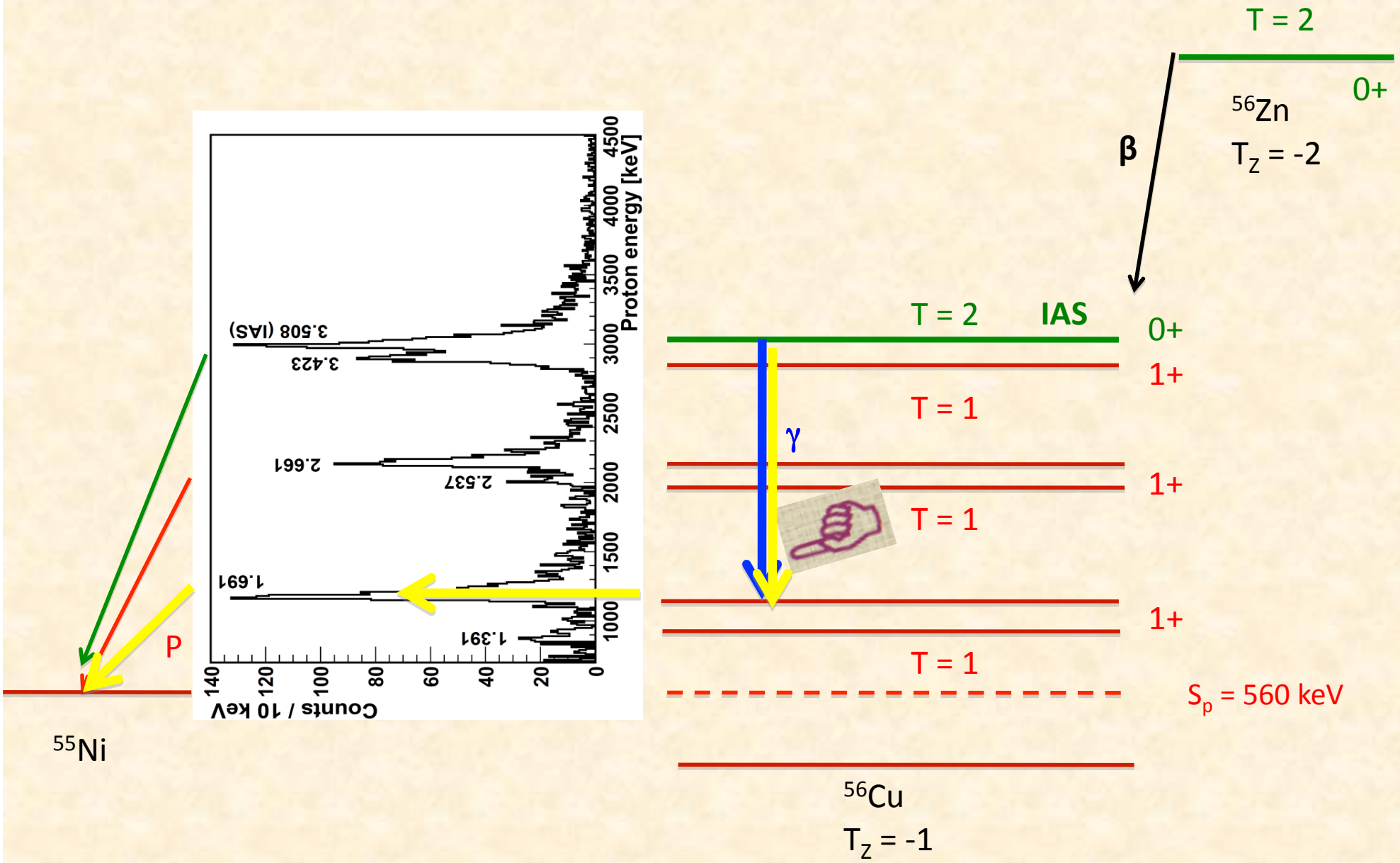
✓(β-γ)-implant time correlations

$T_{1/2}$ = (27 ± 8) ms

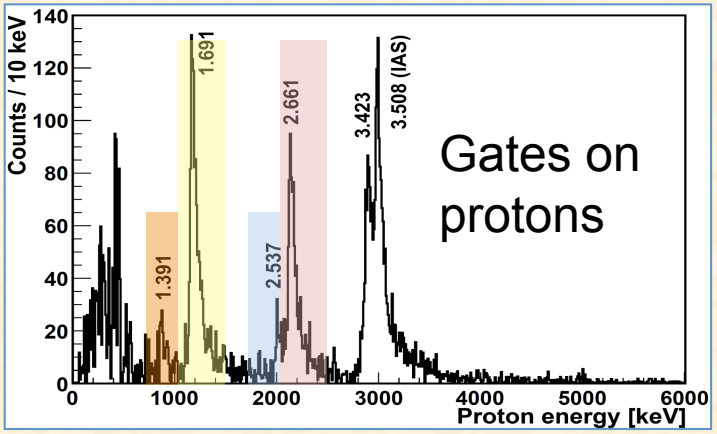
✓ In agreement with the β-implant time correlation value:

$T_{1/2}$ = (32.9 ± 0.8) ms

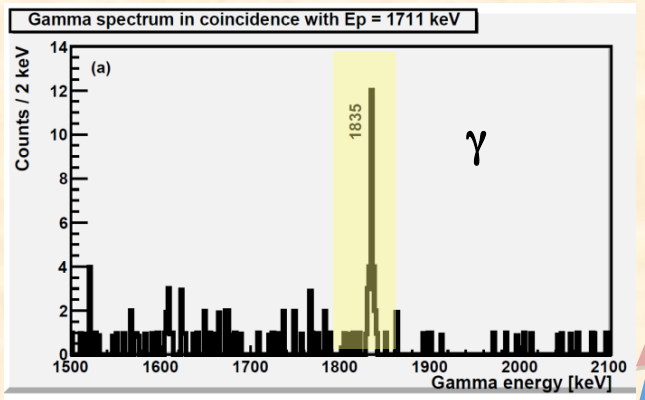
This is the first observation of Beta-delayed gamma-proton decay in the fp shell

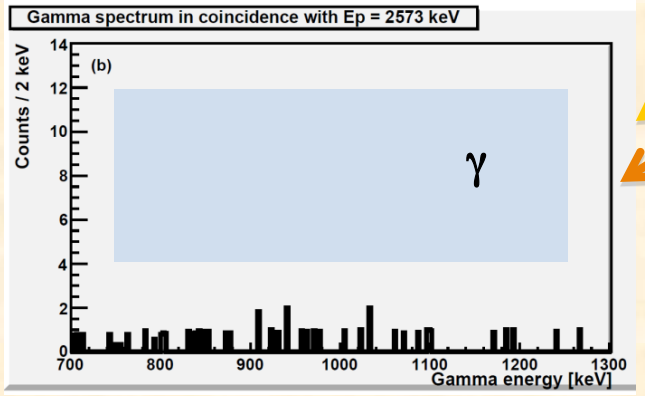


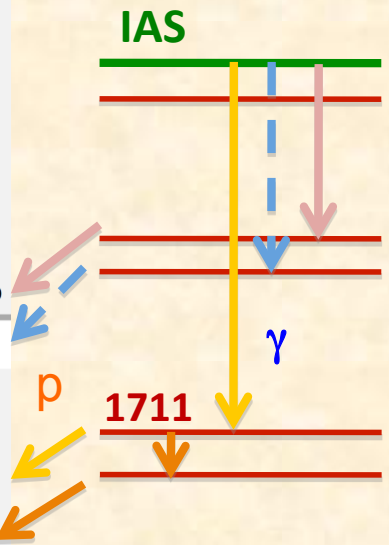
Proton-gamma coincidences

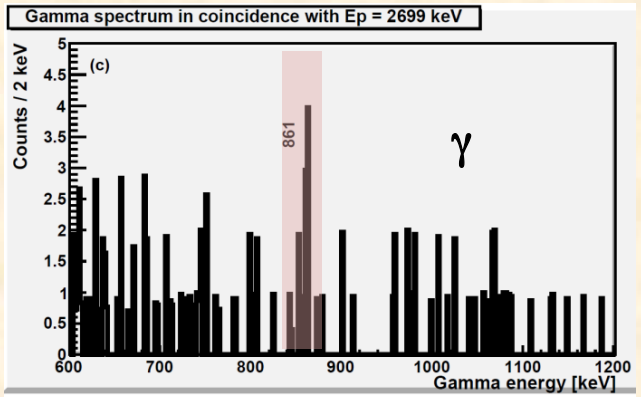


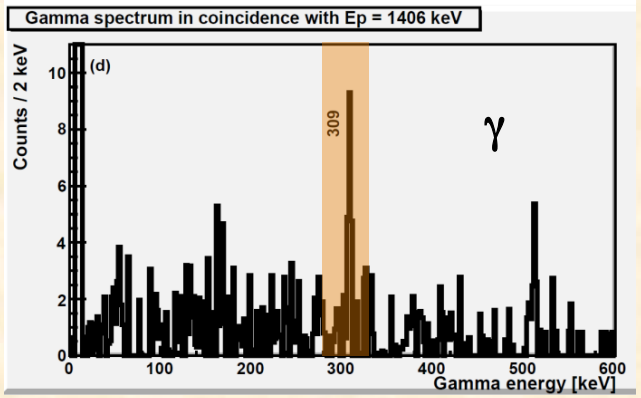
We have observed for the first time beta-delayed gamma-proton emission In three cases !!



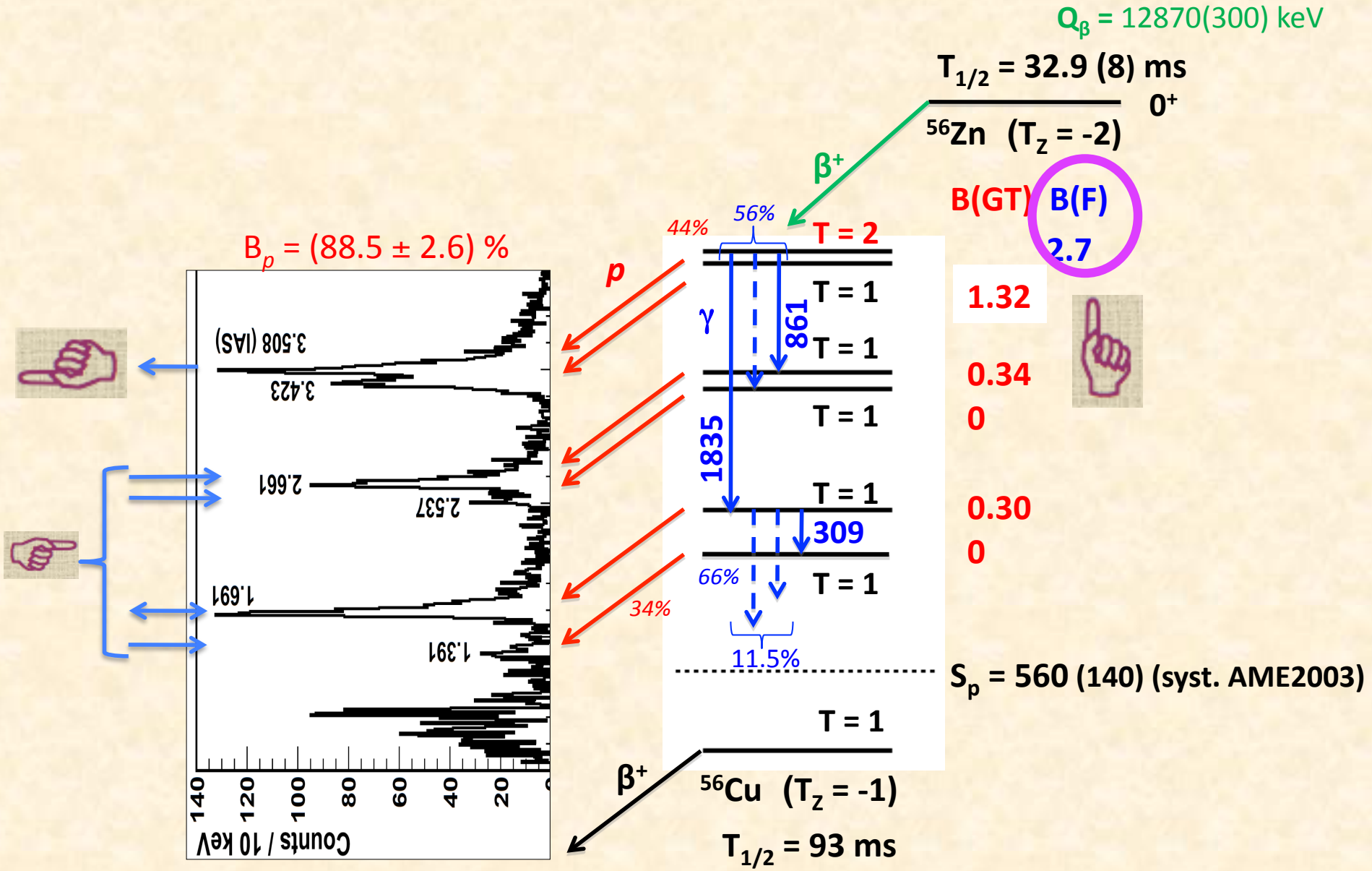




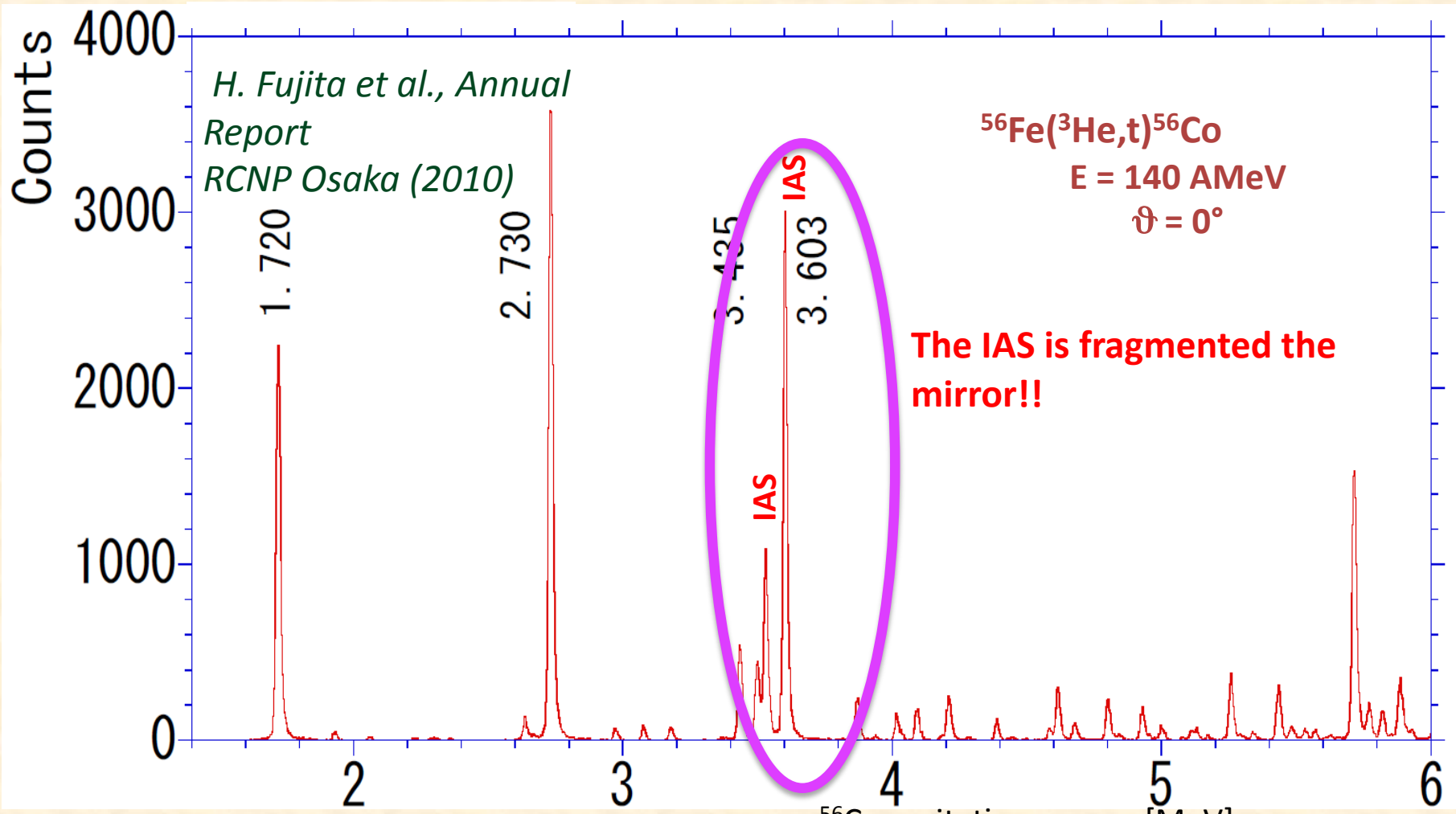


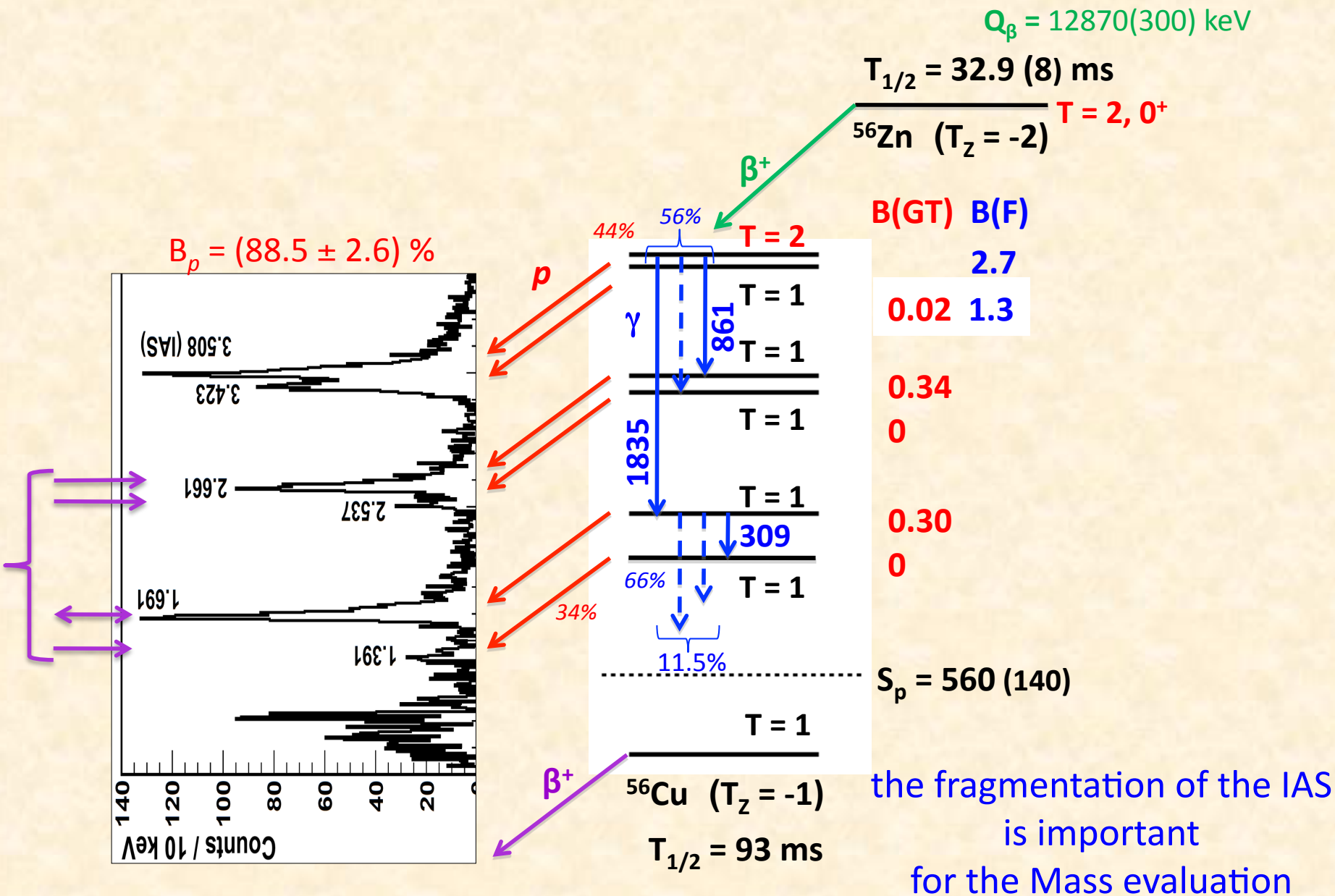


^{56}Zn decay scheme, another surprise

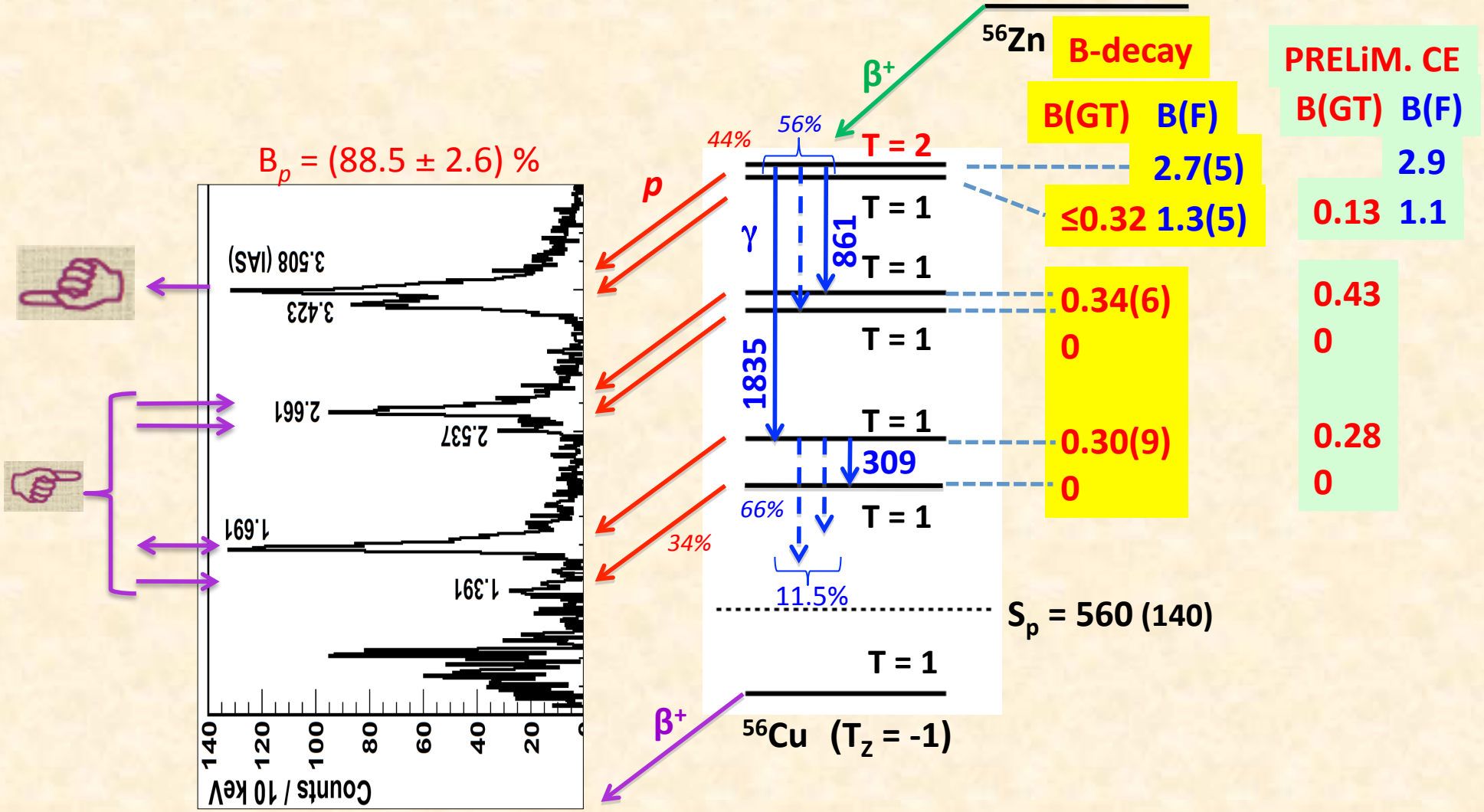


But this is NOT the end of the story!!!

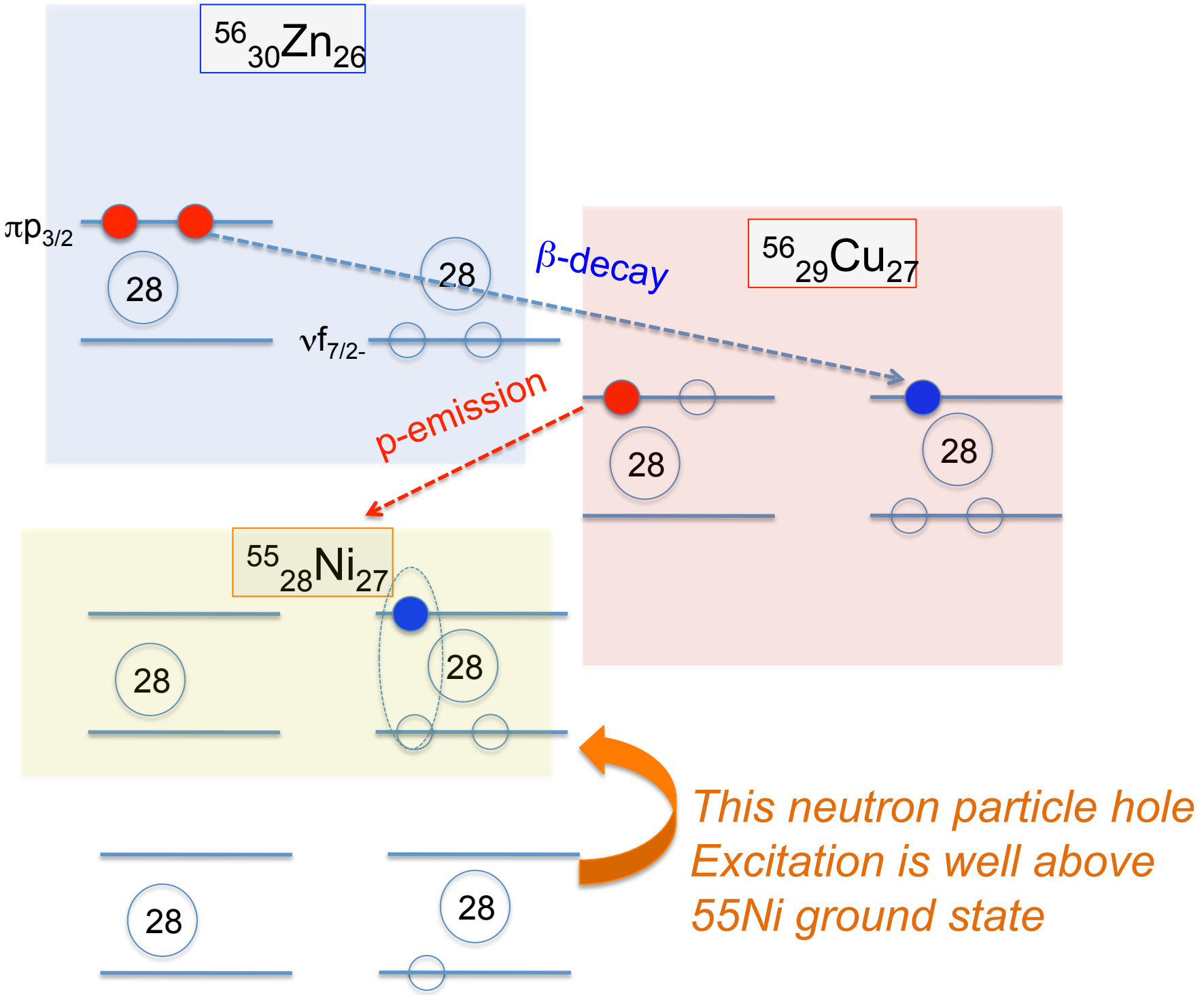


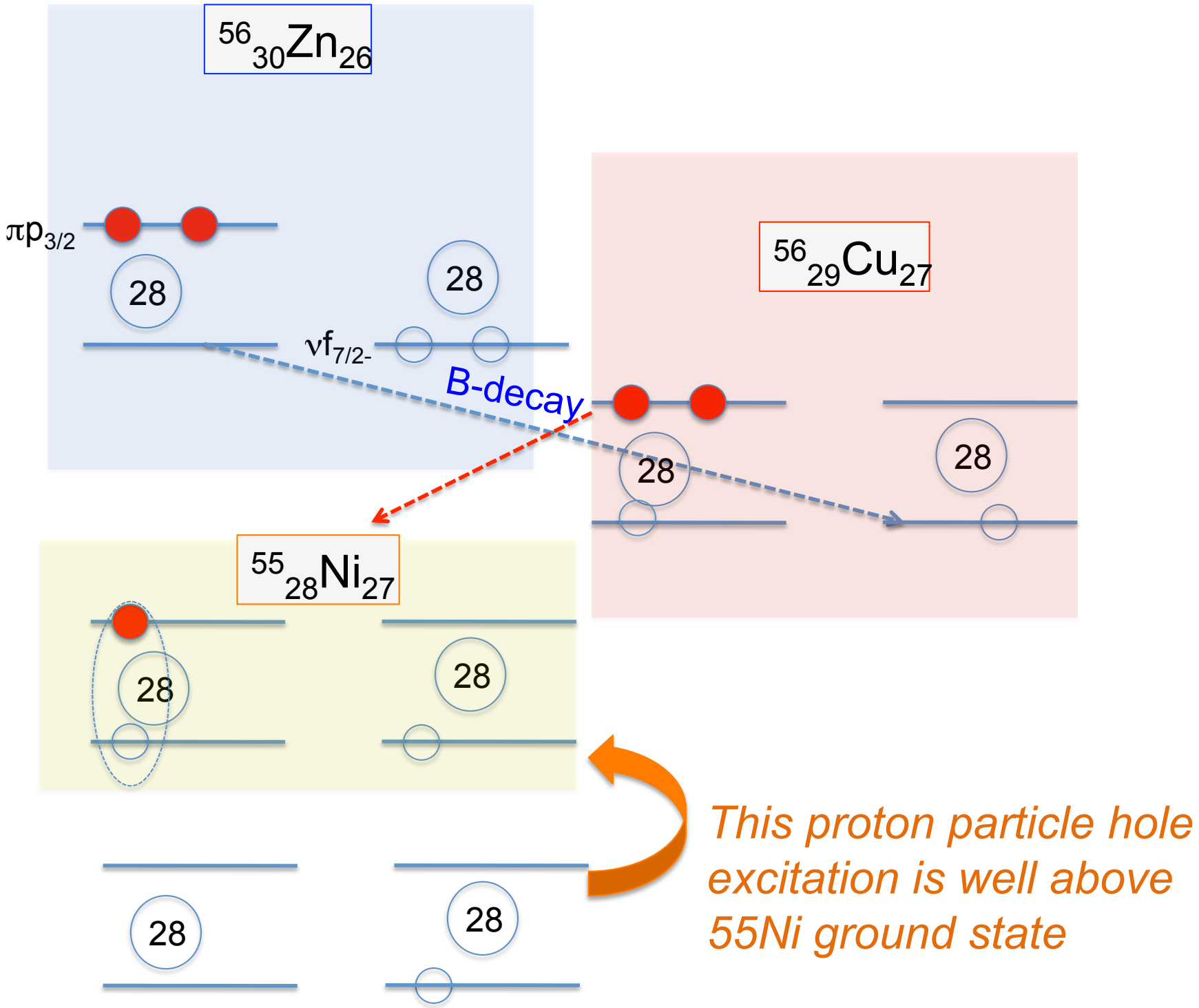

Q_β = 12870(300) keV
$T_{1/2}$ = 32.9 (8) ms
^{56}Zn (T_z = -2)
T = 2, 0$^+$
β^+
B(GT) B(F)
B_p = (88.5 ± 2.6) %
44%
56%
T = 2
T = 1
T = 1
T = 1
T = 1
T = 1
2.7
0.02 1.3
0.34
0
0.30
0
p
γ
861
1835
309
66%
34%
11.5%
S_p = 560 (140)
3.508 (IAS)
3.423
2.661
2.537
1.691
1.391
Counts / 10 keV
140
120
100
80
60
40
20
β^+
^{56}Cu (T_z = -1)
$T_{1/2}$ = 93 ms
the fragmentation of the IAS
is important
for the Mass evaluation

And now we can comapre with the Charge Exchange reaction in the mirrow



We were puzzled for some time


$^{56}_{30}Zn_{26}$
$\pi p_{3/2}$
28
28
$\nu f_{7/2-}$
β-decay
$^{56}_{29}Cu_{27}$
p-emission
28
28
$^{55}_{28}Ni_{27}$
28
28
28
28
This neutron particle hole
Excitation is well above
55Ni ground state


$^{56}_{30}Zn_{26}$
$\pi p_{3/2}$
28
28
$\nu f_{7/2-}$
B-decay
$^{56}_{29}Cu_{27}$
28
28
$^{55}_{28}Ni_{27}$
28
28
28
28
This proton particle hole excitation is well above 55Ni ground state

Summary

"Mirror symmetry Is beautiful"

I have presented the study of the beta decay of the Tz=-2 nucleus 56Zn carried out at GANIL-LISE

We have measured the beta, the protons and the gammas after the decay,

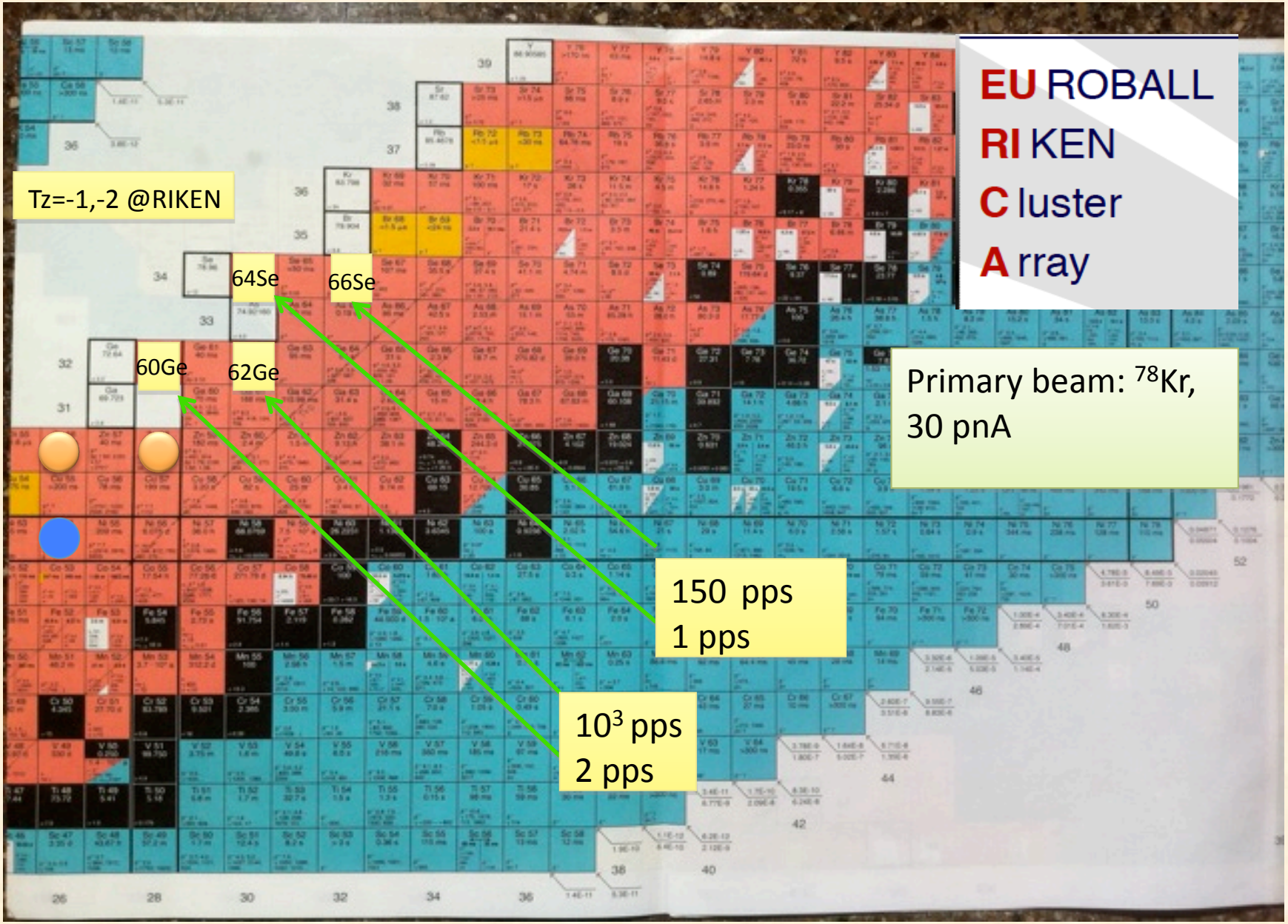
We have observed evidence of the fragmentation of the isobaric analogue state

We have now a good understanding of this decay which could have never been possible without the information from the mirror nucleus 56Fe, in particular the CE experiment at Osaka.

Nuclear structure seams to be ultimately the responsible of the proton-gamma competition observed.

We have observed, for the first time the beta-delayed gamma-proton Decay in the *fp* shell in three branches, this exotic decay affects the conventional way of obtaining the B(F) and B(GT) in exotic proton rich nuclei.

Future studies (hopefully soon) at RIKEN



The Collaboration

Physical review Letters, in print

Observation of the β-delayed γ-proton decay of ^{56}Zn and its impact on the Gamow Teller strength evaluation

S. E. A. Orrigo,[1,*] B. Rubio,[1] Y. Fujita,[2,3] B. Blank,[4] W. Gelletly,[5] J. Agramunt,[1] A. Algora,[1,6] P. Ascher,[4] B. Bilgier,[7] L. Cáceres,[8] R. B. Cakirli,[7] H. Fujita,[3] E. Ganioğlu,[7] M. Gerbaux,[4] J. Giovinazzo,[4] S. Grévy,[4] O. Kamalou,[8] H. C. Kozer,[7] L. Kucuk,[7] T. Kurtukian-Nieto,[4] F. Molina,[1,9] L. Popescu,[10] A. M. Rogers,[11] G. Susoy,[7] C. Stodel,[8] T. Suzuki,[3] A. Tamii,[3] and J. C. Thomas[8]

[1] *Instituto de Física Corpuscular, CSIC-Universidad de Valencia, E-46071 Valencia, Spain*
[2] *Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[3] *Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan*
[4] *Centre d'Etudes Nucléaires de Bordeaux Gradignan, CNRS/IN2P3 - Université Bordeaux 1, 33175 Gradignan Cedex, France*
[5] *Department of Physics, University of Surrey, Guildford GU2 7XH, Surrey, UK*
[6] *Inst. of Nuclear Research of the Hung. Acad. of Sciences, Debrecen, H-4026, Hungary*
[7] *Department of Physics, Istanbul University, Istanbul, 34134, Turkey*
[8] *Grand Accélérateur National d'Ions Lourds, BP 55027, F-14076 Caen, France*
[9] *Comisión Chilena de Energía Nuclear, Casilla 188-D, Santiago, Chile*
[10] *SCK.CEN, Boeretang 200, 2400 Mol, Belgium*
[11] *Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*

END