ECOS-EURISOL Joint Town Meeting

Institut de Physique Nucléaire, Orsay

EURISOL ENSAR October 28-31, 2014

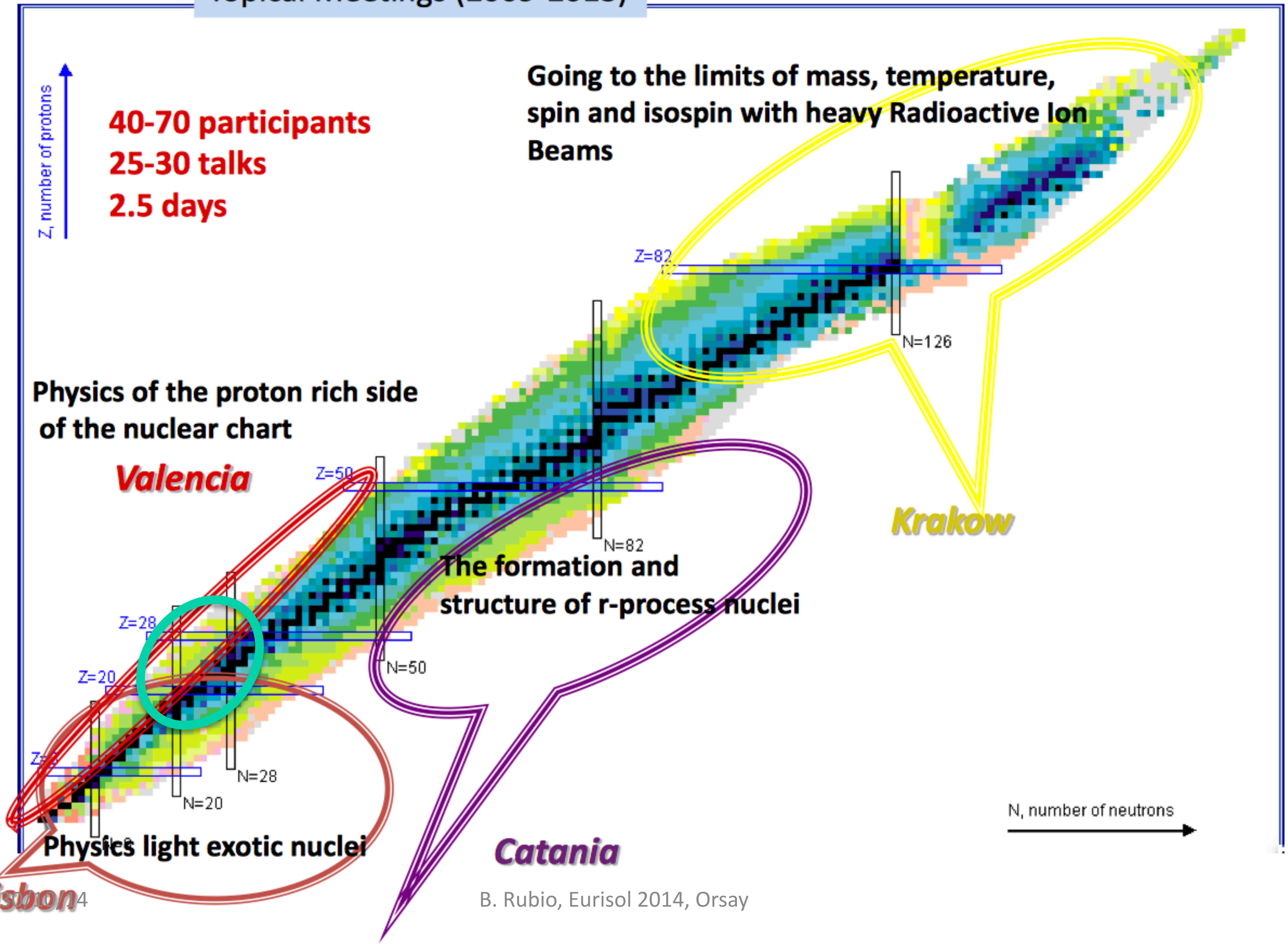
"Beta decay of exotic fp shell nuclei, exotic decay of fp shell nuclei"

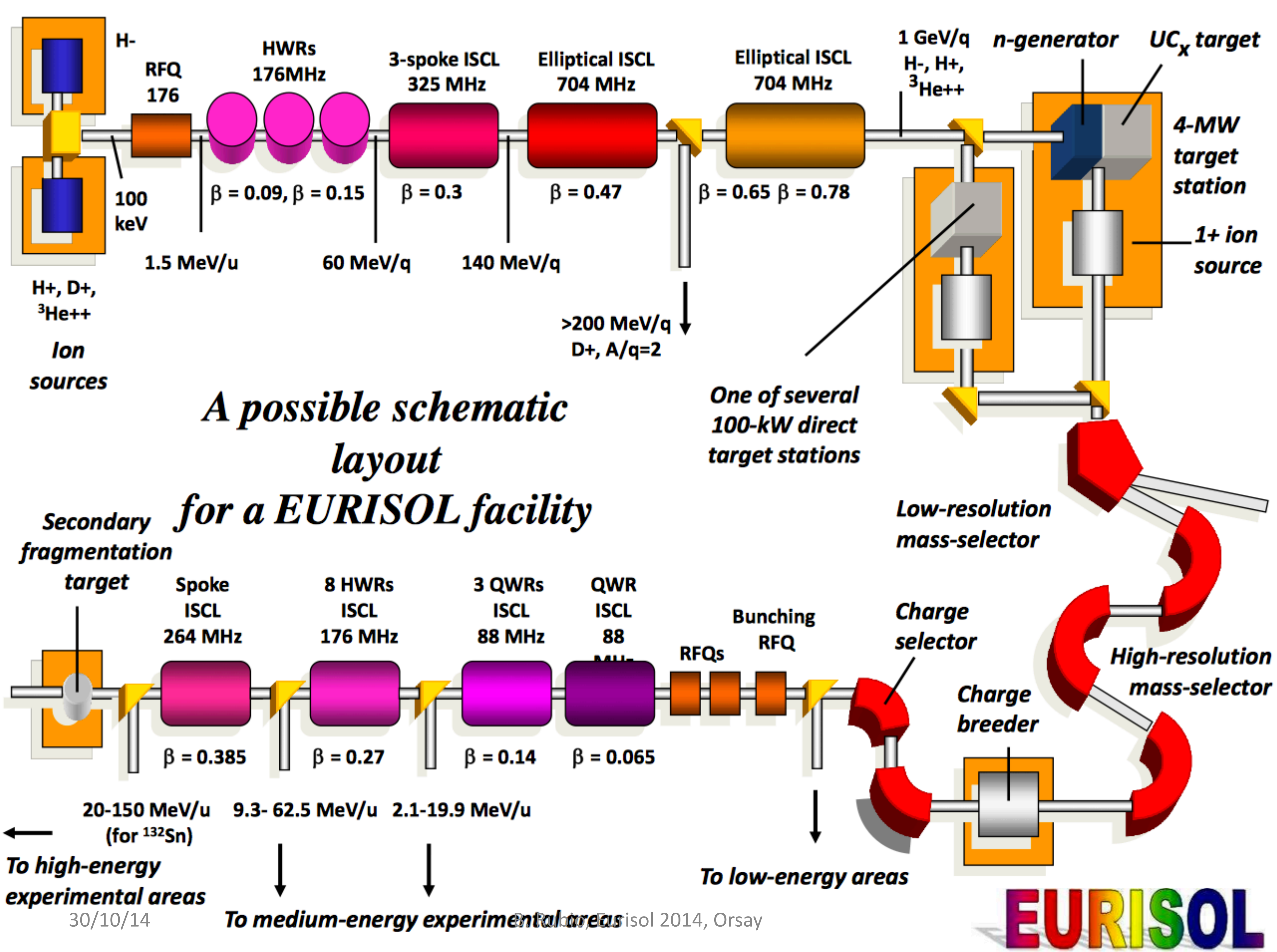
Berta Rubio
IFIC-Valencia

INFN Angela Bonaccorso
Istituto Nazionale di Fisica Nucleare

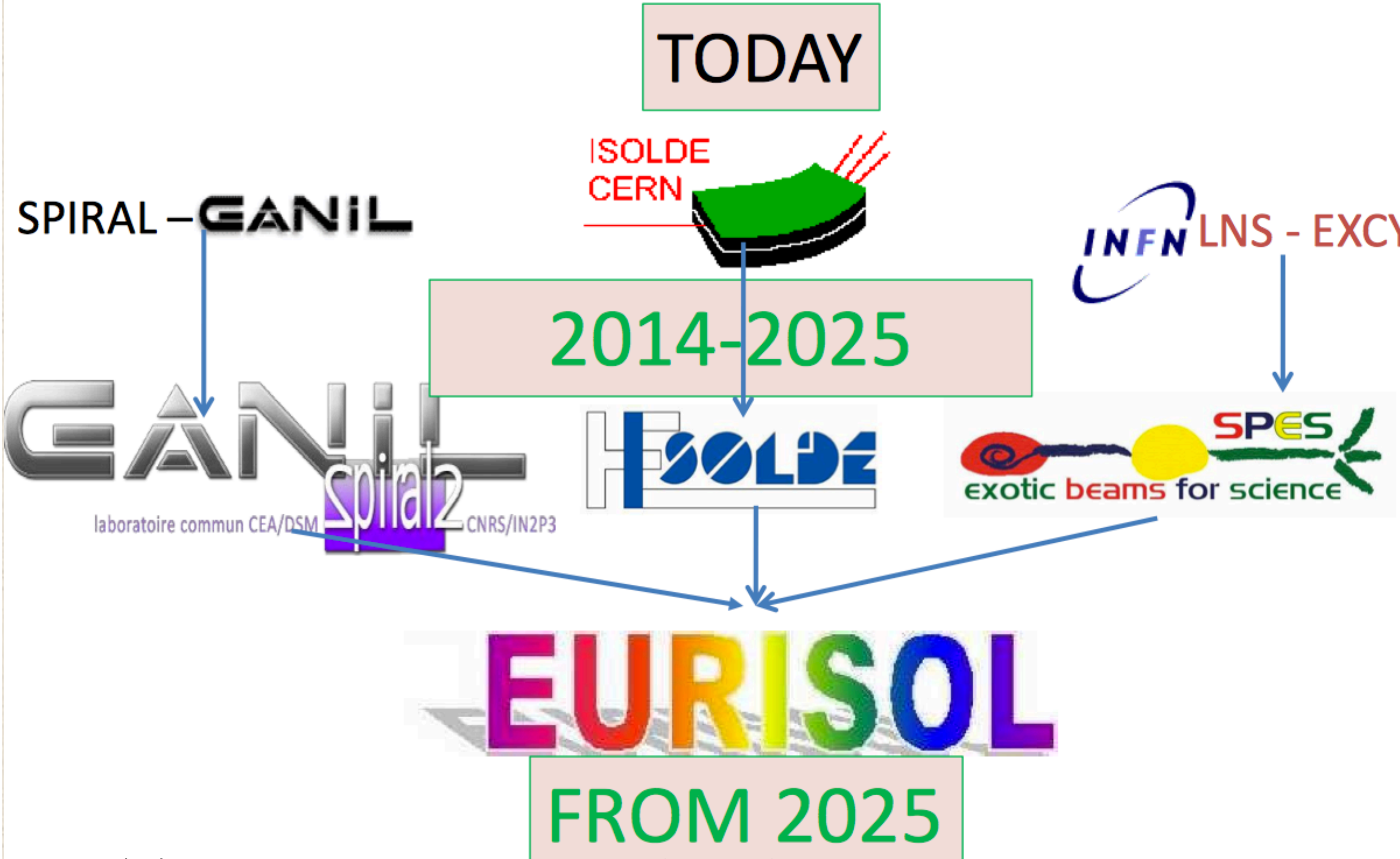
EURISOL User Group

Topical Meetings (2009-2013)




A possible schematic layout for a EURISOL facility
H-
RFQ 176
HWRs 176MHz
3-spoke ISCL 325 MHz
Elliptical ISCL 704 MHz
Elliptical ISCL 704 MHz
1 GeV/q H-, H+, ^{3}He++
n-generator
UC_x target
4-MW target station
1+ ion source
100 keV
β = 0.09, β = 0.15
β = 0.3
β = 0.47
β = 0.65 β = 0.78
1.5 MeV/u
60 MeV/q
140 MeV/q
H+, D+, ^{3}He++
Ion sources
>200 MeV/q D+, A/q=2
One of several 100-kW direct target stations
Low-resolution mass-selector
High-resolution mass-selector
Charge selector
Charge breeder
Secondary fragmentation target
Spoke ISCL 264 MHz
8 HWRs ISCL 176 MHz
3 QWRs ISCL 88 MHz
QWR ISCL 88
RFQs
Bunching RFQ
β = 0.385
β = 0.27
β = 0.14
β = 0.065
20-150 MeV/u (for ^{132}Sn)
9.3- 62.5 MeV/u
2.1-19.9 MeV/u
To high-energy experimental areas
To medium-energy experimental areas
To low-energy areas
EURISOL

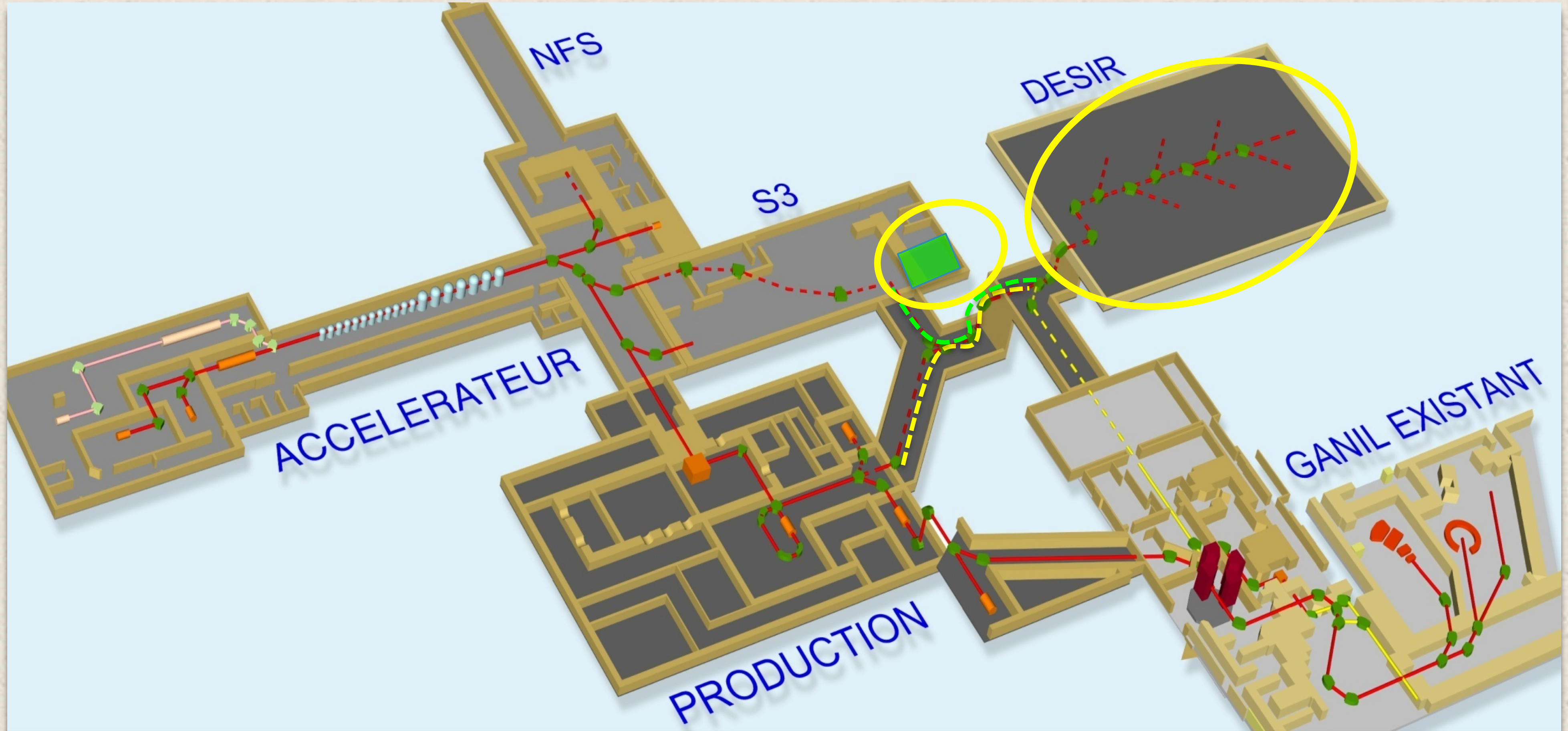
ISOL Roadmap in EUROPE



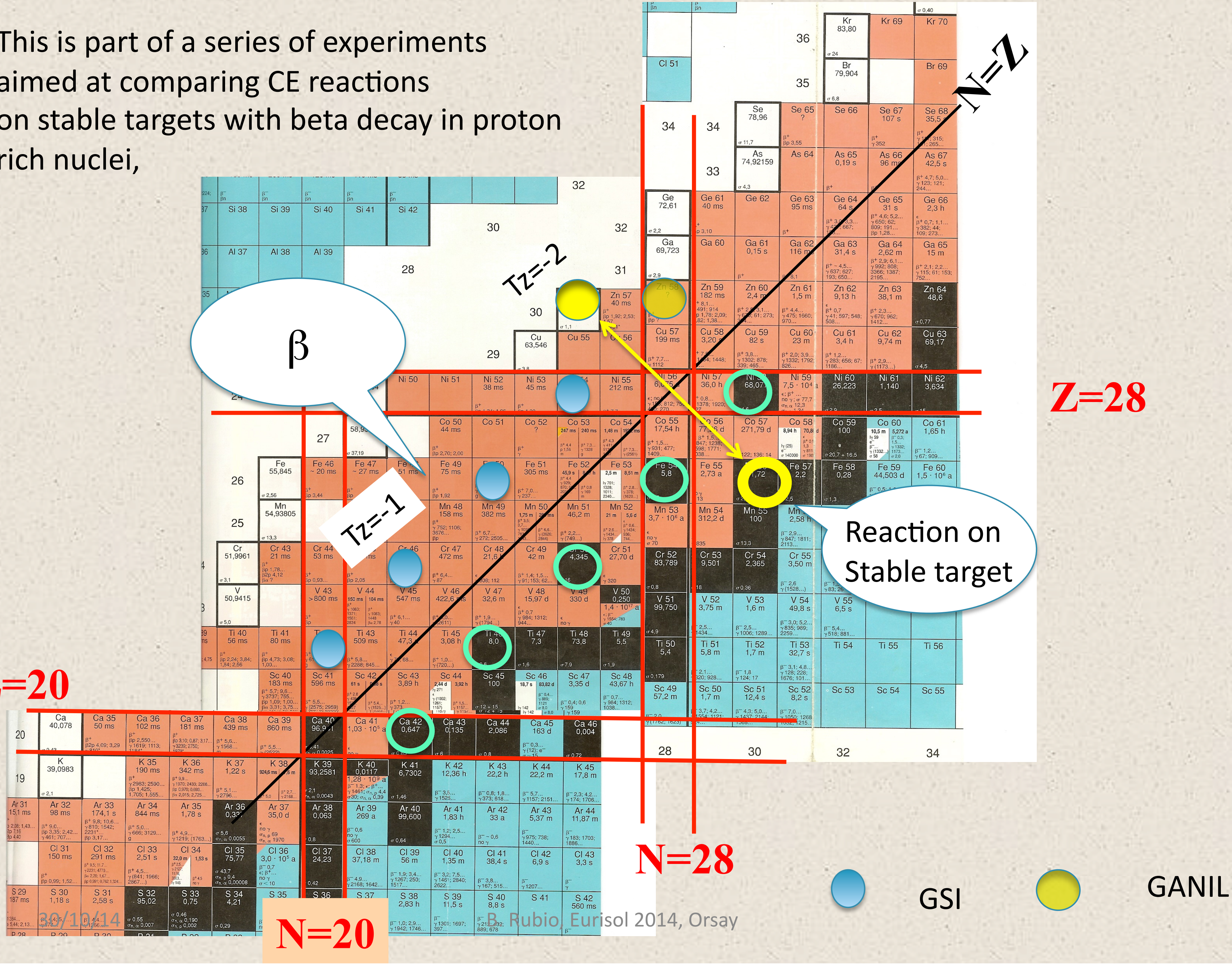
SPIRAL – GANIL

GANIL spiral2

laboratoire commun CEA/DSM CNRS/IN2P3



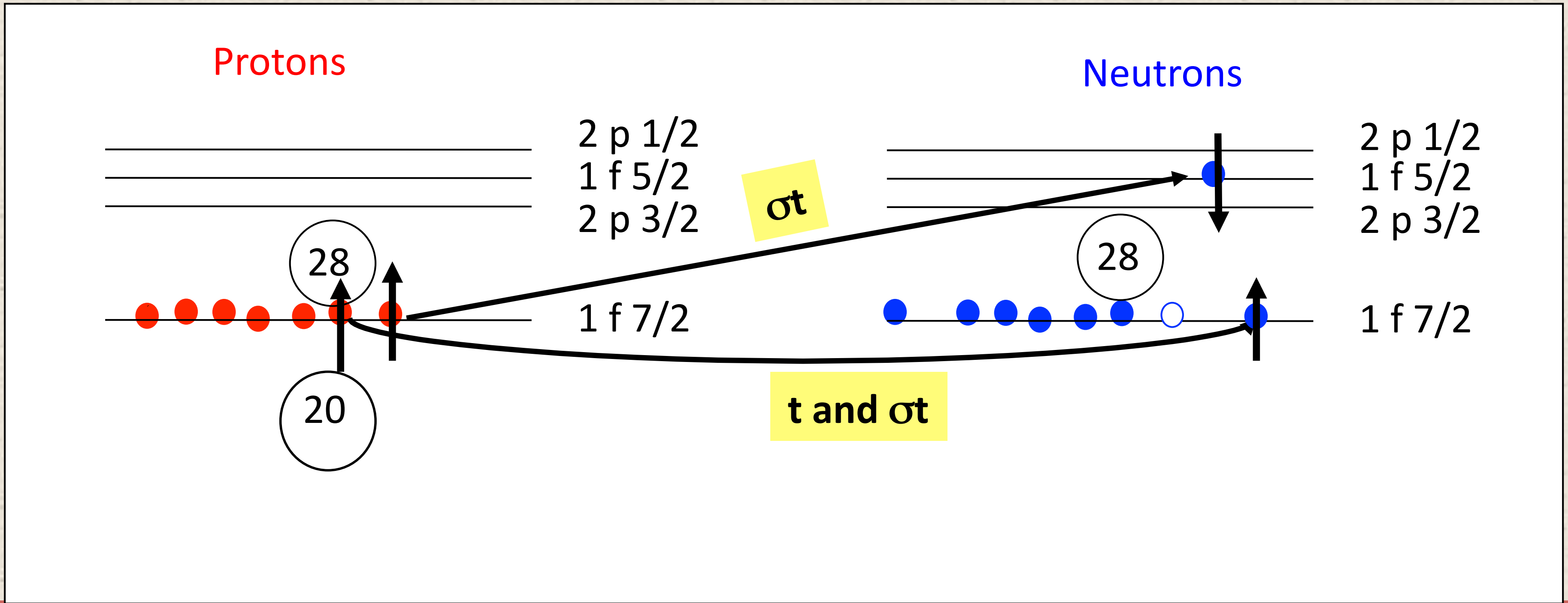
This is part of a series of experiments aimed at comparing CE reactions on stable targets with beta decay in proton rich nuclei,



Beta decay and Charge Exchange are two processes governed by the same operator

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

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

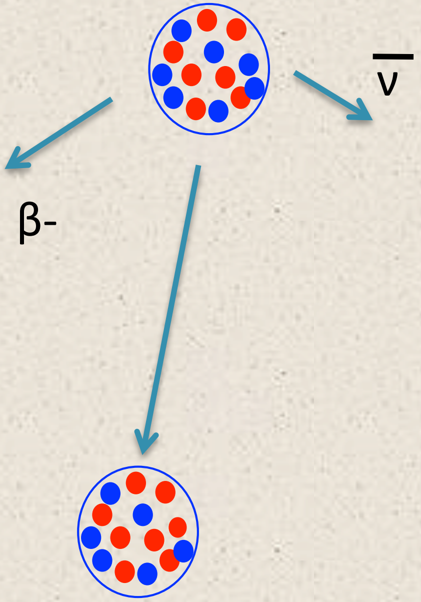


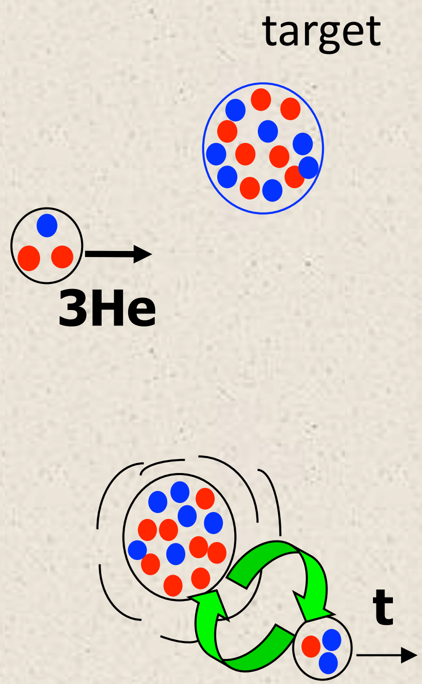
Beta decay

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

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

Charge Exchange Reactions





Beta Decay: Absolute Normalization of B(GT).

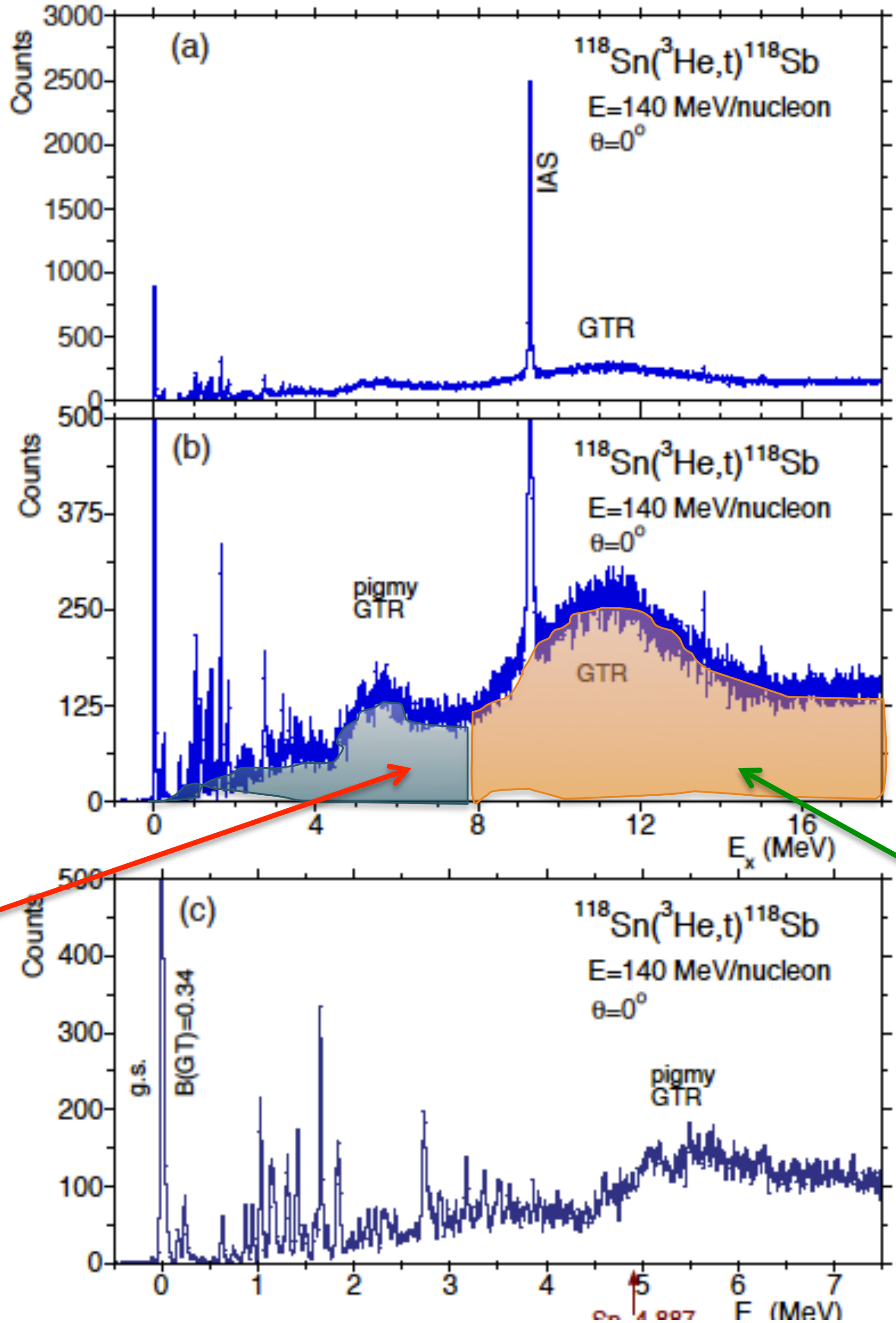
CE reactions: No restriction in excitation energy of Gamow-Teller states.

Fermi and GT strength observed in CE reactions

Fujita et al RCNP
Nuclear Physics
66 (2011) 549–606

Radioactive initial nucleus

Typical beta decay range



Stable Target Today

Radioactive nucleus

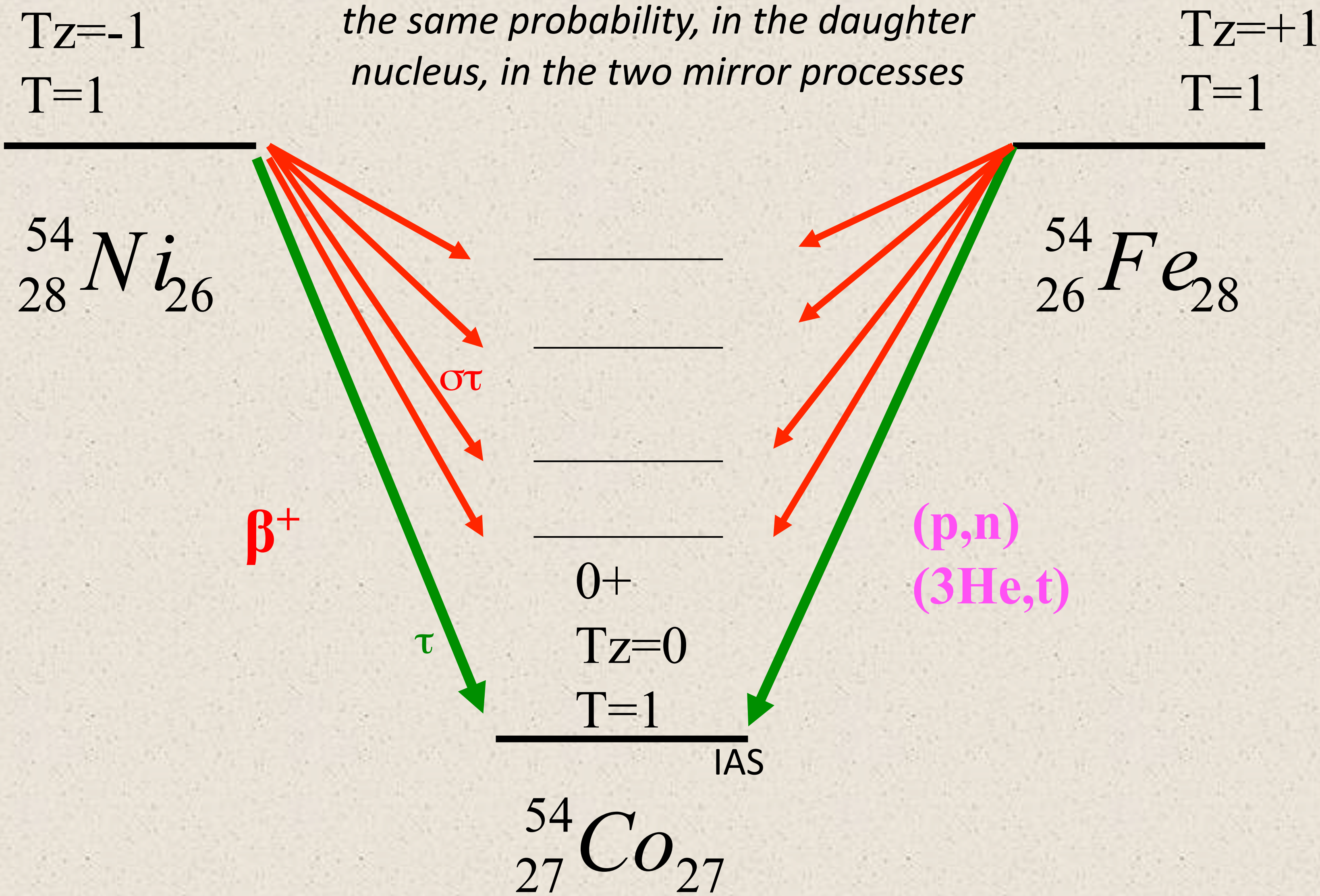
tomorrow

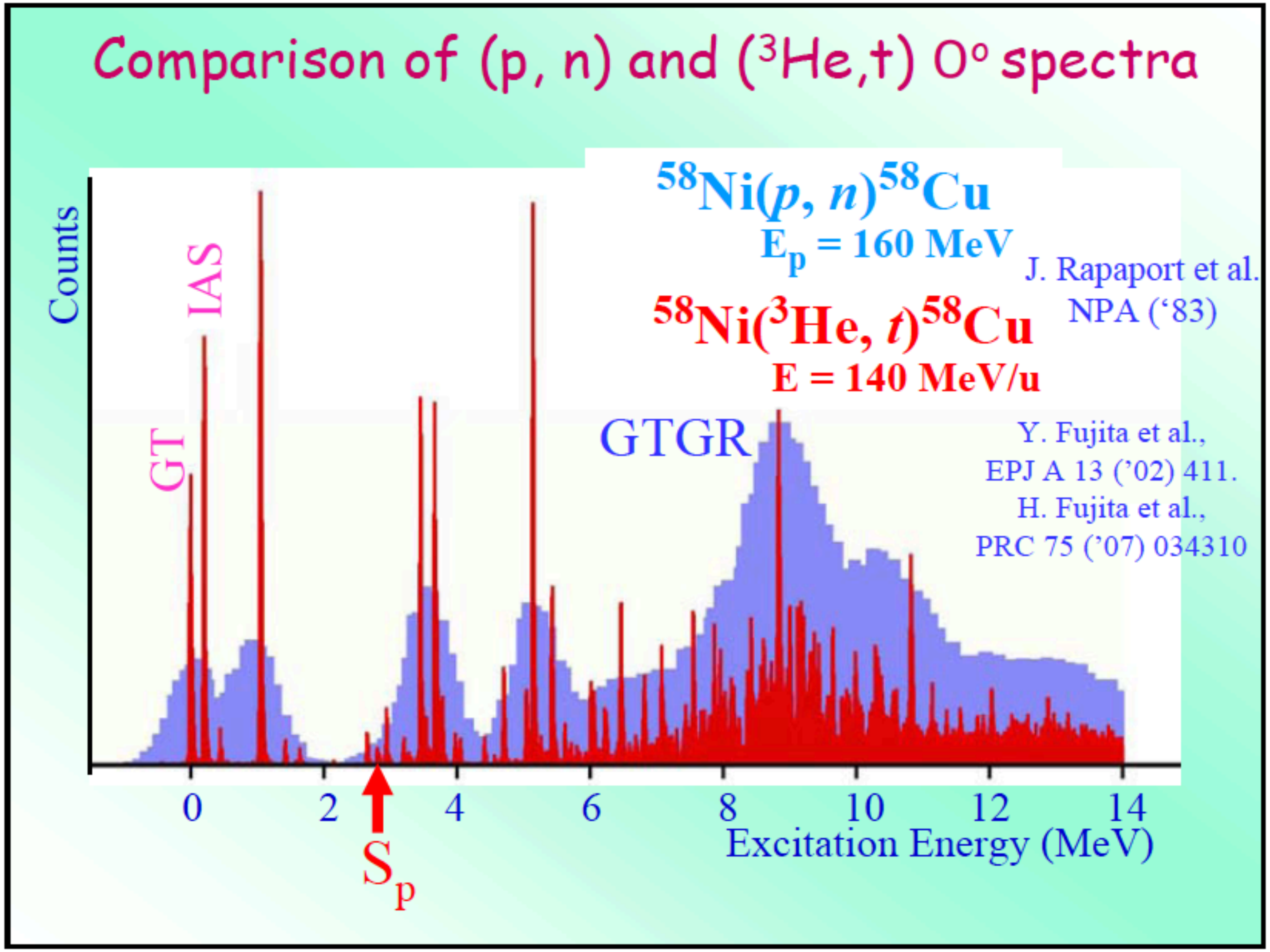
We need CE if
we want to know
What happens here

"Beta decay of exotic fp shell nuclei ”
(exotic here=short half lifes)

We could compare them in mirror nuclei

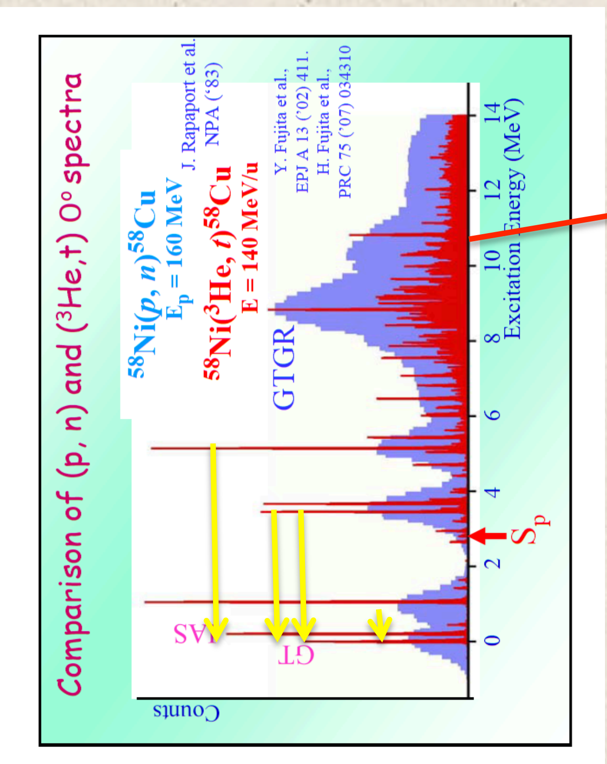
If isospin symmetry exists, mirror nuclei should populate the same states with the same probability, in the daughter nucleus, in the two mirror processes



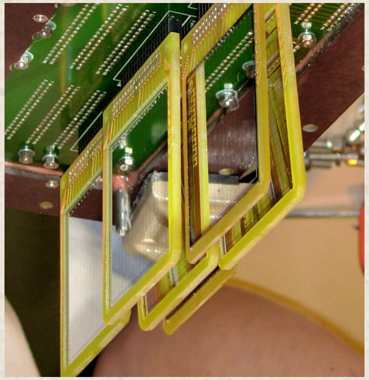


Courtesy Y. Fujita, quality of RCNP experiments with the Big Ridden spectrometer

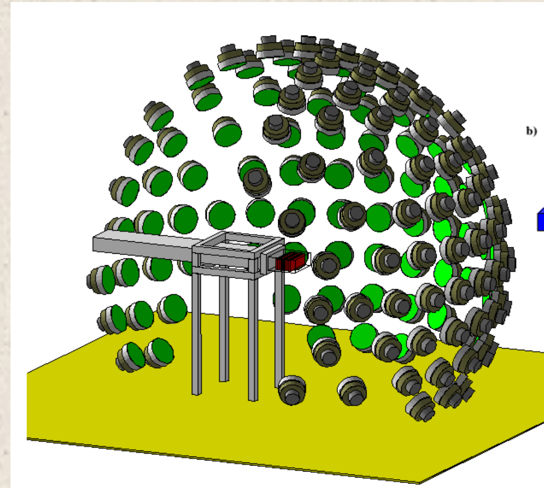
Charge exchange reactions in inverse kinematics
Cannot achieve the same energy resolution, one possibility
Is to look at the gamma de-excitation of the levels with a setup
with good Dopper correction



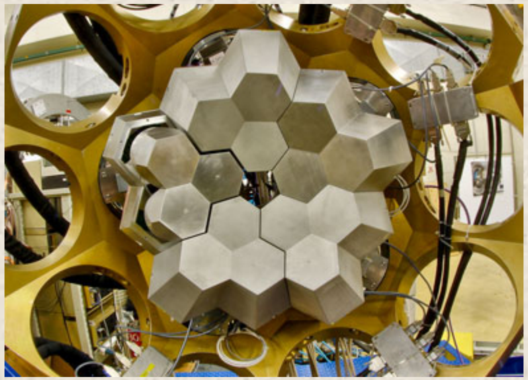
p



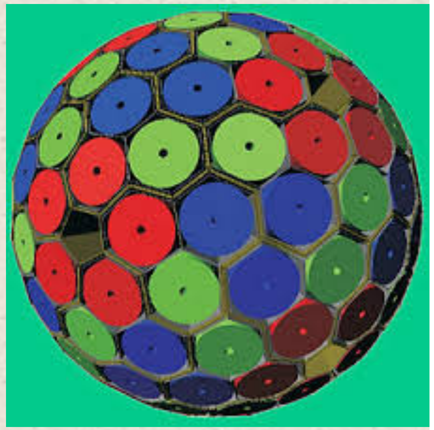
Today

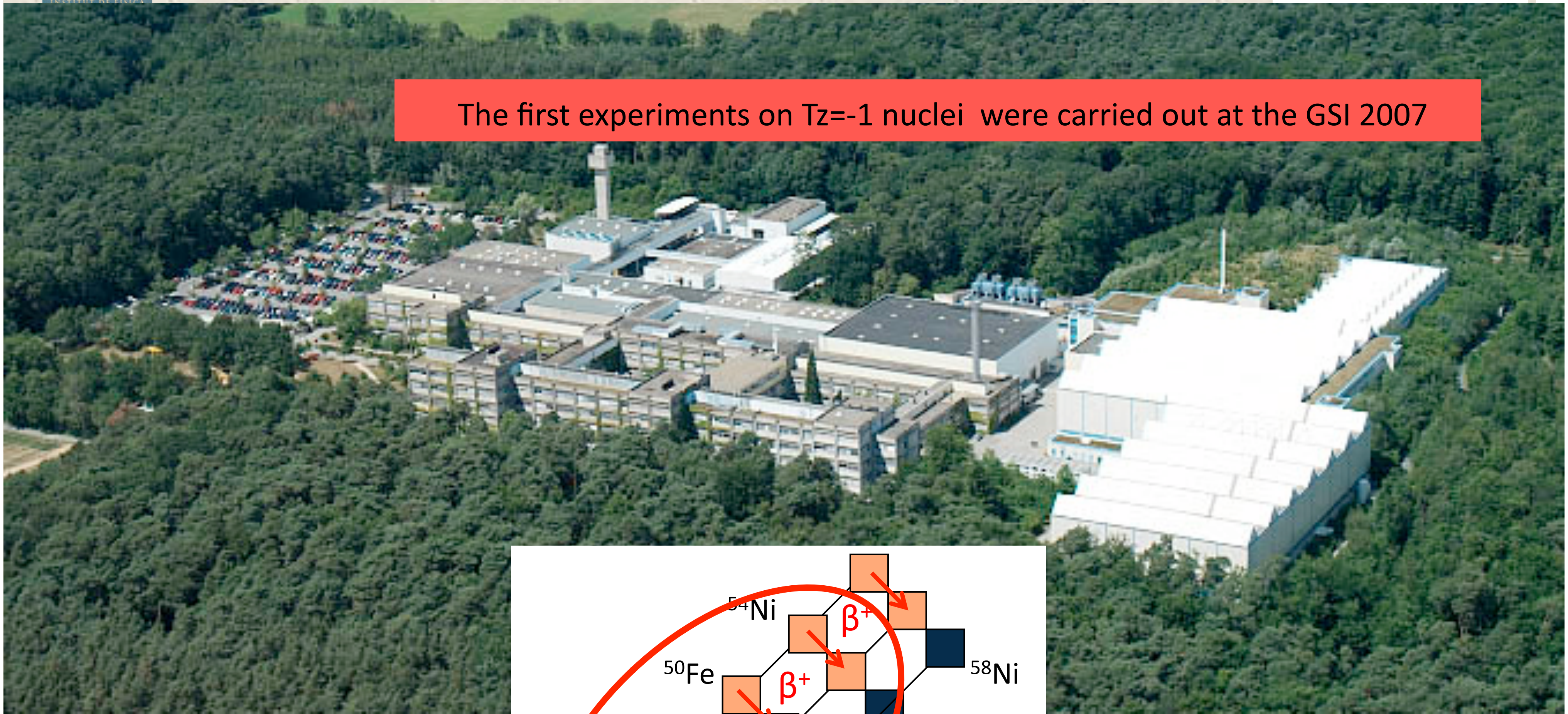


ow

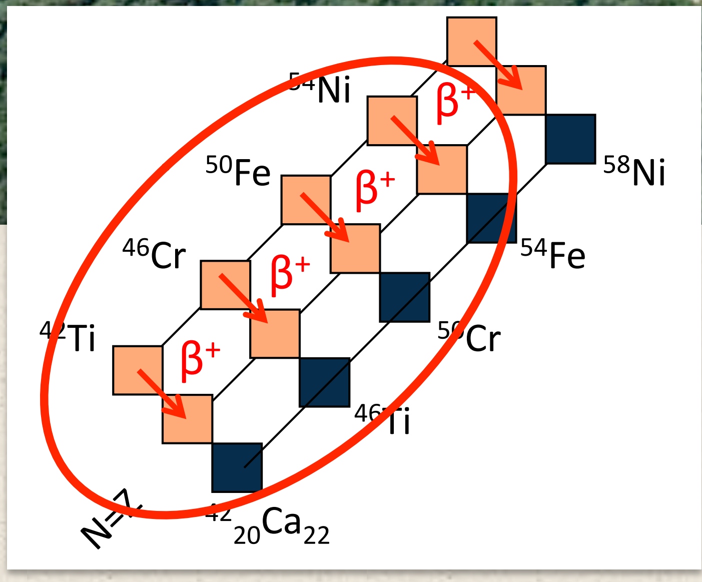


AGATA
ADVANCED GAMMA
TRACKING ARRAY

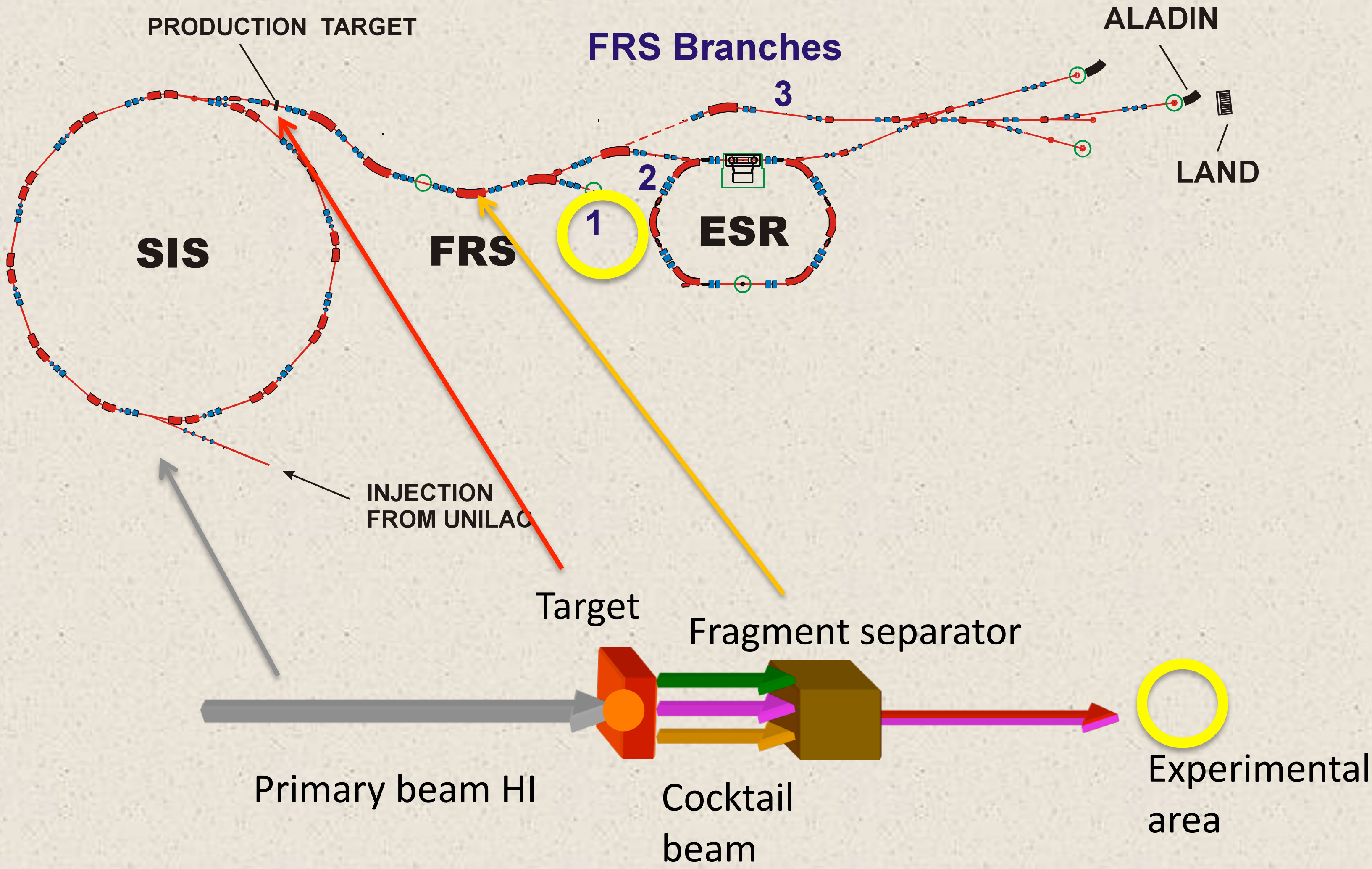




The first experiments on Tz=-1 nuclei were carried out at the GSI 2007



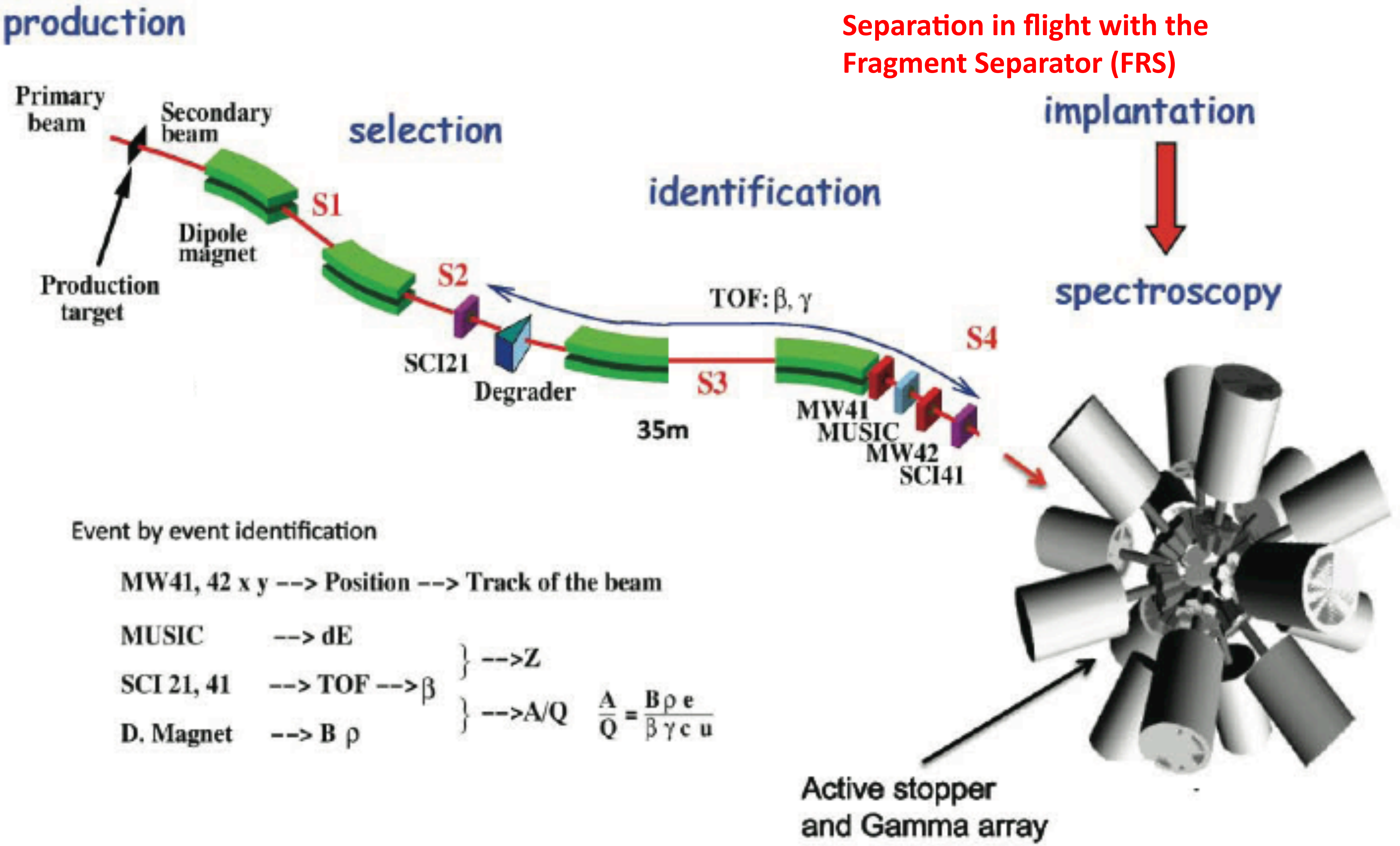
THE RARE ISOTOPE FACILITY AT GSI (no experiments of this kind possible anymore)



Beta Decay Experiments @ RISING

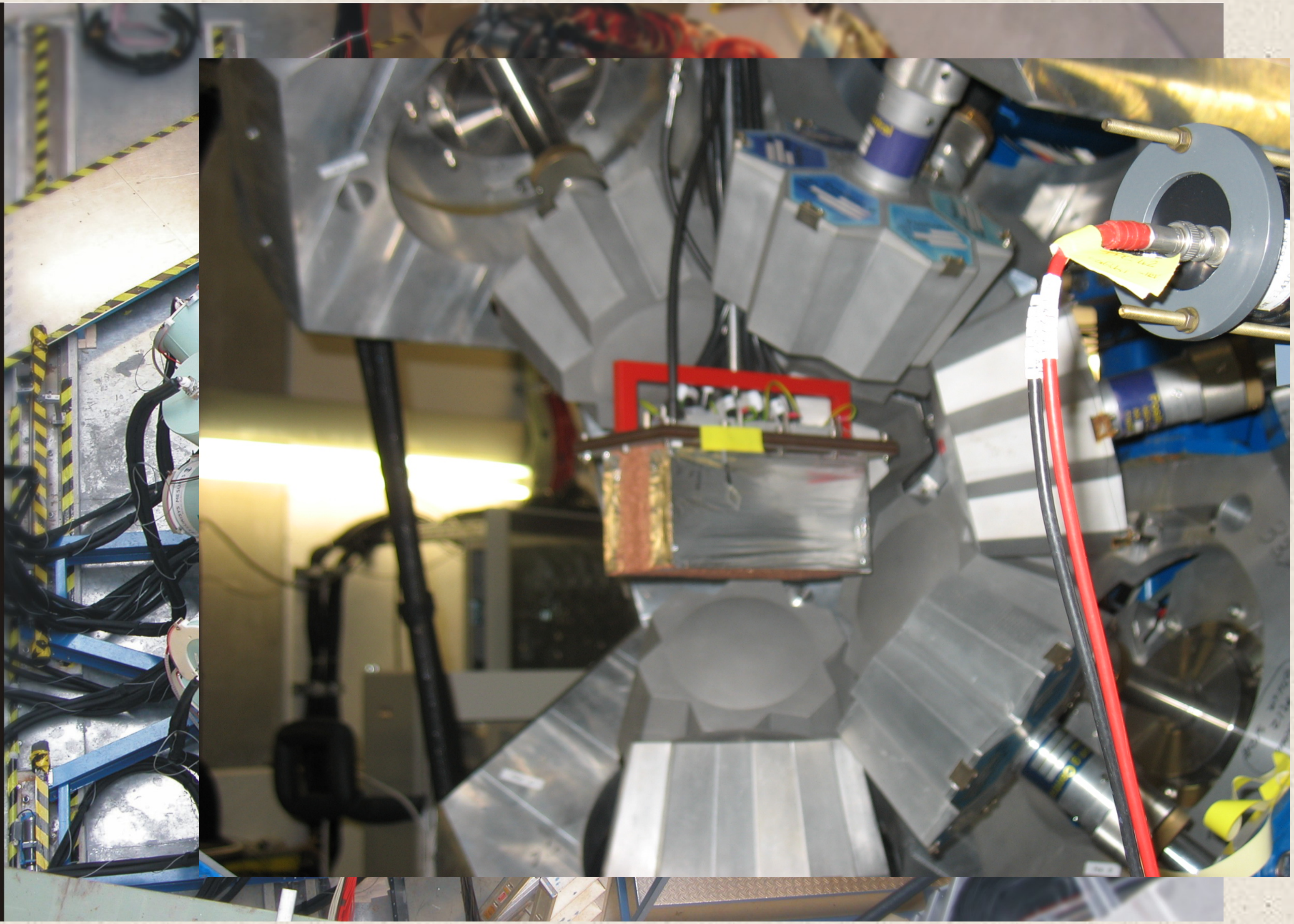
Beam 58Ni@680 MeV/u 10^9 pps (part per spill) Target Be 4g/cm2

Separation in flight with the Fragment Separator (FRS)

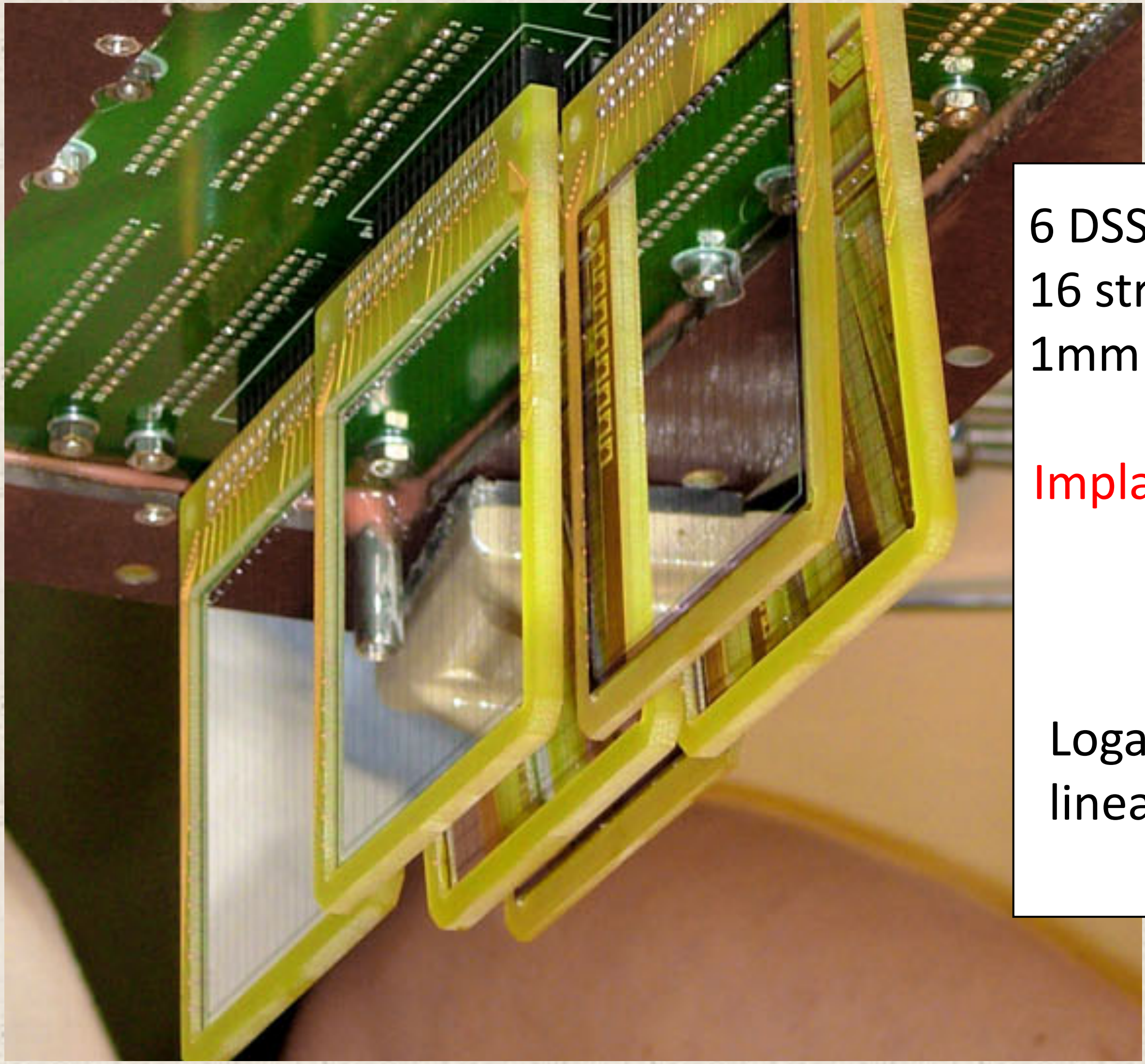


RISING (Ge Array)

stopped beam setup



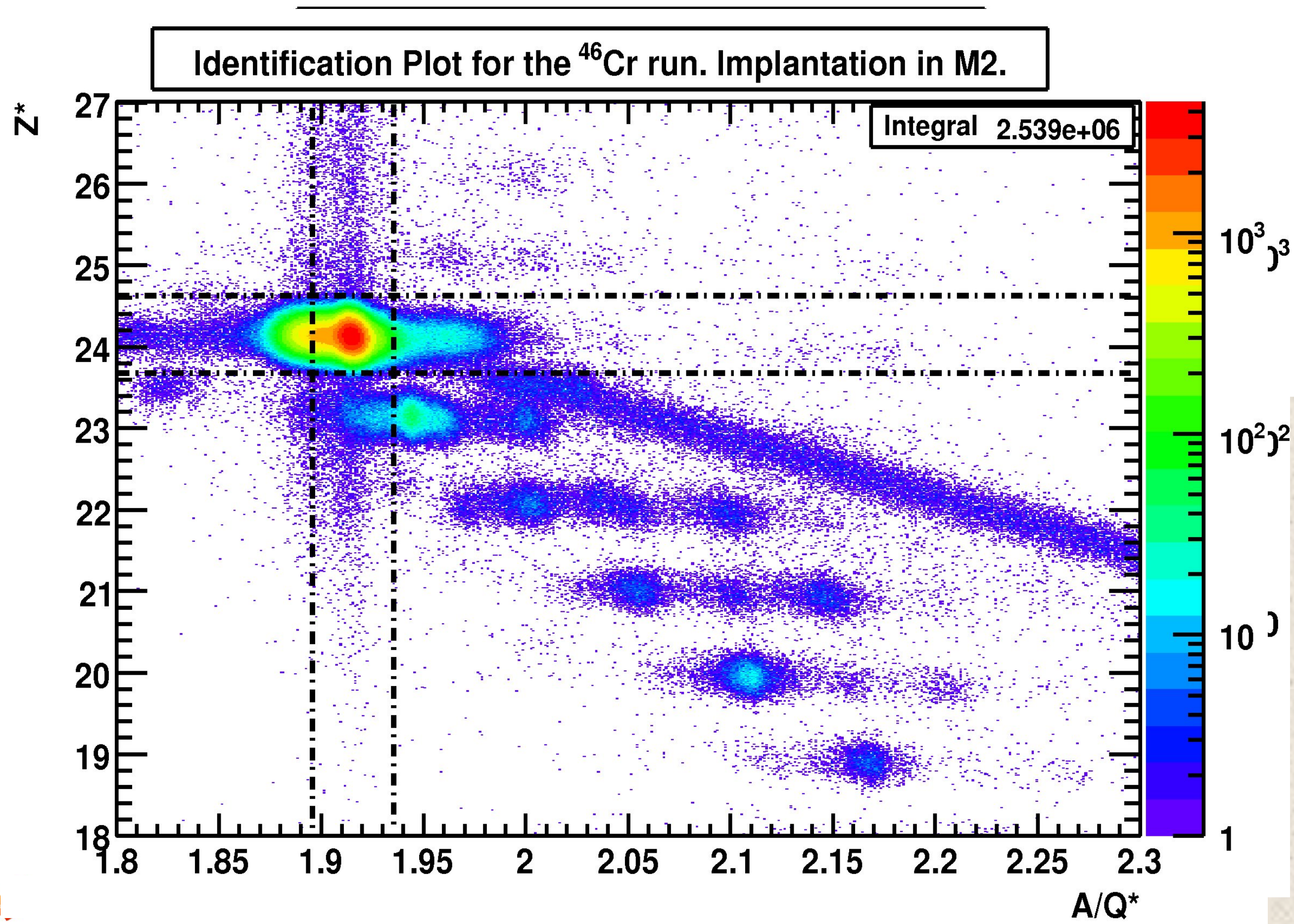
Detector Setup (Rising and DSSSD)

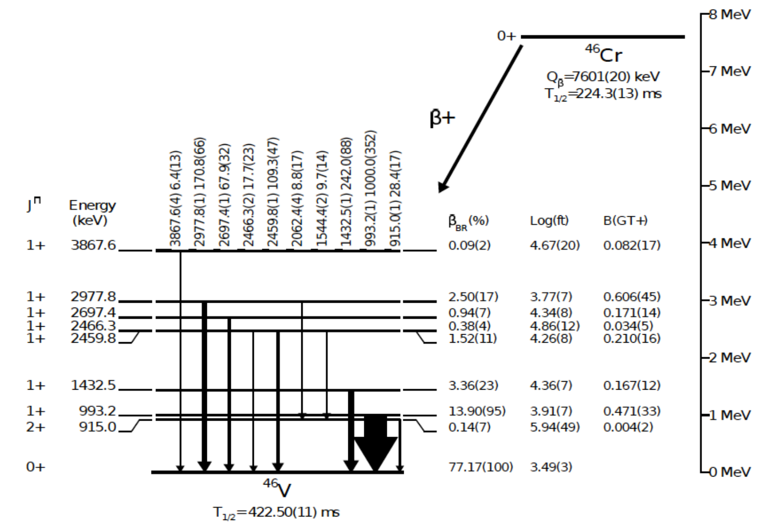


6 DSSSD detectors 1mm with 16 strips X and 16 strips Y, 1mm thick, 5 x 5 cm area

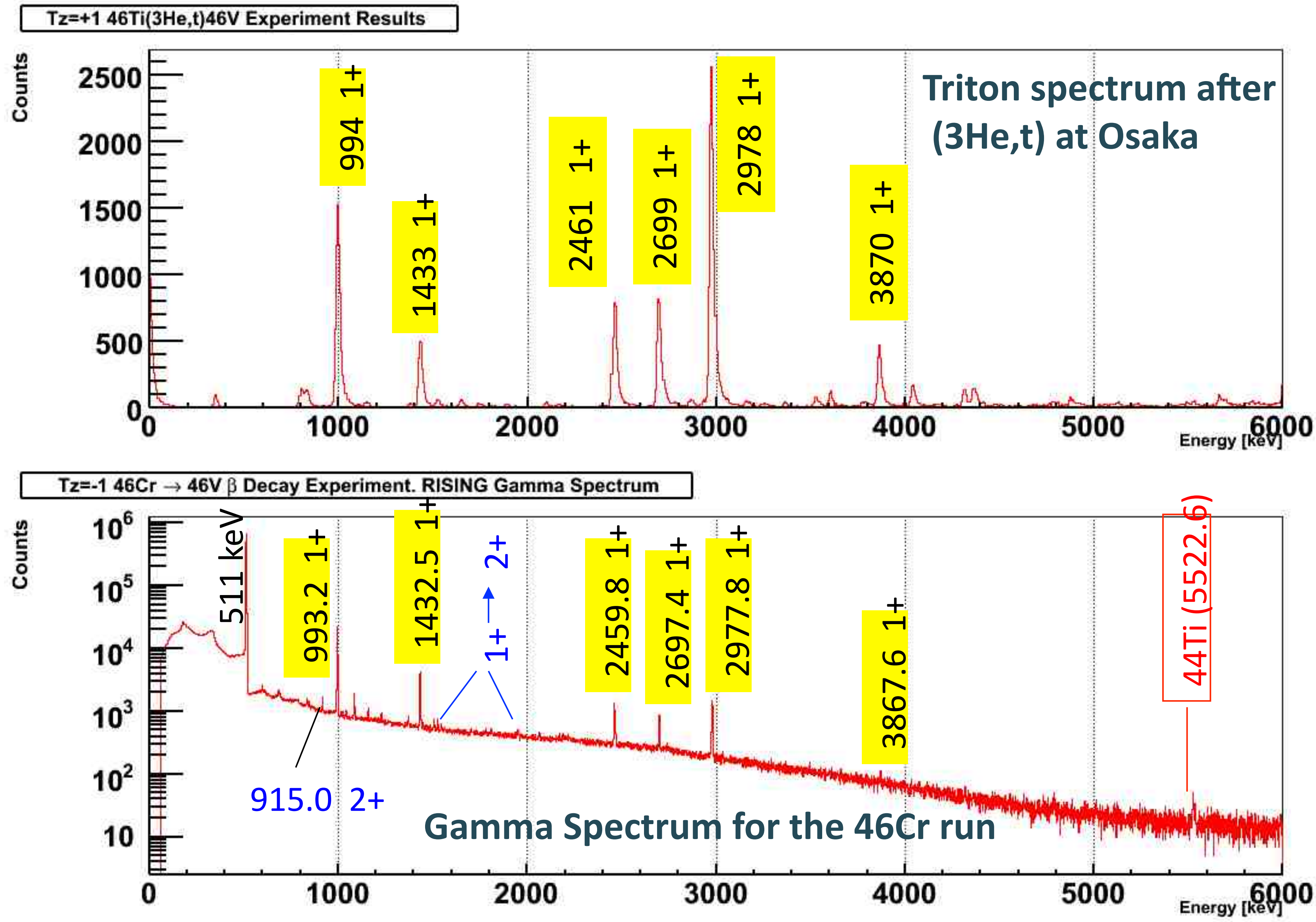
Implantations and Decay detectors

Logarithmic preamplifier linear up to 10 MeV.

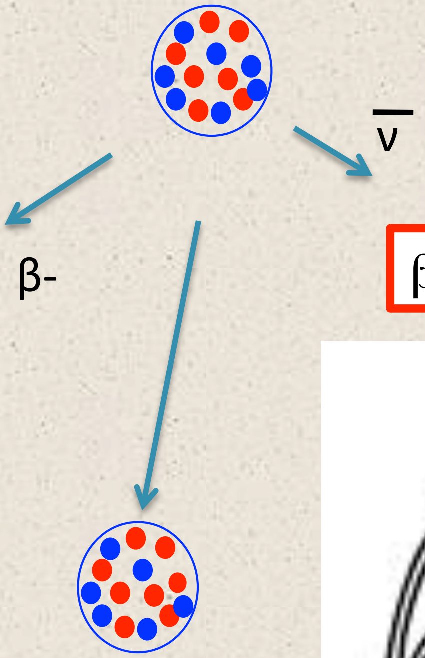




Run	Total Measurement Time	Total Number of Implantations	Counting rates in M2 [ions/sec]	Counting Rates per Pixel[ions/sec]
^{54}Ni	2151 min	6.38 10^6	Imp. 50.4 Decay 62.9	~ 0.47 ~ 0.59
^{50}Fe	1402 min	2.80 10^6	Imp. 33.8 Decay 40.4	~ 0.23 ~ 0.38
^{46}Cr	1140 min	3.3 10^6	Imp. 45.3 Decay 74.2	~ 0.40 ~ 0.66
^{42}Ti	531 min	6.46 10^5	Imp. 20.7 Decay 32.8	~ 0.17 ~ 0.26

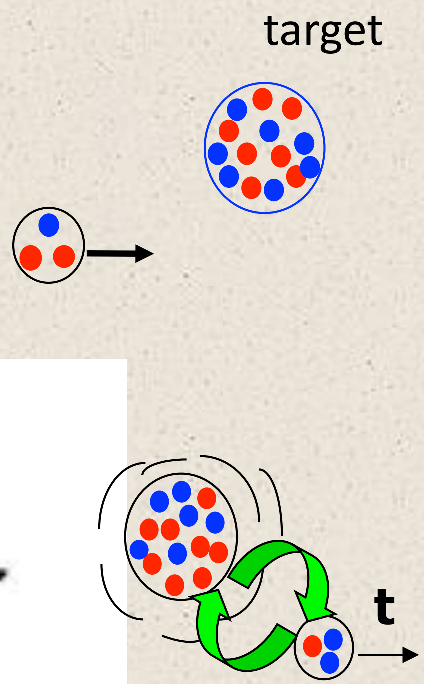

Tz=+1 46Ti(3He,t)46V Experiment Results
Counts
Triton spectrum after
(3He,t) at Osaka
994 1+
1433 1+
2461 1+
2699 1+
2978 1+
3870 1+
Energy [keV]
Tz=-1 46Cr → 46V β Decay Experiment. RISING Gamma Spectrum
511 keV
993.2 1+
1432.5 1+
1+ → 2+
2459.8 1+
2697.4 1+
2977.8 1+
3867.6 1+
44Ti (5522.6)
915.0 2+
Gamma Spectrum for the 46Cr run
Energy [keV]

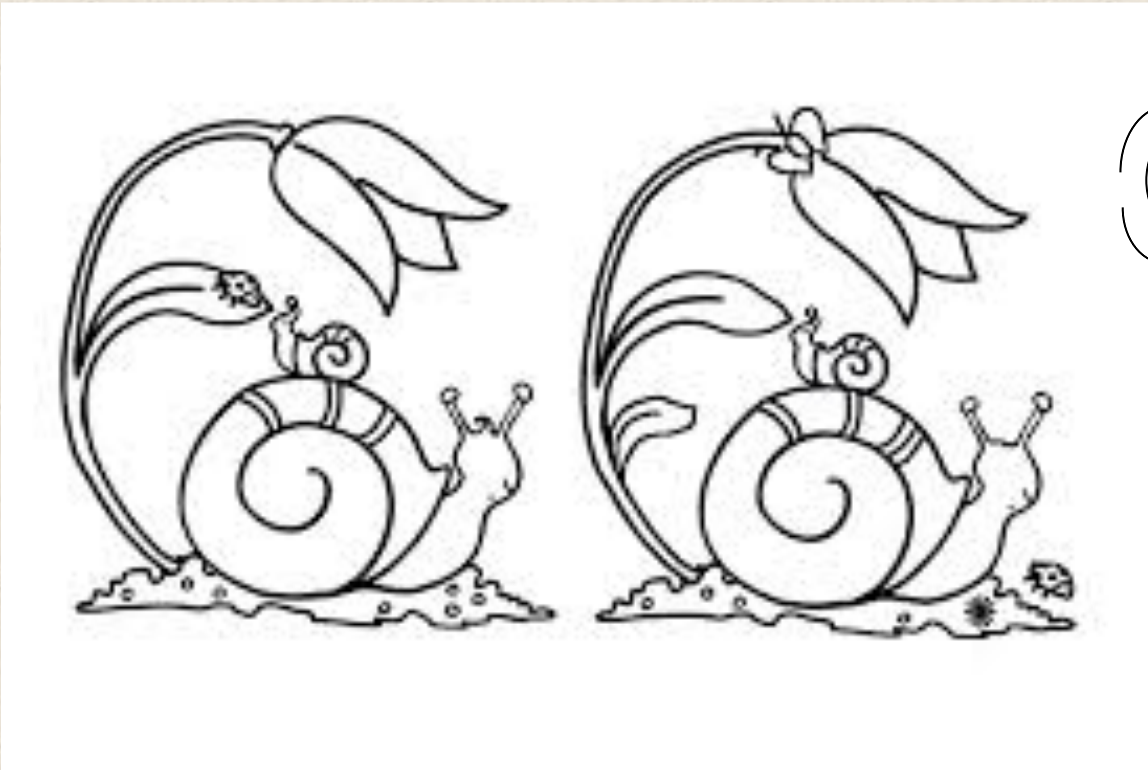
Are they really identical?



β−decay

3He,t





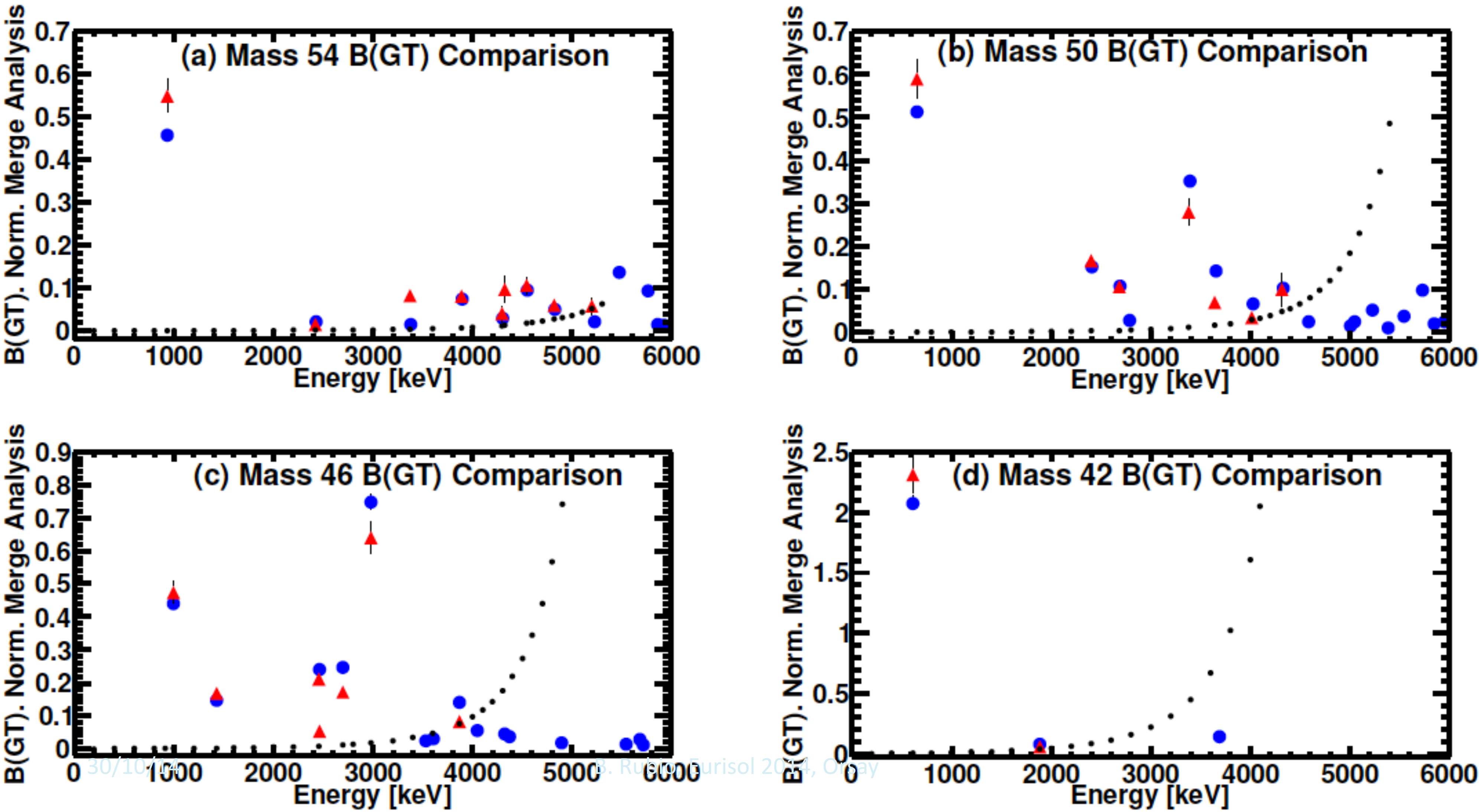
Find the difference

The $T_z = -1 \rightarrow 0$, β decays of ^{54}Ni, ^{50}Fe, ^{46}Cr, and ^{42}Ti and comparison with mirror (^{3}He,t) measurements

F. Molina,[1,*] B. Rubio,[1,†] Y. Fujita,[2,3] W. Gelletly,[4] J. Agramunt,[1] A. Algora,[1,5] J. Benlliure,[6] P. Boutachkov,[7]

β−decay

3He,t

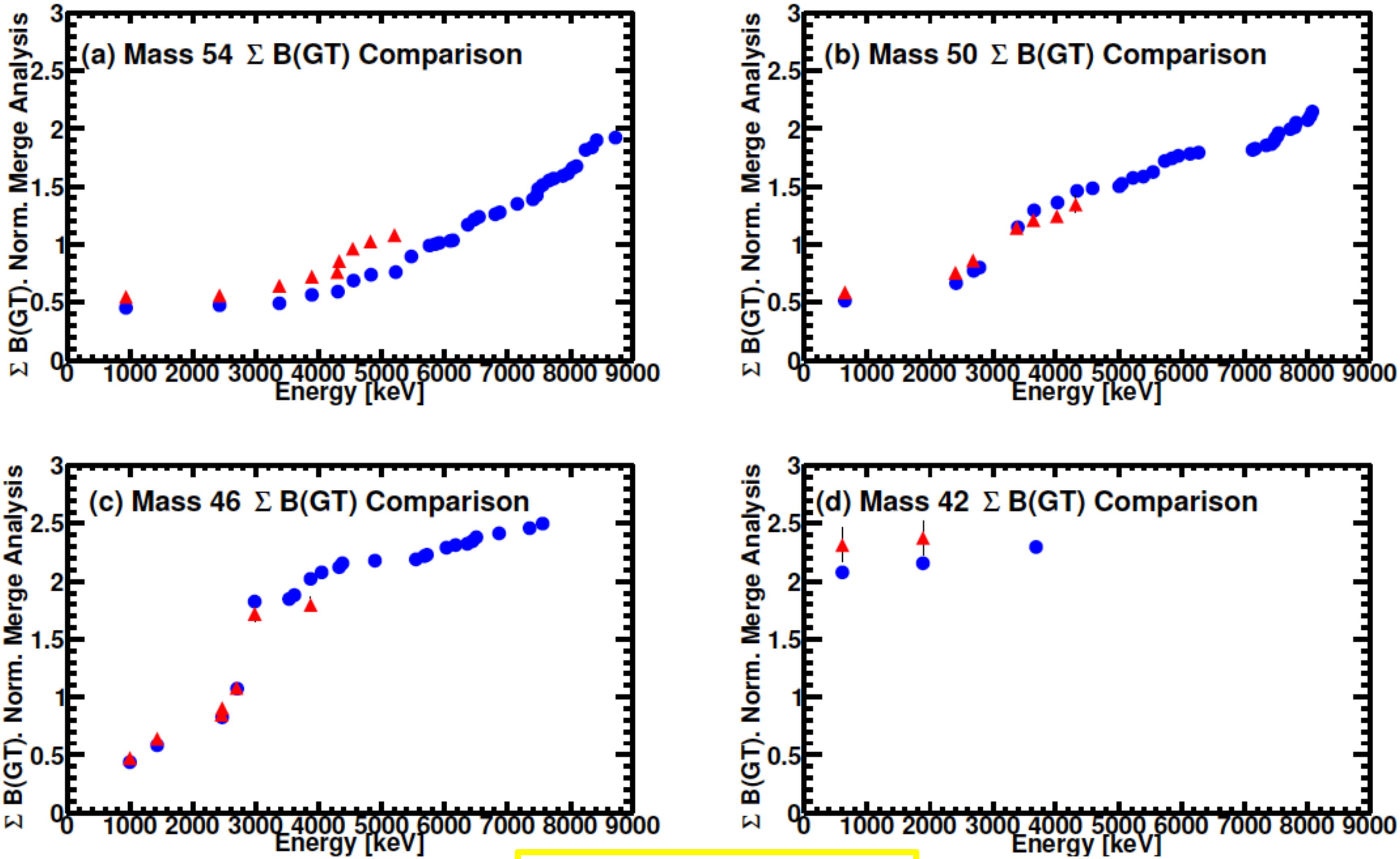


β−decay

3He,t

Accumulated B(GT)

Even inside the Q window, we miss some strength at high energy



Are they really identical?

The $T_z = -1 \rightarrow 0$, β decays of ^{54}Ni, ^{50}Fe, ^{46}Cr, and ^{42}Ti and comparison with mirror (^{3}He, t) measurements

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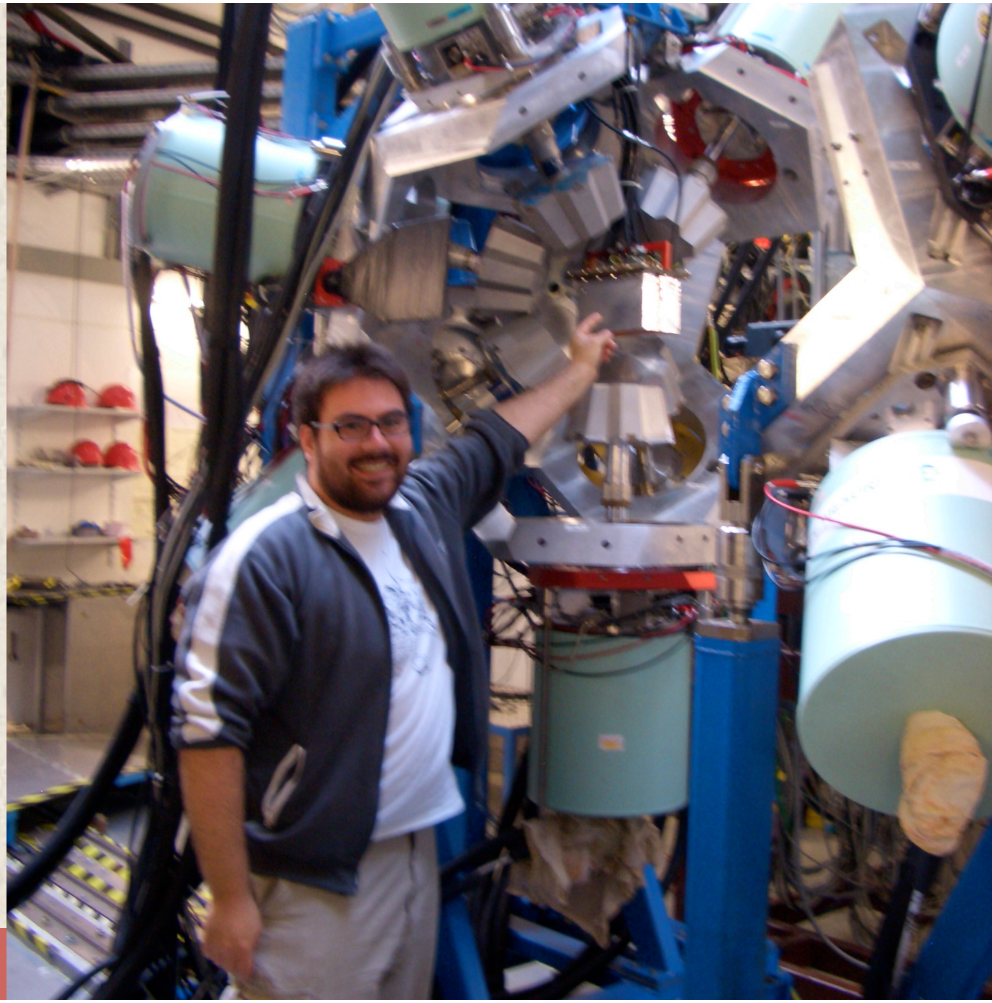
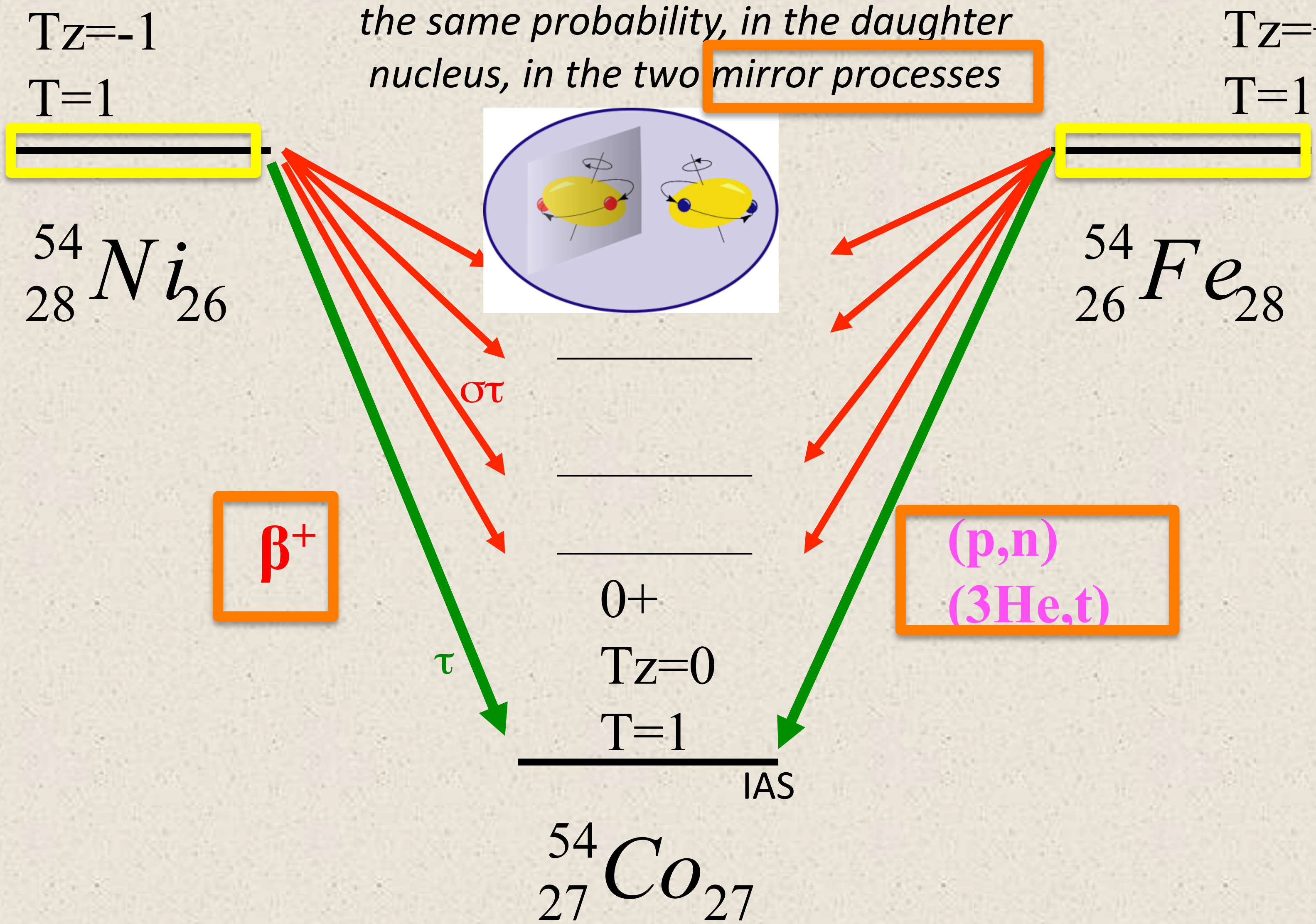
PRC
(with the referees)



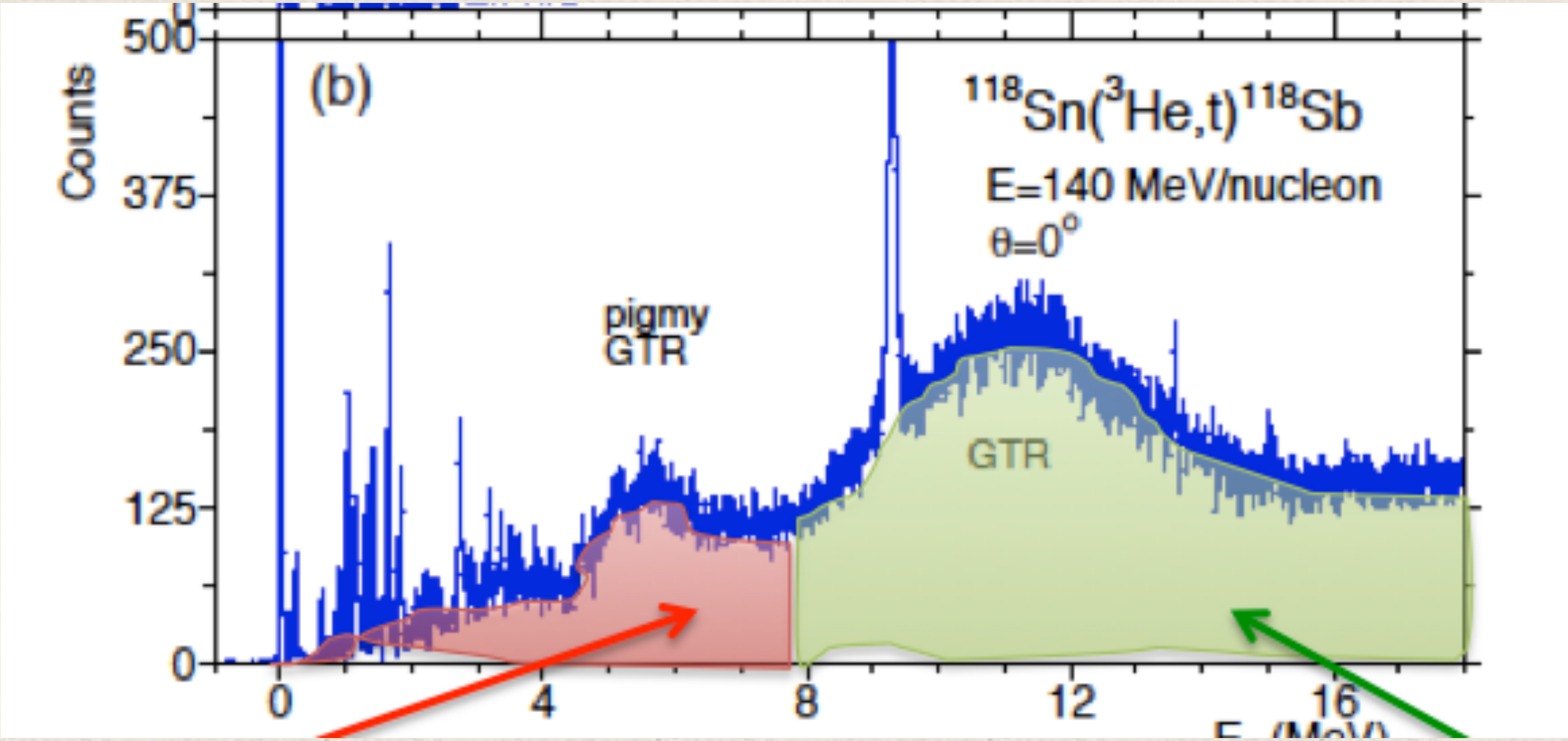
IFIC(Valencia)-Osaka-Surrey-Santiago de Compostela-Istanbul-Warsaw-Lund-Lueven Legnaro

We could compare them in mirror nuclei

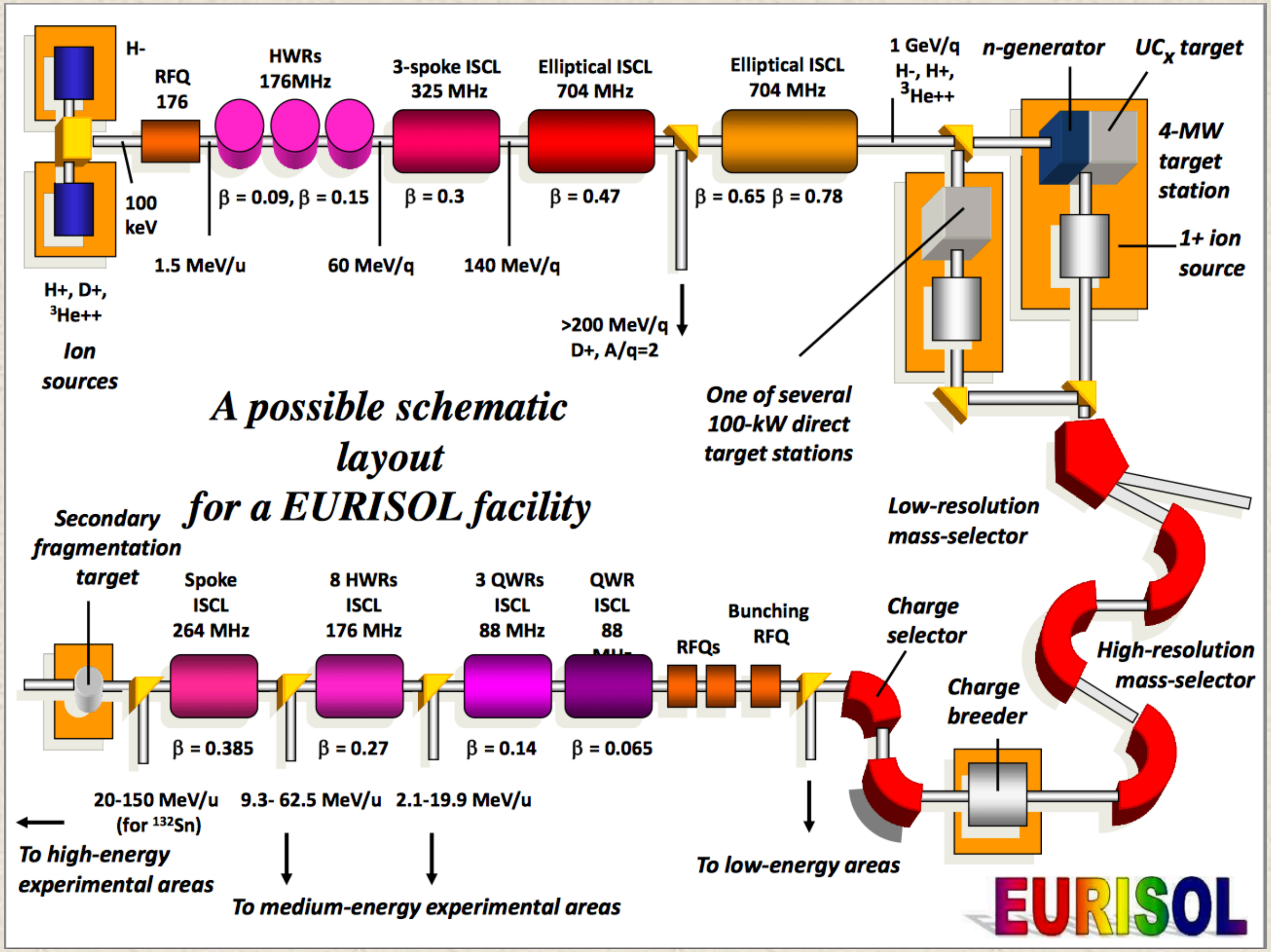
If isospin symmetry exists, mirror nuclei should populate the same states with the same probability, in the daughter nucleus, in the two mirror processes



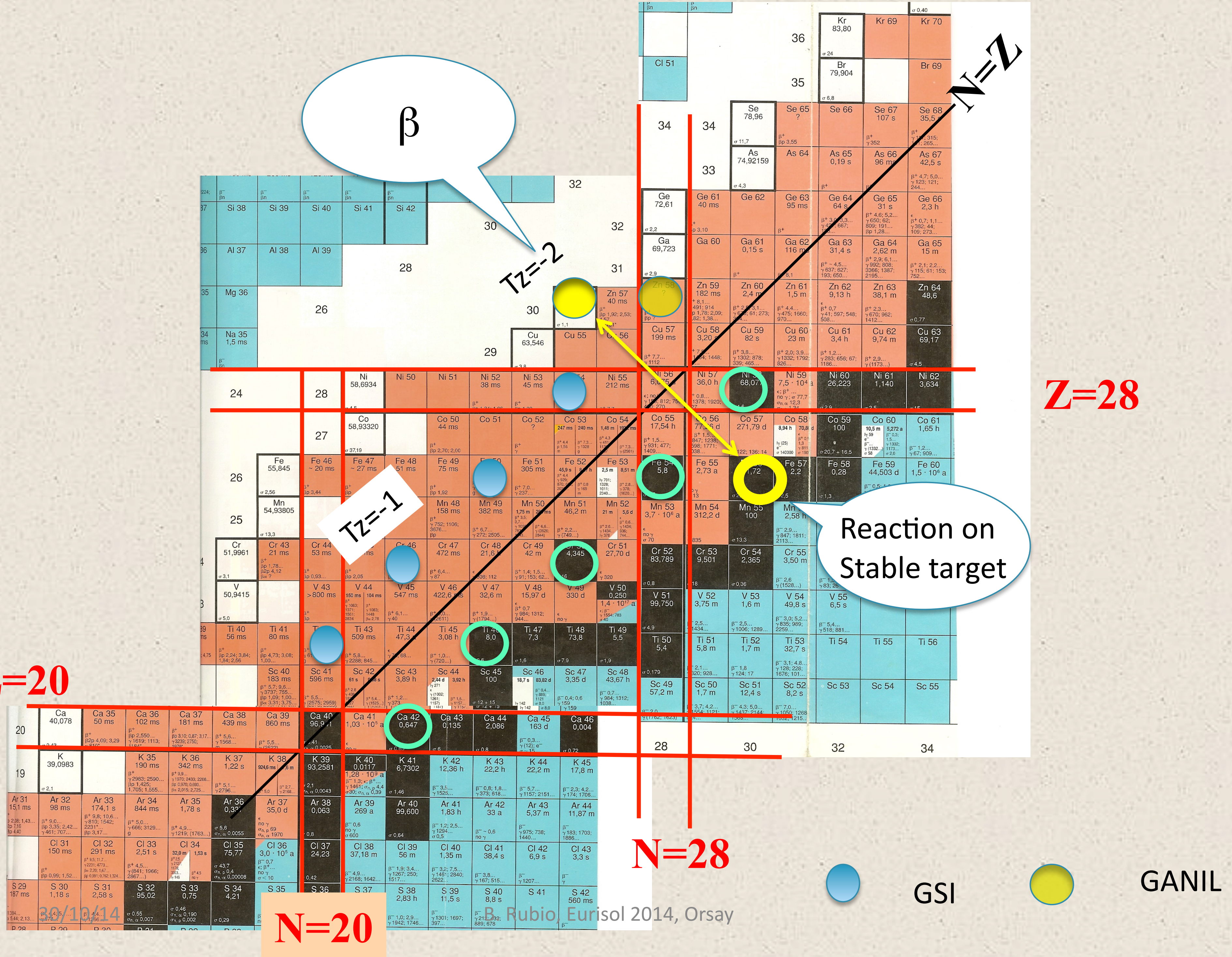
Only the day we can make both kind of experiments on the same radioactive target, we will have an answer

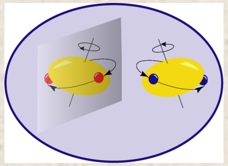


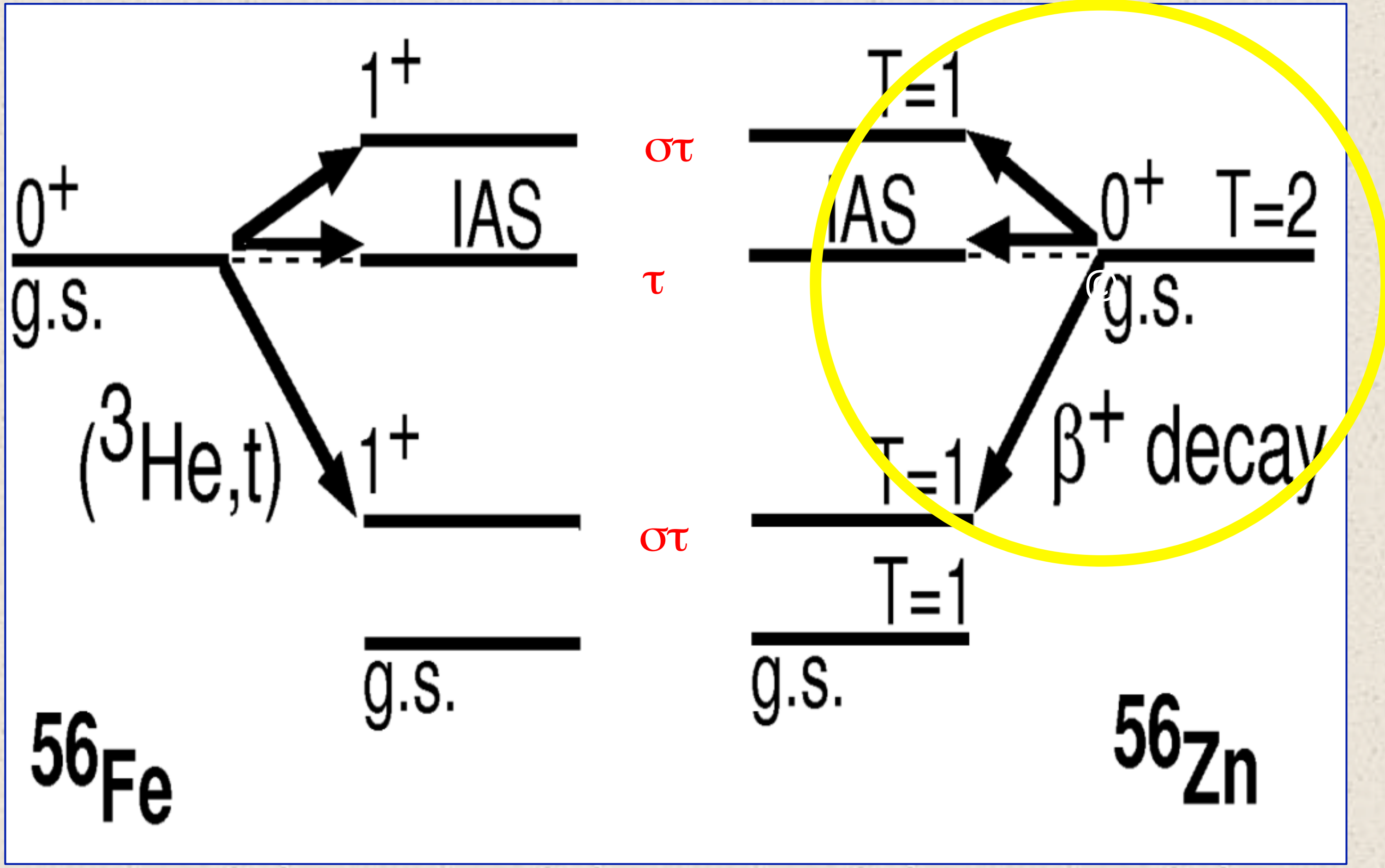
tomorrow


H-
RFQ
176
HWRs
176MHz
3-spoke ISCL
325 MHz
Elliptical ISCL
704 MHz
Elliptical ISCL
704 MHz
1 GeV/q
H-, H+,
^{3}He++
n-generator
UC_x target
4-MW
target
station
1+ ion
source
100
keV
β = 0.09, β = 0.15
β = 0.3
β = 0.47
β = 0.65 β = 0.78
1.5 MeV/u
60 MeV/q
140 MeV/q
H+, D+,
^{3}He++
Ion
sources
>200 MeV/q
D+, A/q=2
A possible schematic
layout
for a EURISOL facility
One of several
100-kW direct
target stations
Low-resolution
mass-selector
Secondary
fragmentation
target
Spoke
ISCL
264 MHz
8 HWRs
ISCL
176 MHz
3 QWRs
ISCL
88 MHz
QWR
ISCL
88
RFQs
Bunching
RFQ
Charge
selector
High-resolution
mass-selector
Charge
breeder
β = 0.385
β = 0.27
β = 0.14
β = 0.065
20-150 MeV/u
(for ^{132}Sn)
9.3- 62.5 MeV/u
2.1-19.9 MeV/u
To high-energy
experimental areas
To medium-energy experimental areas
To low-energy areas
EURISOL

”Exotic decay of fp shell nuclei"


β
Tz=-2
Tz=-1
N=Z
Z=28
Z=20
N=28
N=20
Reaction on
Stable target
GSI
GANIL

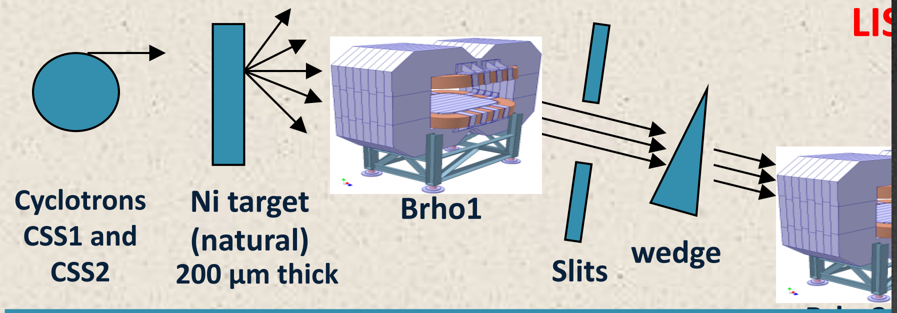


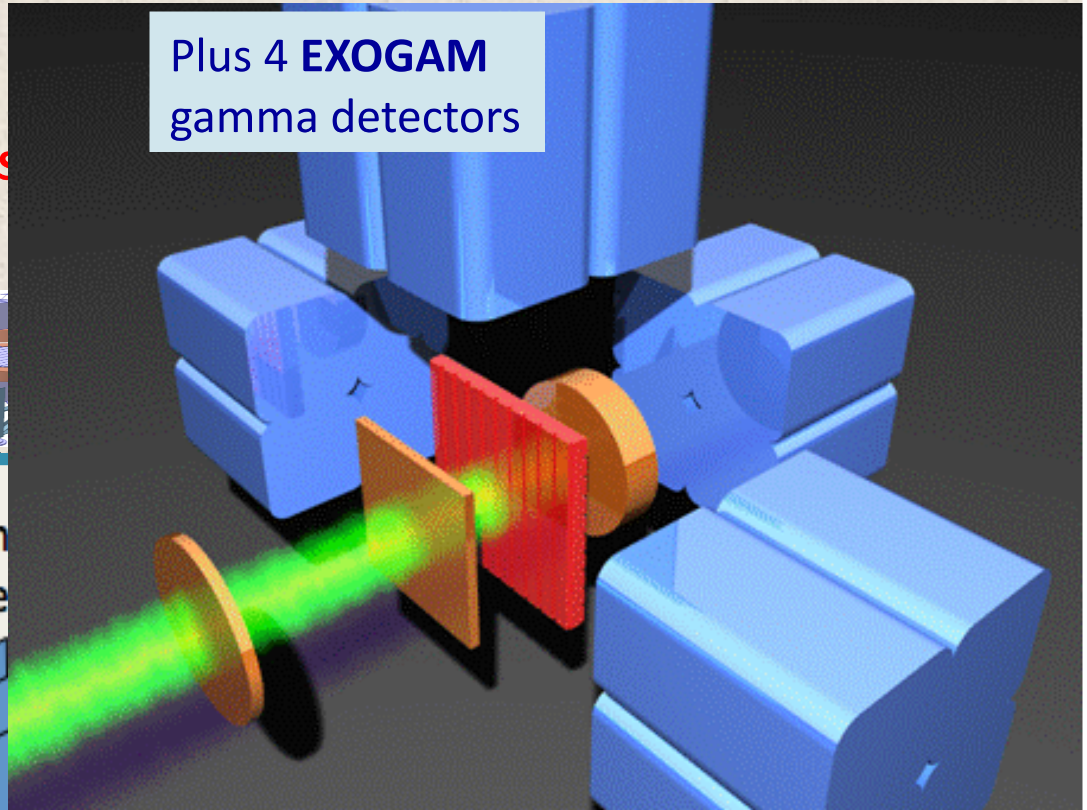

1+
0+
IAS
g.s.
(3He,t)
1+
g.s.
56Fe
στ
τ
στ
T=1
IAS
0+ T=2
g.s.
β+ decay
T=1
T=1
g.s.
56Zn

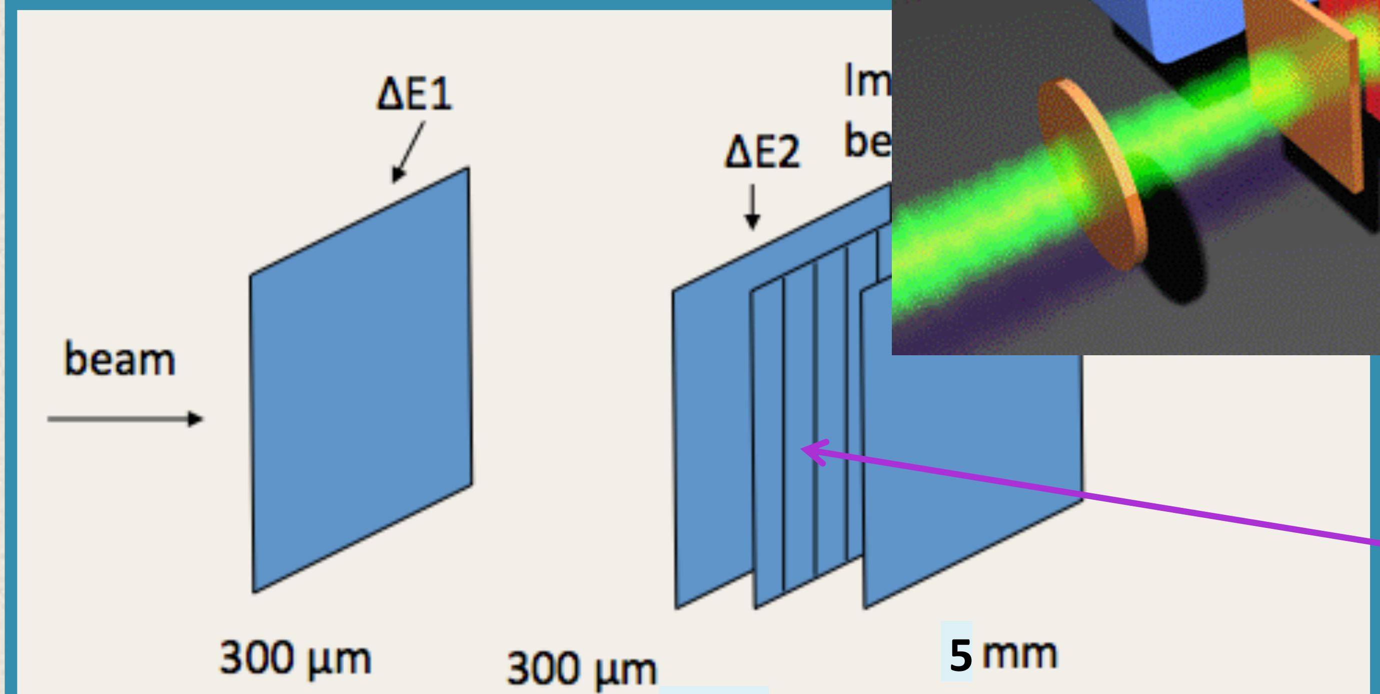
$^{58}Ni^{26+}$ (74.5 AMeV) + ^{nat}Ni @ GANIL 2010

74.5 MeV / nucleon

Incoming $^{58}Ni^{26+}$ 3.7 eμA intensity







DSSSD detector

Implantation and decay (β, p)

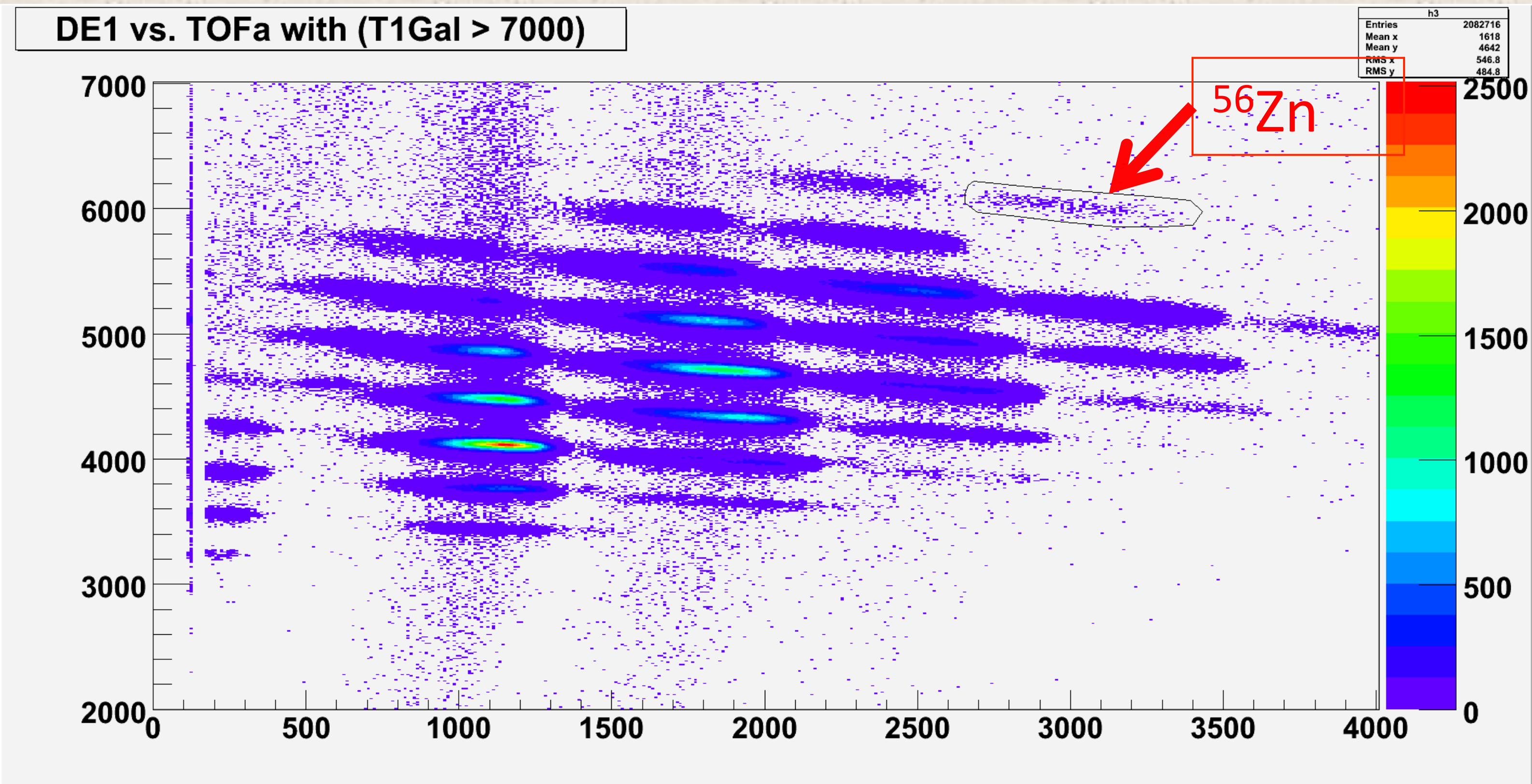
- ✓ 16 strips X and 16 strips Y
- ✓ 300 μm thick
- ✓ 3 mm pitch

As expected, the statistics are limited:

In 3 days:

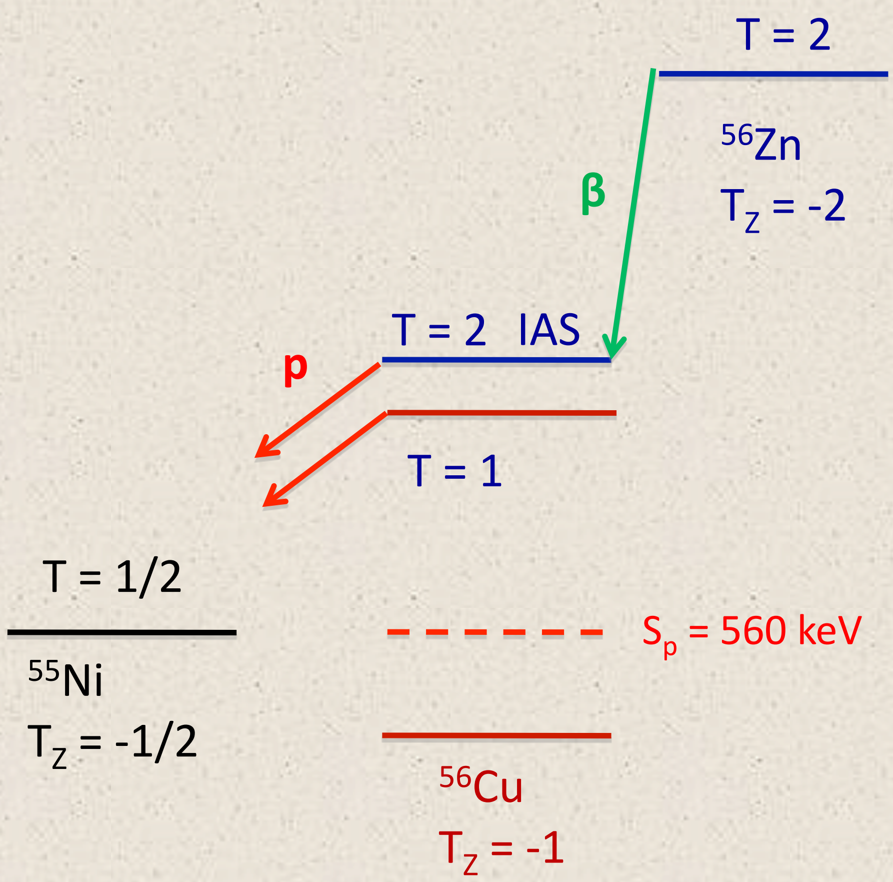
Total ^{56}Zn implantations = 8861

0.033 imp/s

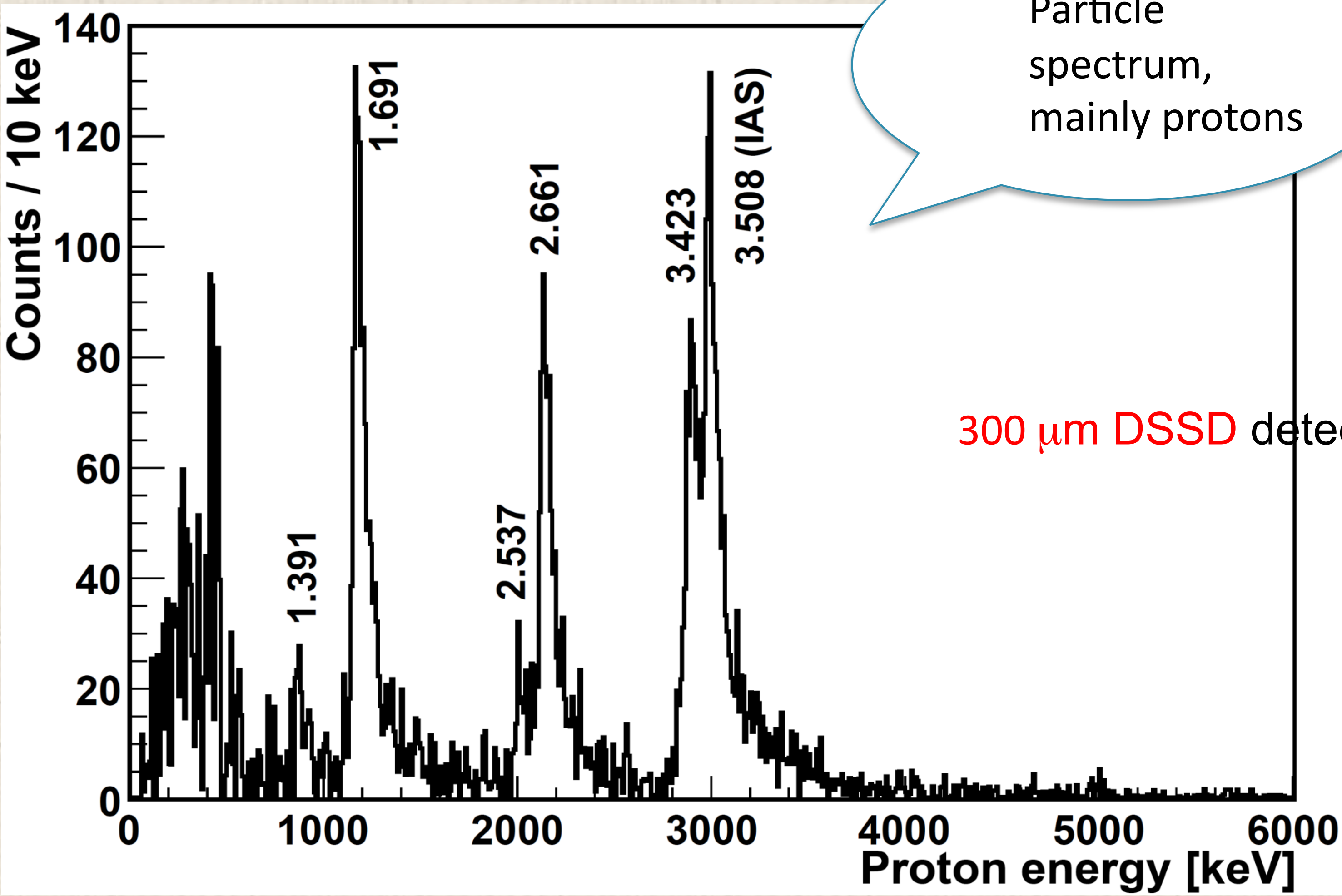


Expectations for the beta decay of 56Zn

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



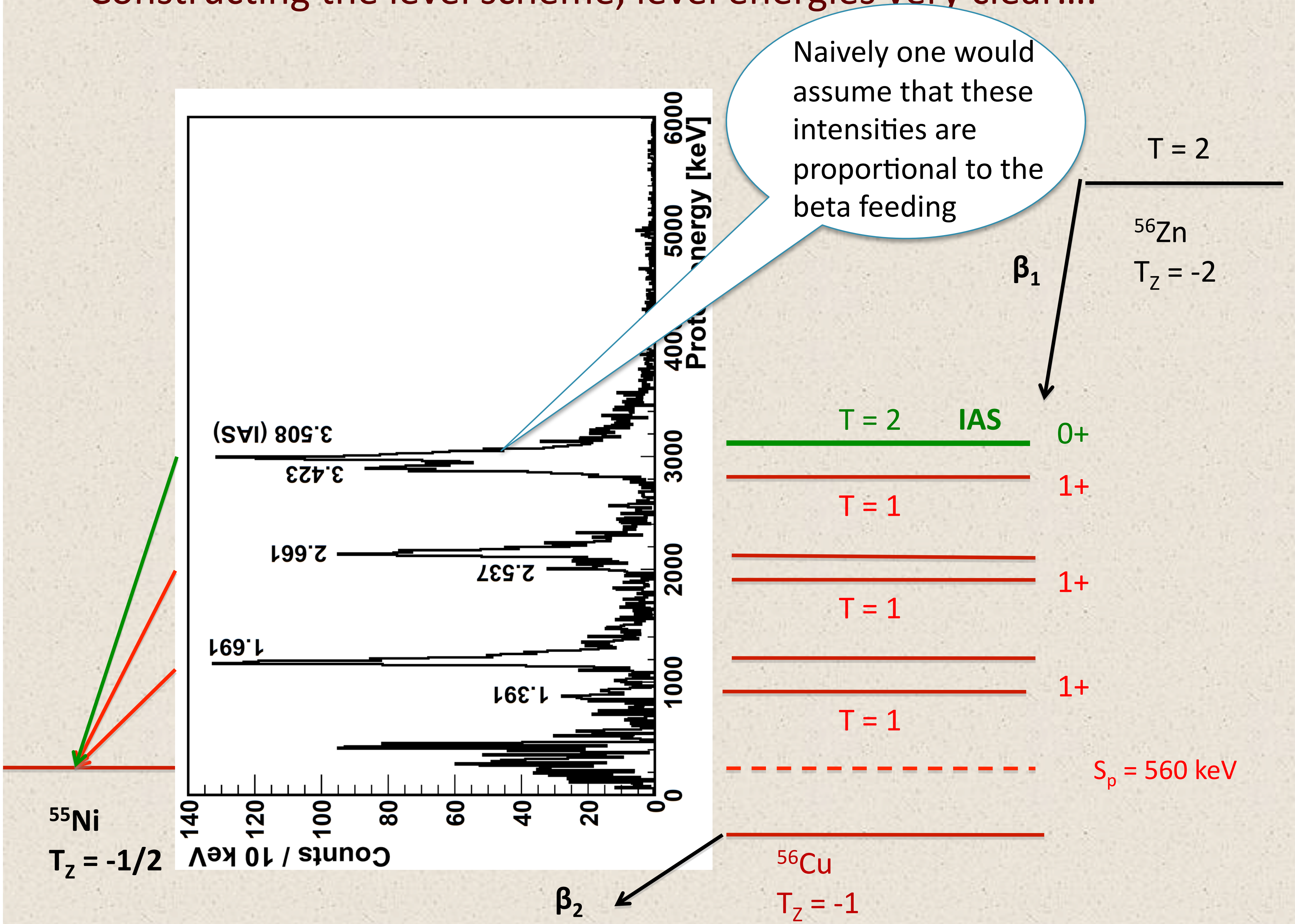
This is indeed what we saw



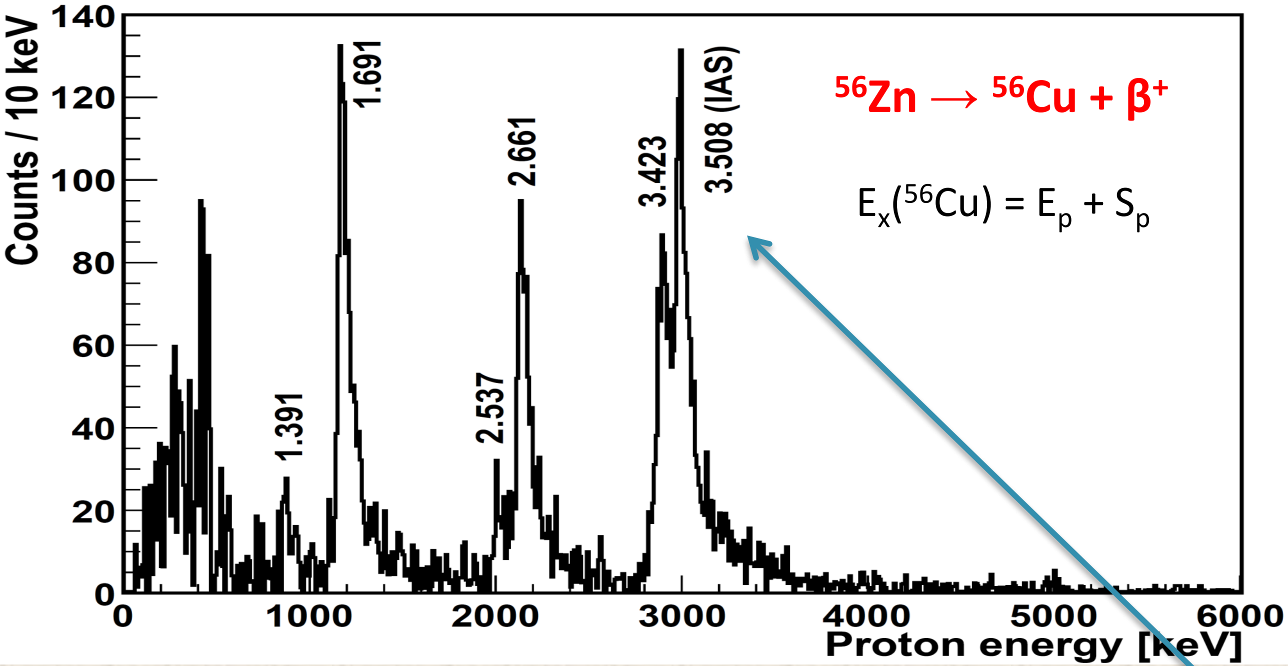
Particle spectrum, mainly protons

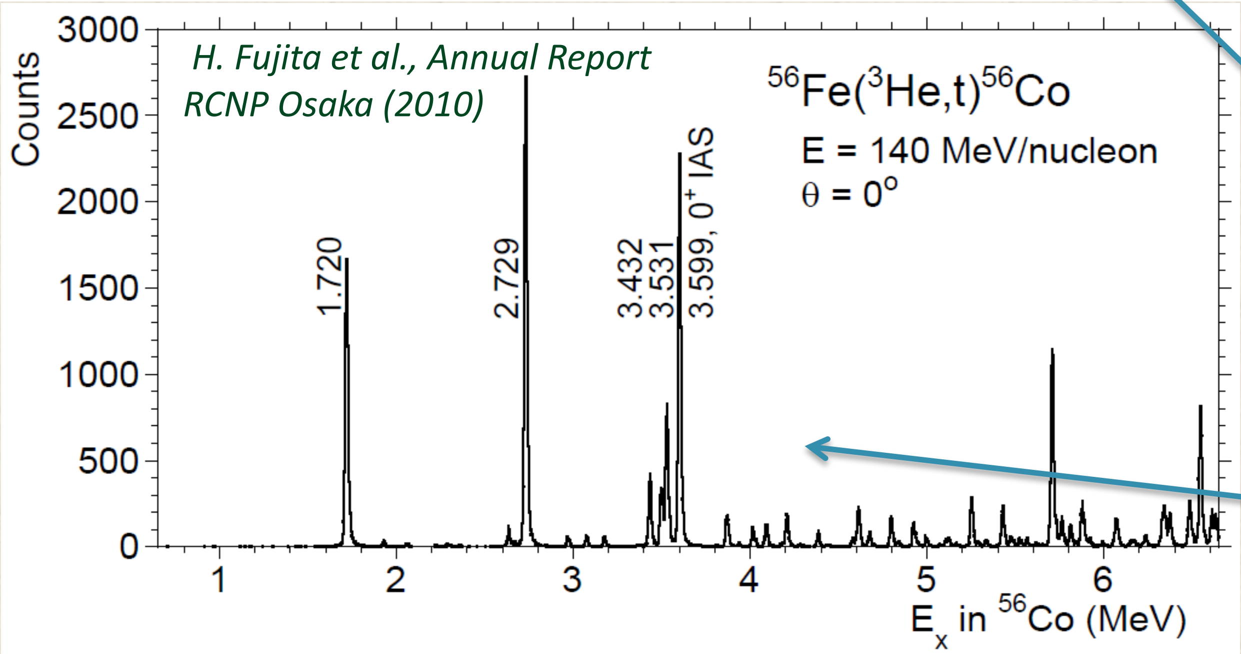
300 μm DSSD detector

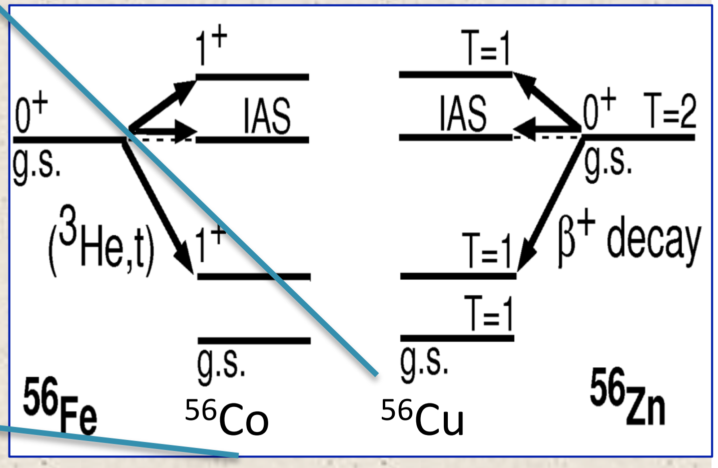
Constructing the level scheme, level energies very clear….



Comparison of mirror transitions for A = 56



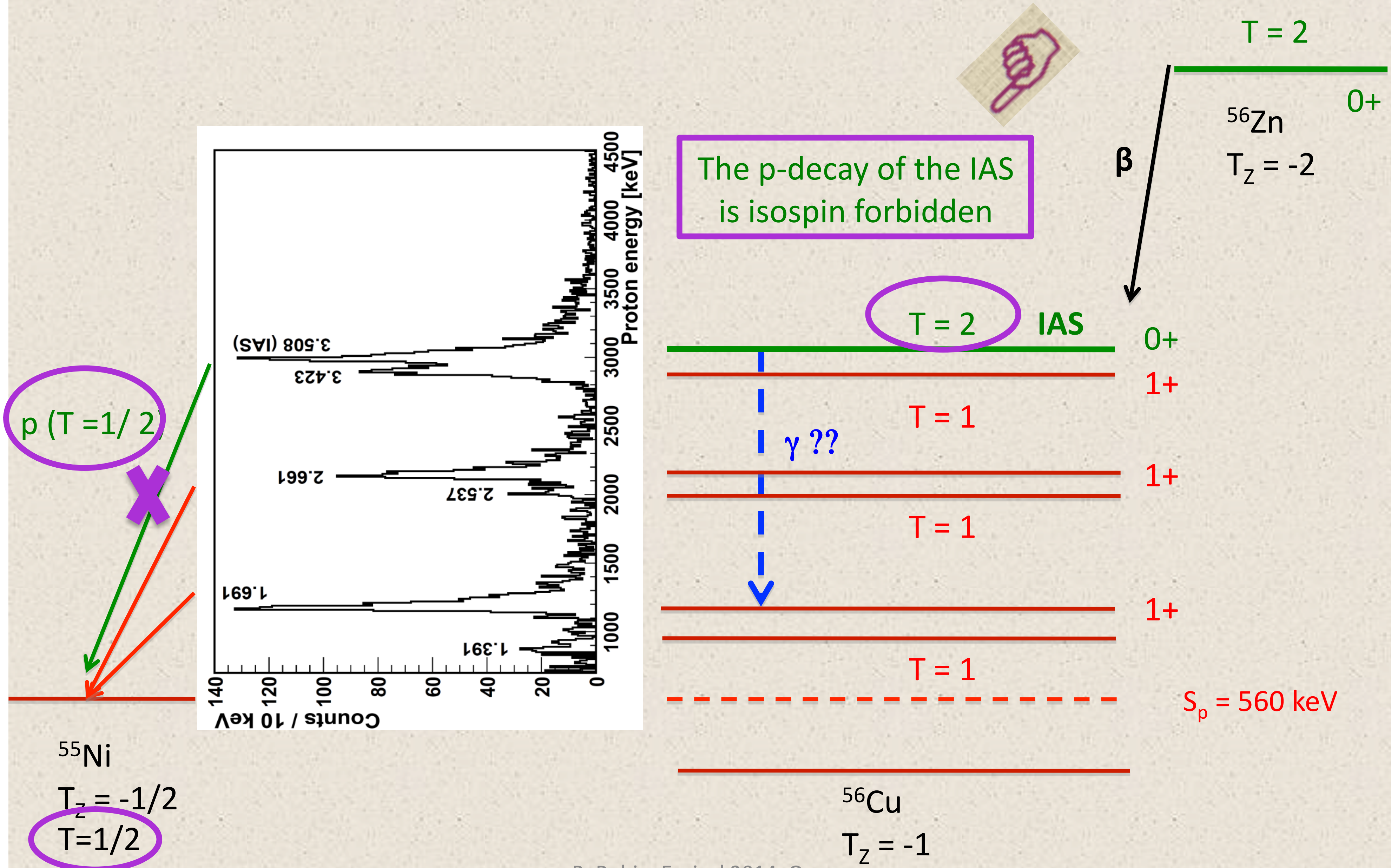




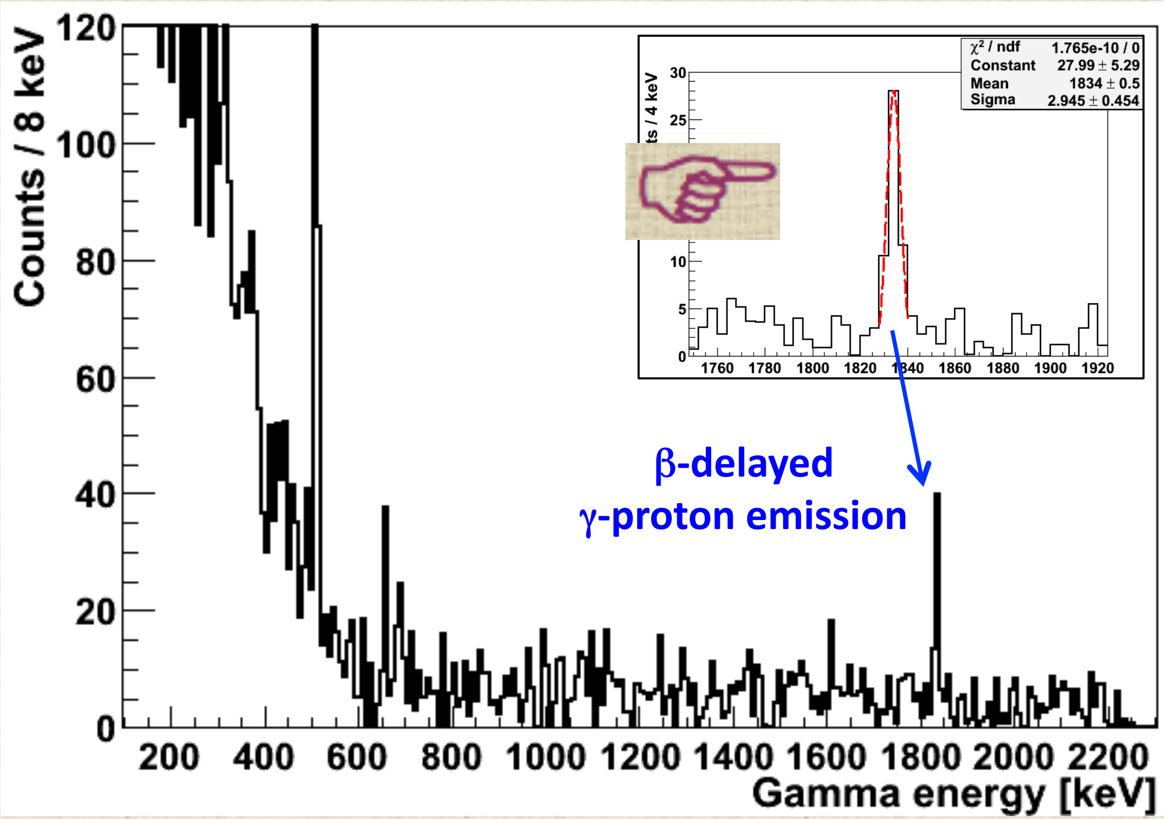
Isospin symmetry holds well !

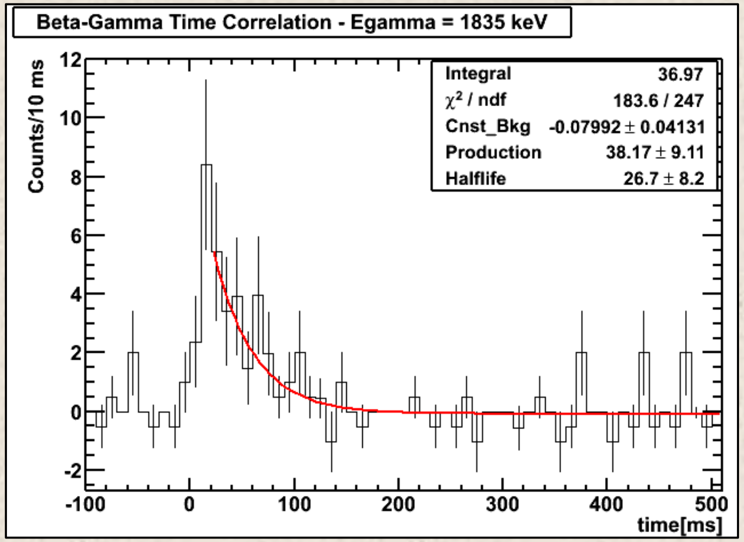
All the dominant transitions are observed in both β decay and CE starting from mirror nuclei

Constructing the ^{56}Zn decay scheme…



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

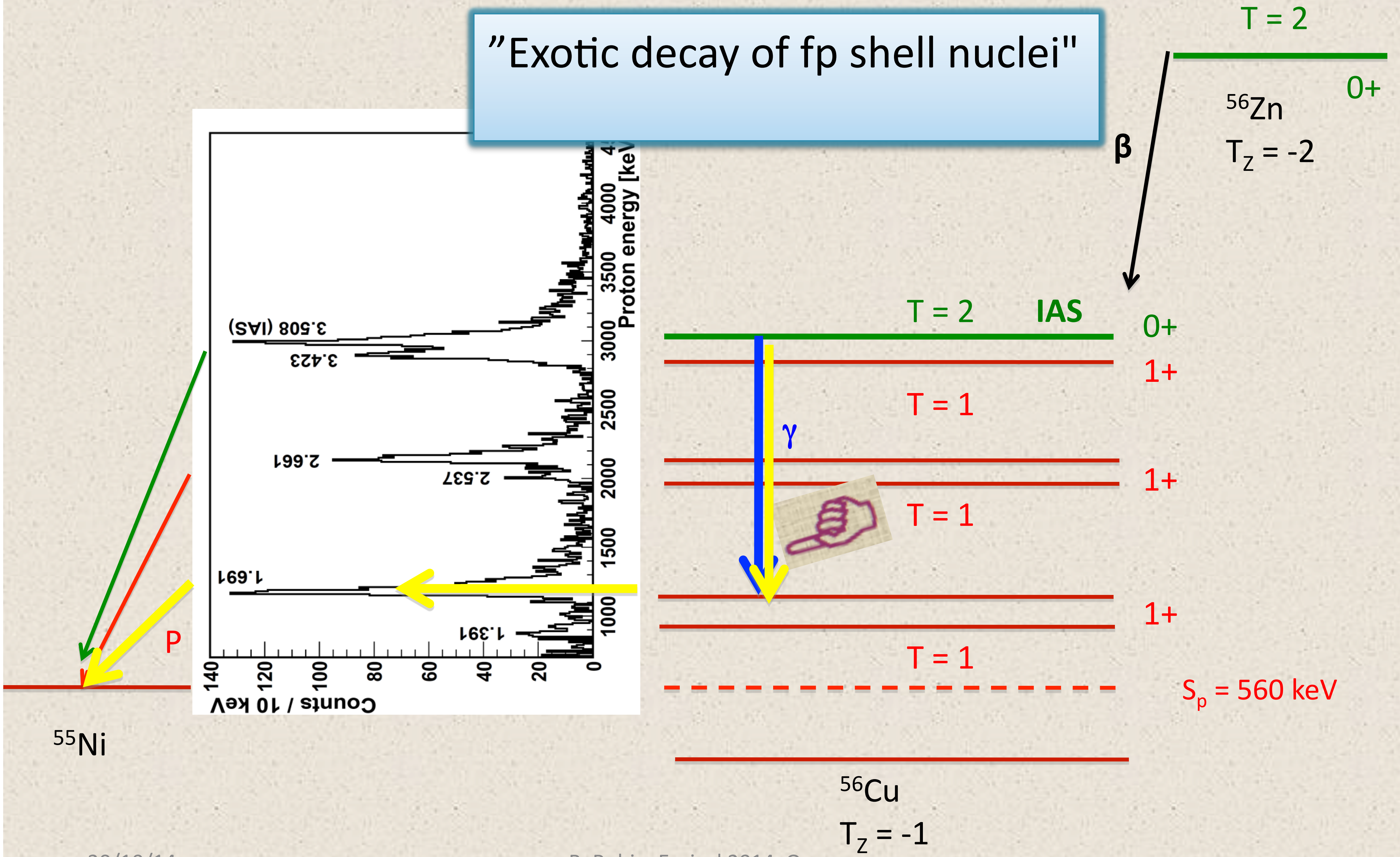
✓(β-γ)-implant time correlations

$T_{1/2}$ = (27 ± 8) ms

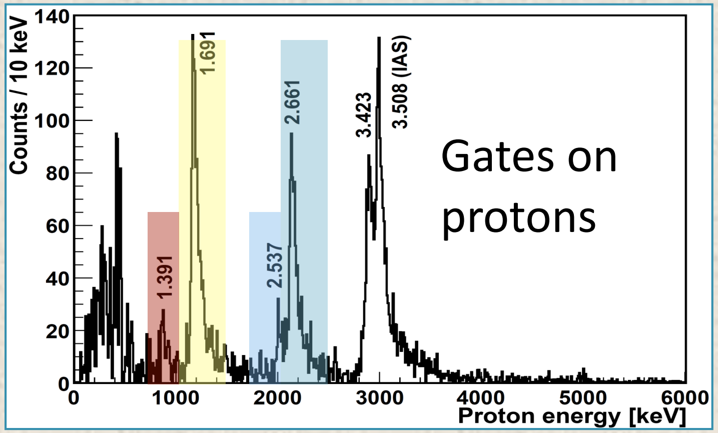
✓ In agreement with the β-implant time correlation value:

$T_{1/2}$ = (32.9 ± 0.8) ms

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



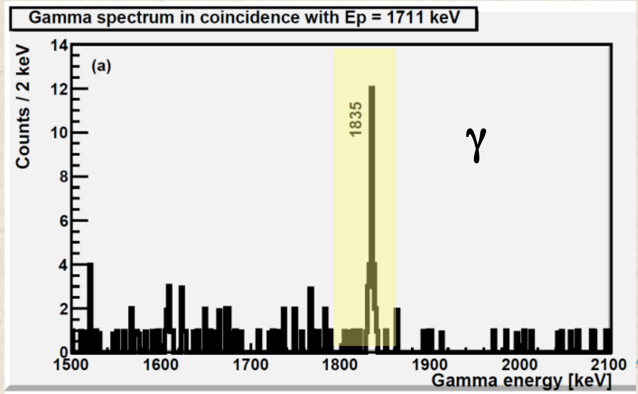
Proton-gamma coincidences

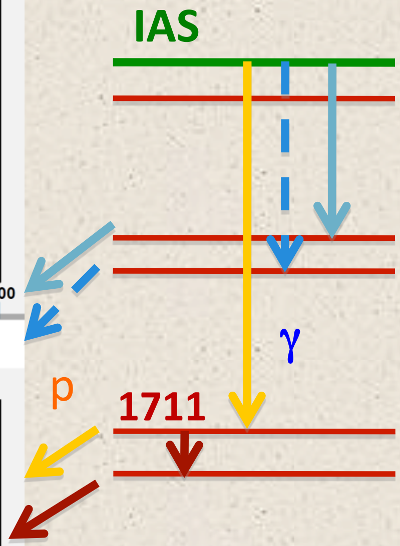


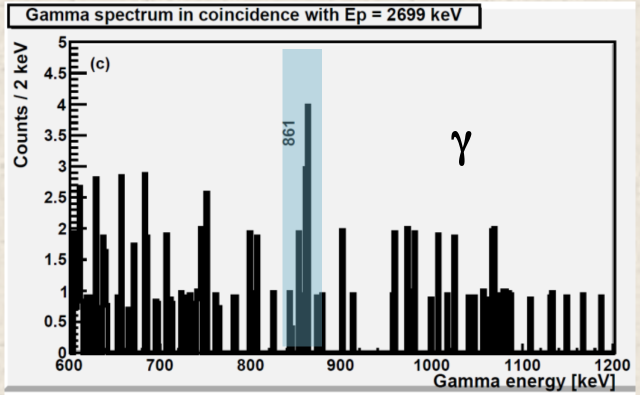
We have observed for the first time

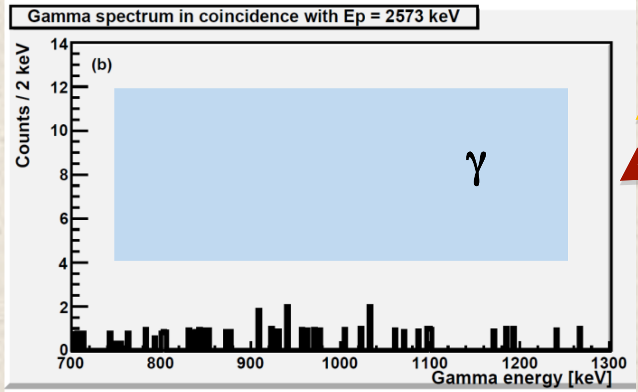
beta-delayed gamma-proton emission

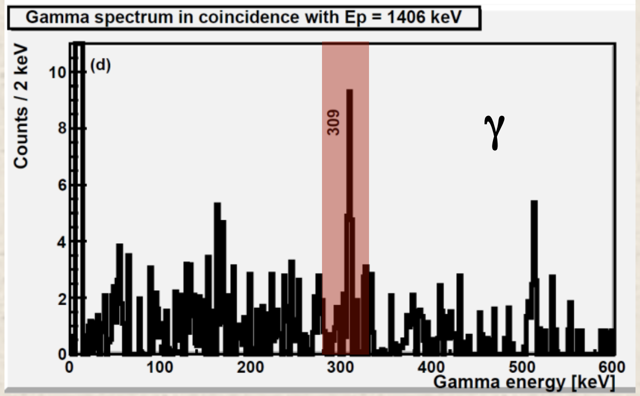
In three cases !!



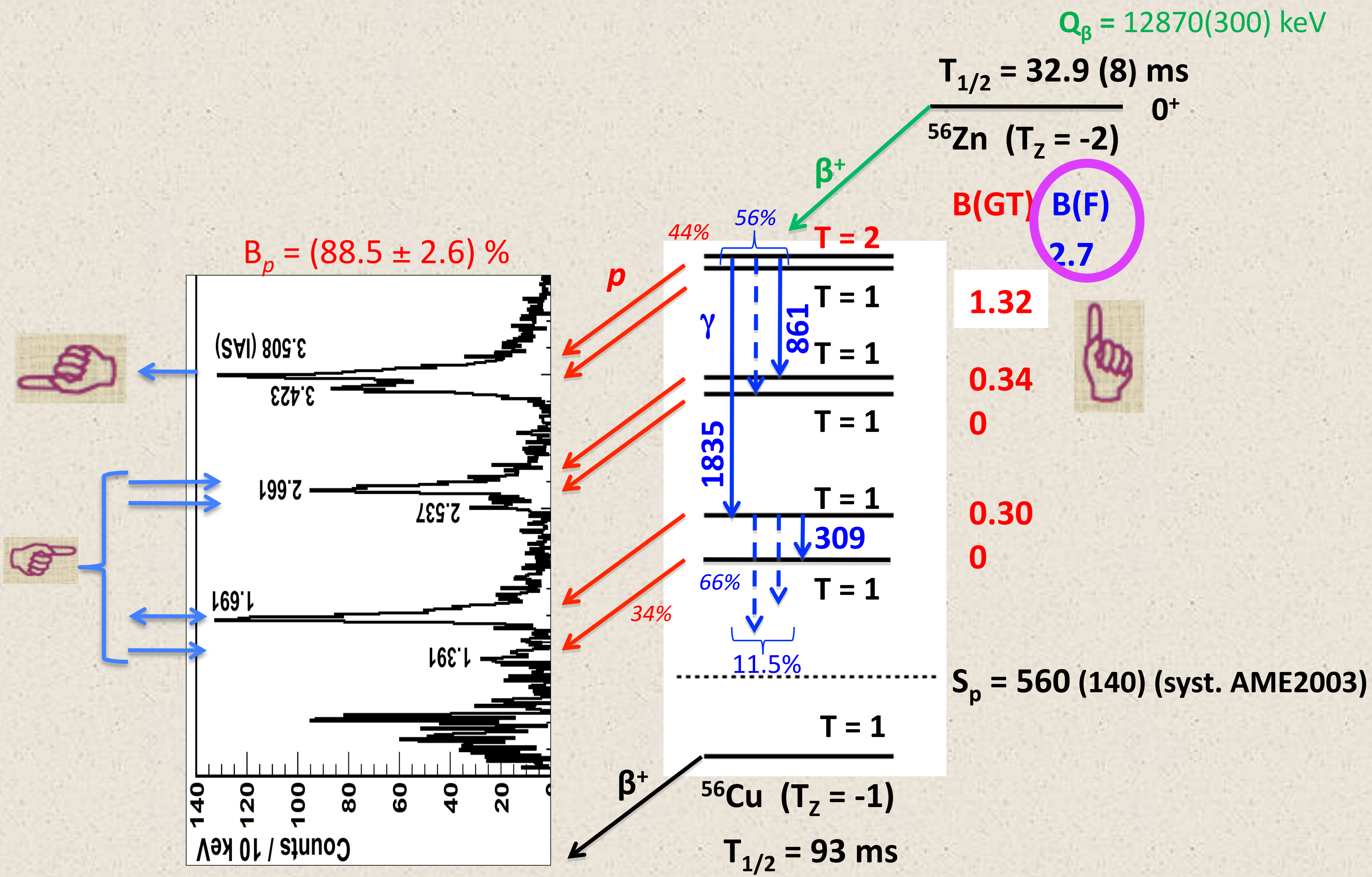




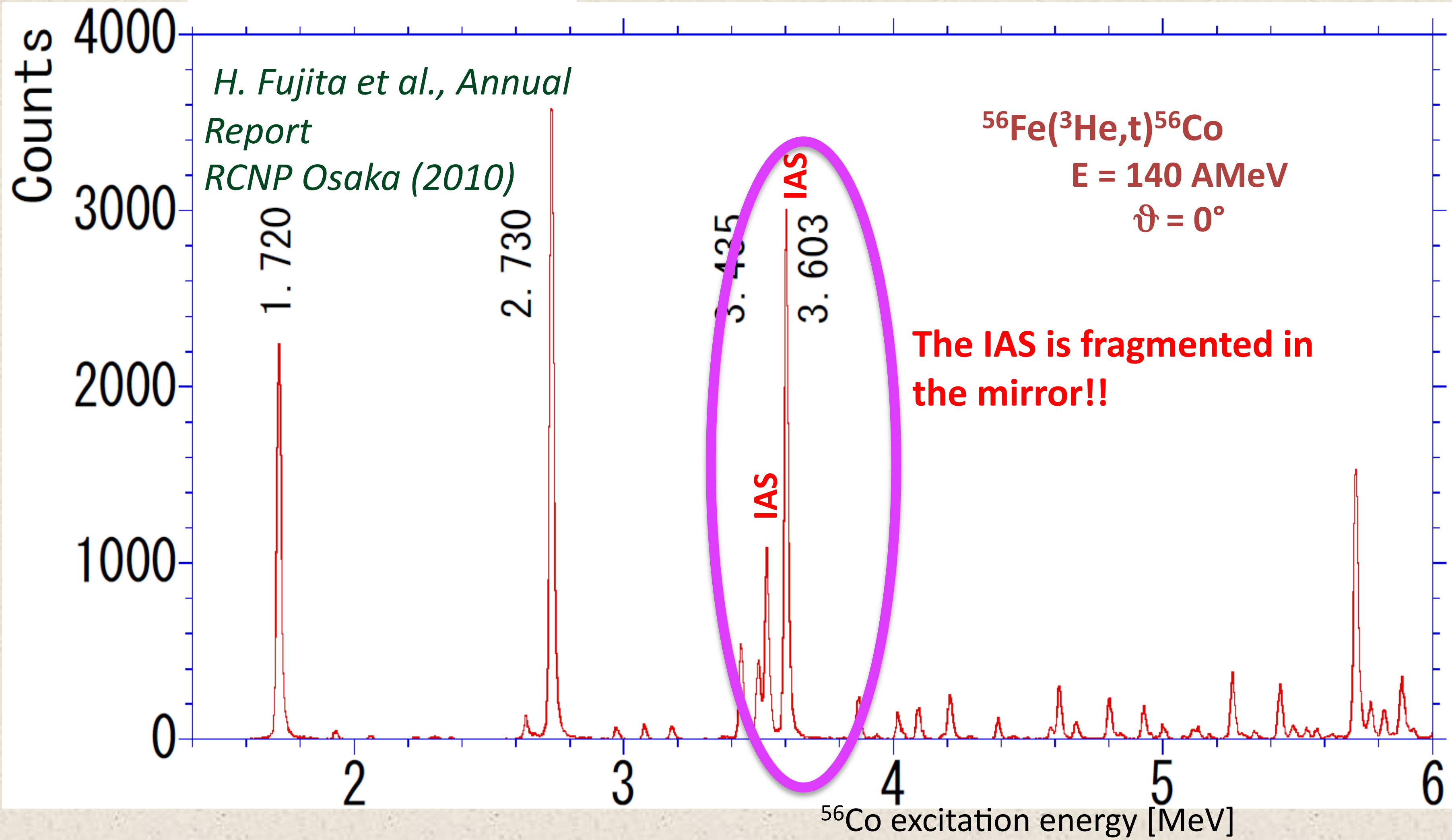


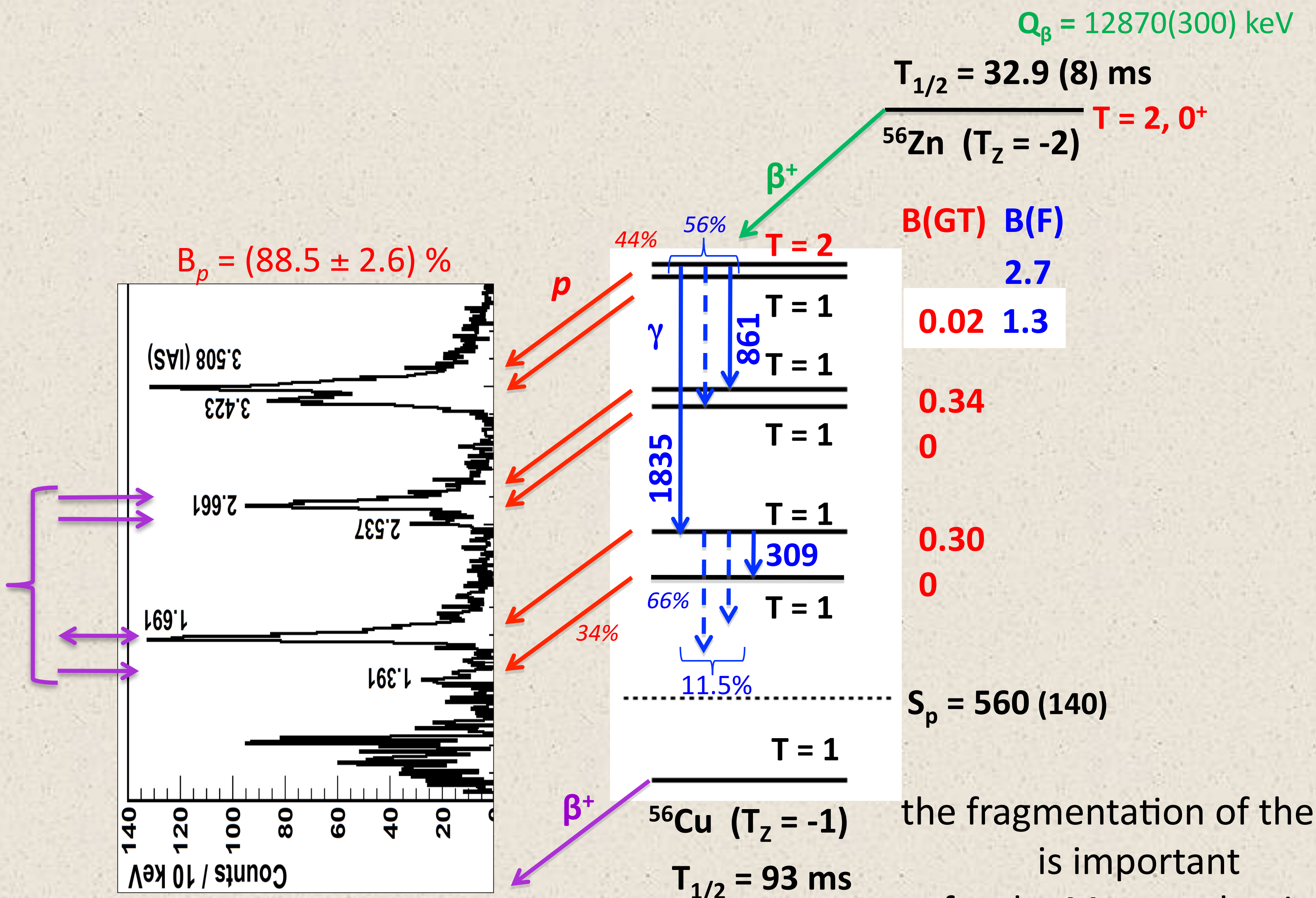


^{56}Zn decay scheme, another surprise



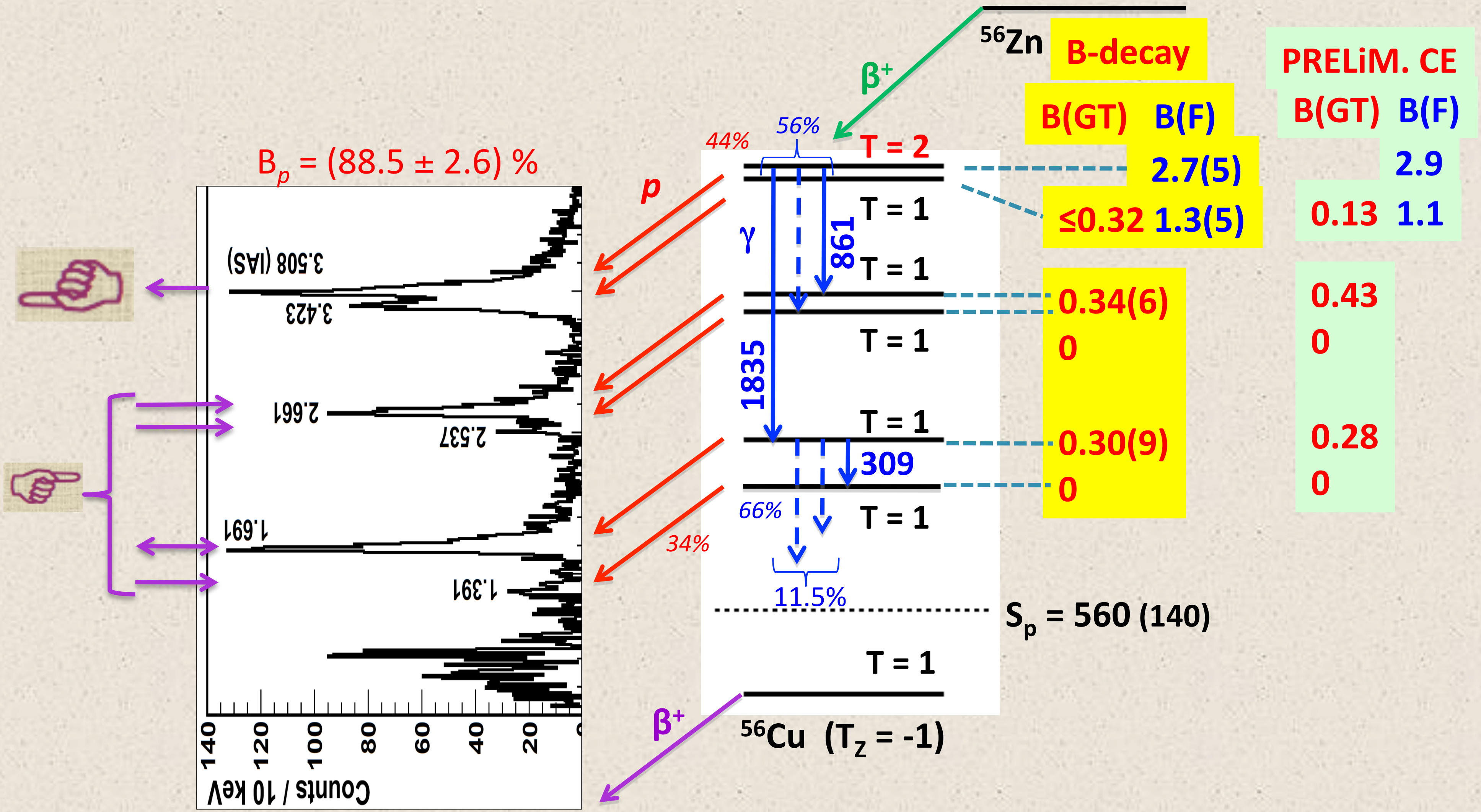
But this is NOT the end of the story!!!





the fragmentation of the IAS is important for the Mass evaluation

And now we can compare with the Charge Exchange reaction in the mirror



PRL **112,** 222501 (2014) PHYSICAL REVIEW LETTERS week ending 6 JUNE 2014

Observation of the β-Delayed γ-Proton Decay of ^{56}Zn and its Impact on the Gamow-Teller Strength Evaluation

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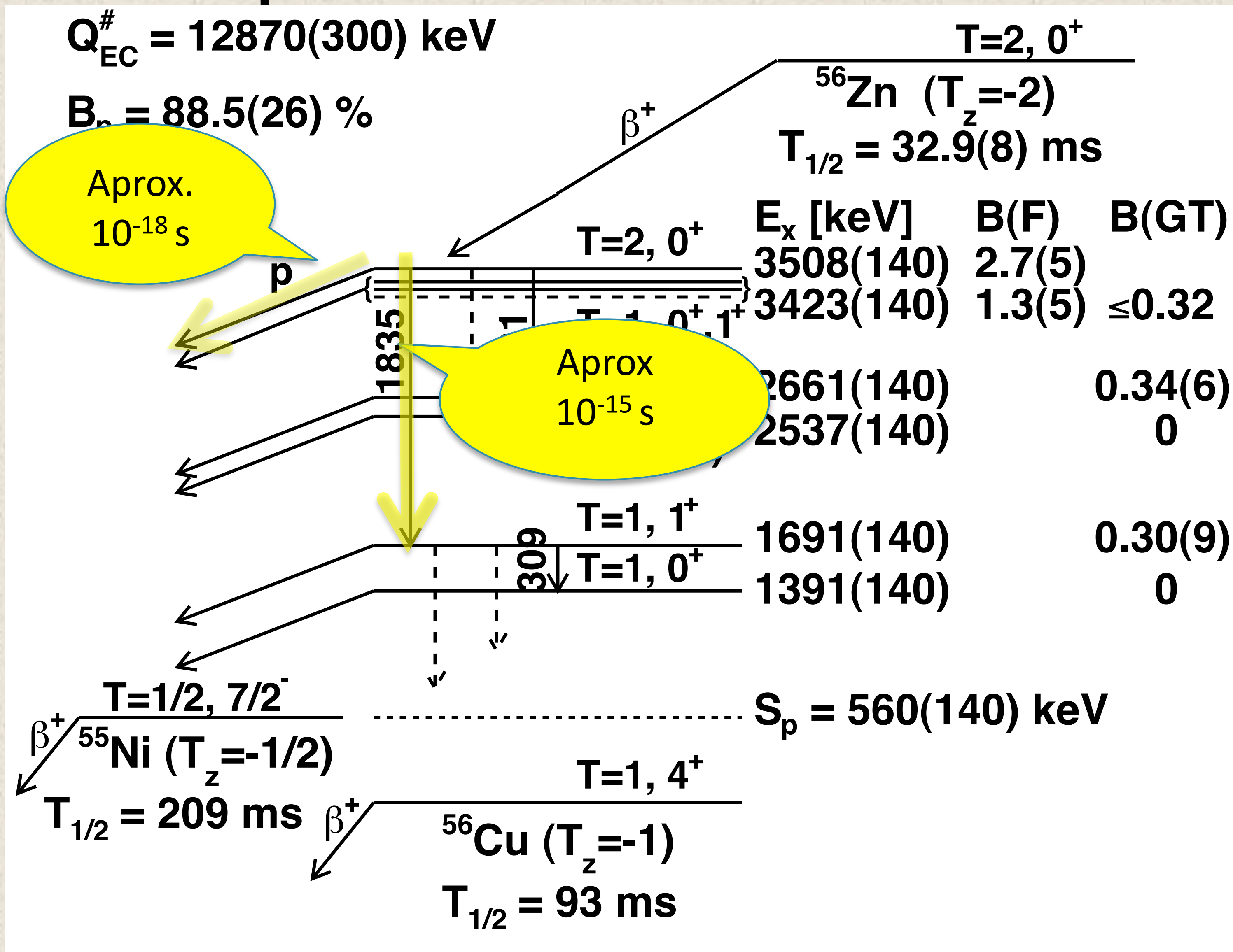
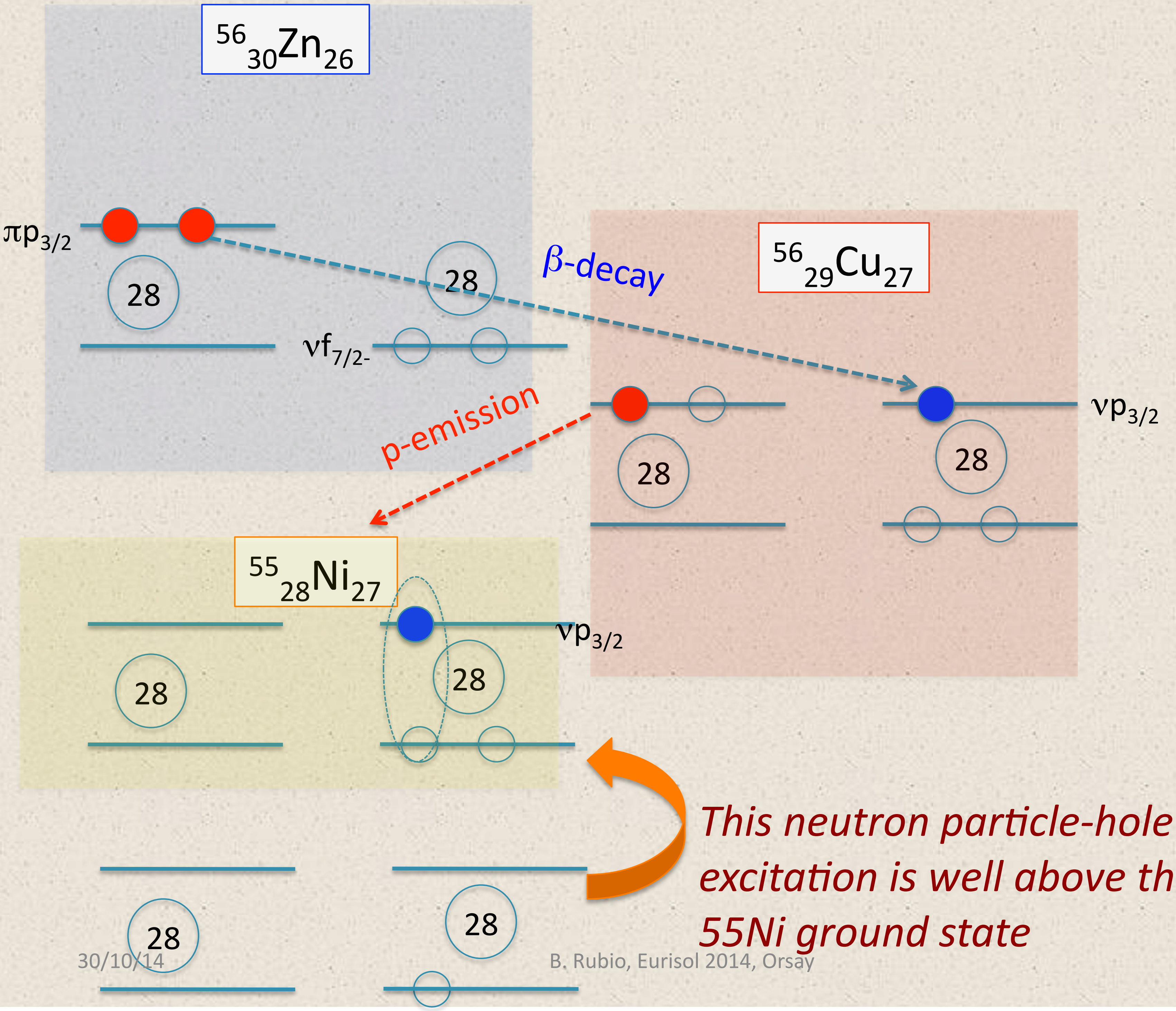
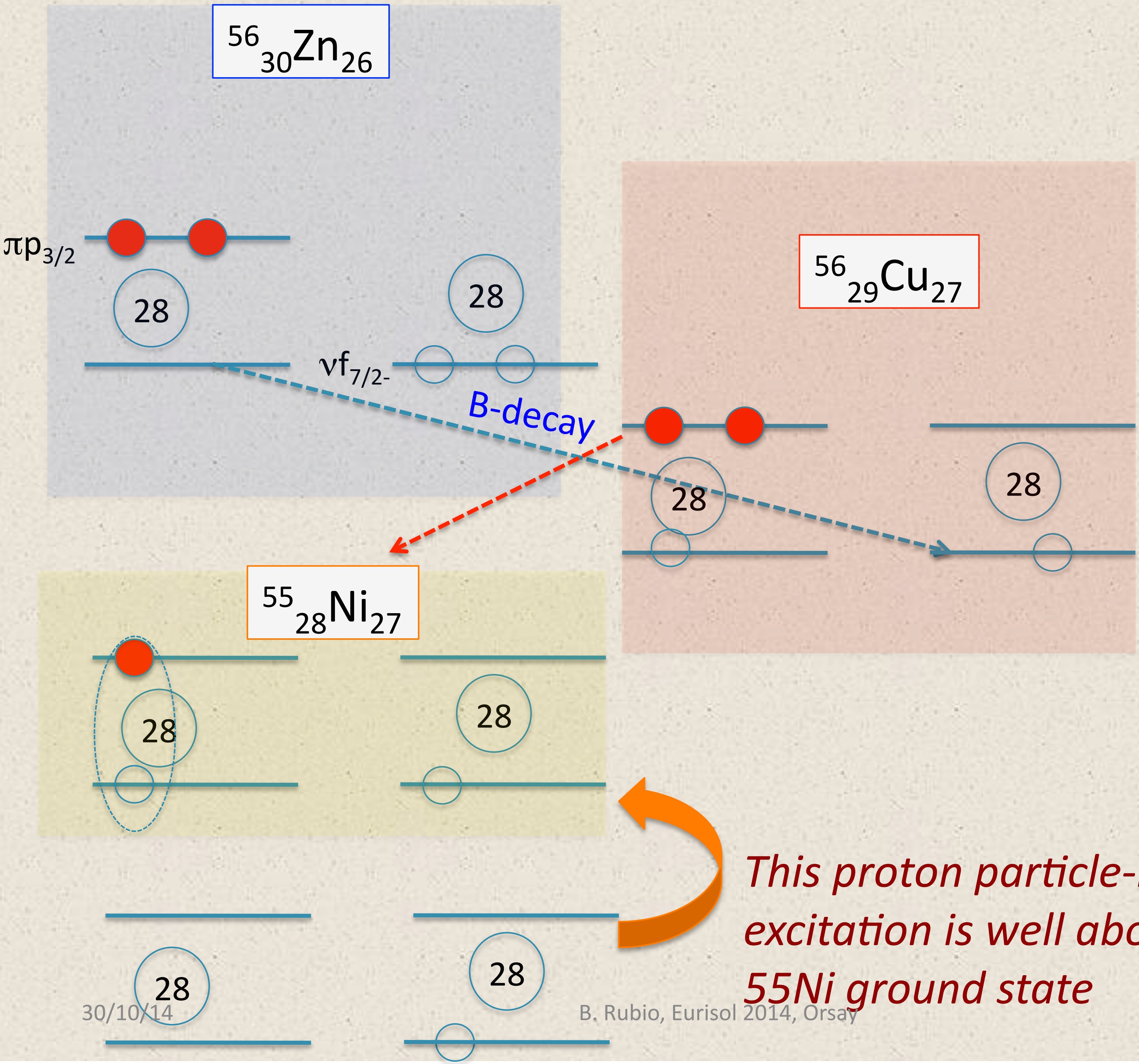
We were puzzled for some time….





This neutron particle-hole excitation is well above the 55Ni ground state



This proton particle-hole excitation is well above 55Ni ground state

On going understanding….by Piet van Isacker.

Trying to understand the β-delayed proton and γ decays of ^{56}Zn

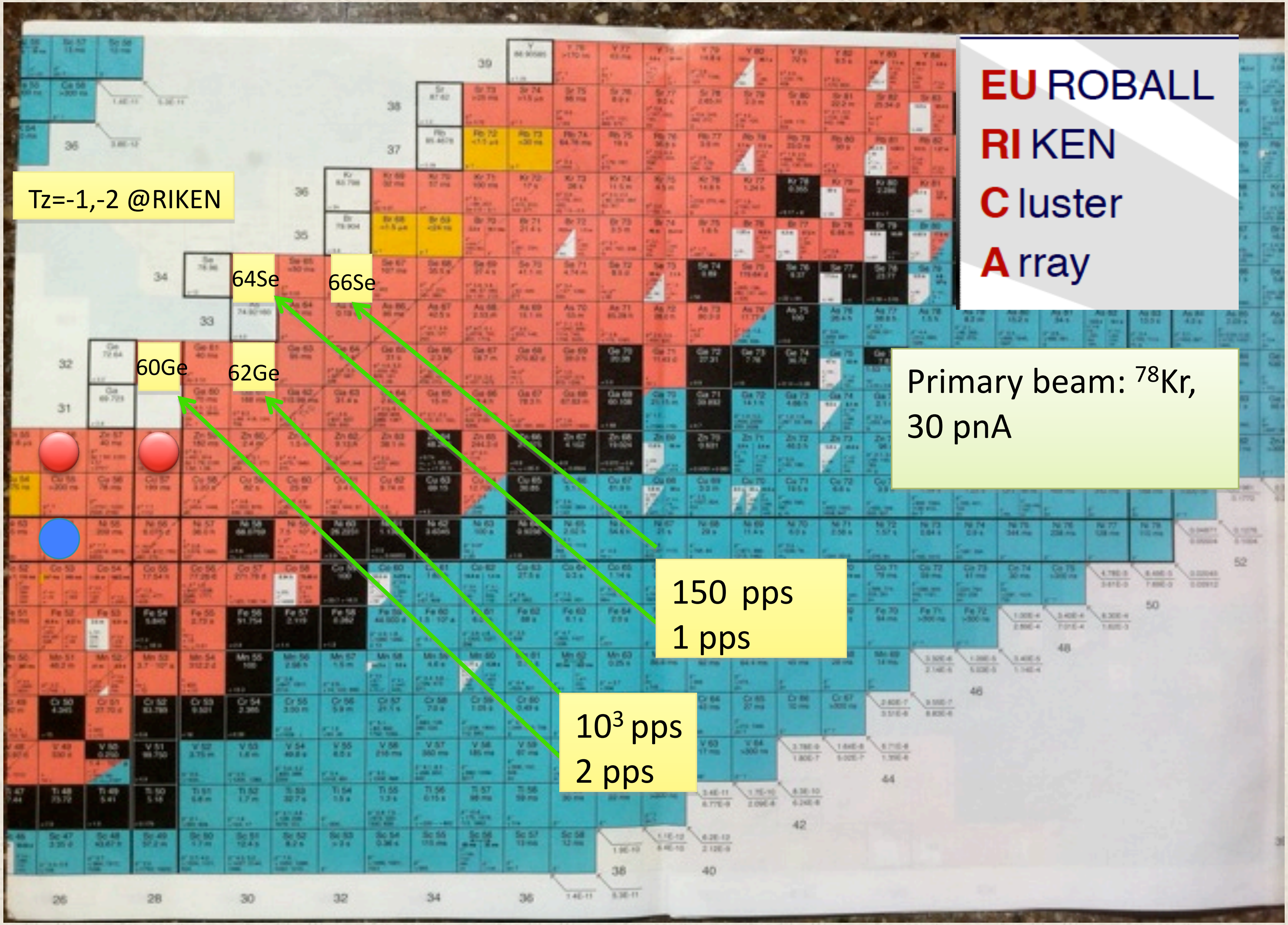
1. Outline of the approach

We assume that the actors of this play are the nucleon holes in the $1f_{7/2}$ shell and the nucleon particles in the $2p_{3/2}$ shell. Basis states with good isospin are considered and this requires that the nucleons occupying the two shells can be neutrons or protons.

5. Proton decay

If we accept that the second 0^+ state with $T = 1$ (see below for a problem with that) is the one that mixes with the isobaric analog state, then proton decay will remain hindered. Either a proton in the $2p_{3/2}$ shell is emitted to form a one-particle-two-hole excitation in ^{55}Ni or the proton is emitted from the $1f_{7/2}$ shell and the decay proceeds towards a two-particle-three-hole excitation in ^{55}Ni. It can be expected (but should be checked) that these excitations occur above the energy window available for the proton decay from ^{56}Cu.

Today (in principle) one can continue this kind of studies at RIKEN



Conclusion

Beta-decay studies are a powerful tool to understand nuclear structure
far from the stability

One needs intense radioactive beams if one wants to extract the real physics
Some of these experiments can be carried out at the Eurisol distributed facility

Some experiments such as the one to one comparison between beta decay
And Charge Exchange reactions on a shot living radiactive nucleus
will probably demand EURISOL in full glory