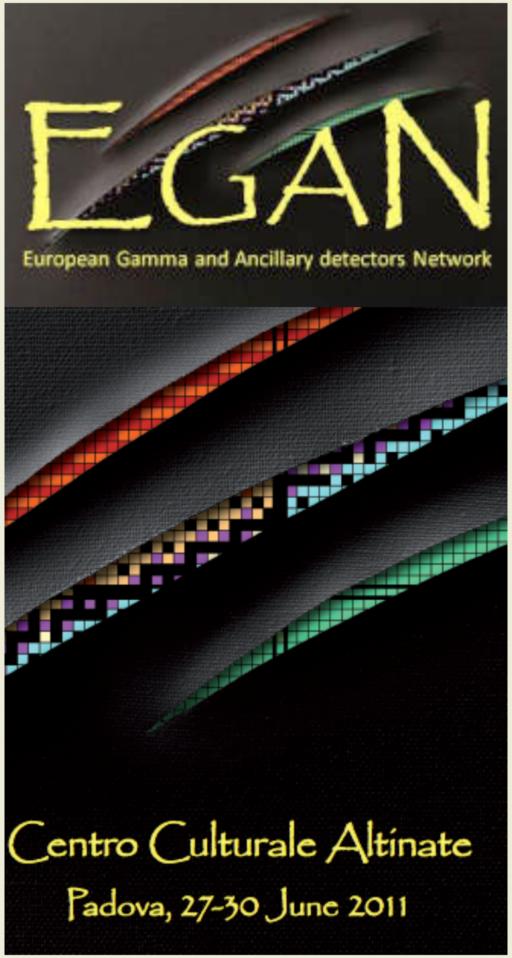
Studies of the Beta Decays of Tz=-1 nuclei, comparison with Charge Exchange reactions and M1 transition "quasi-rule .



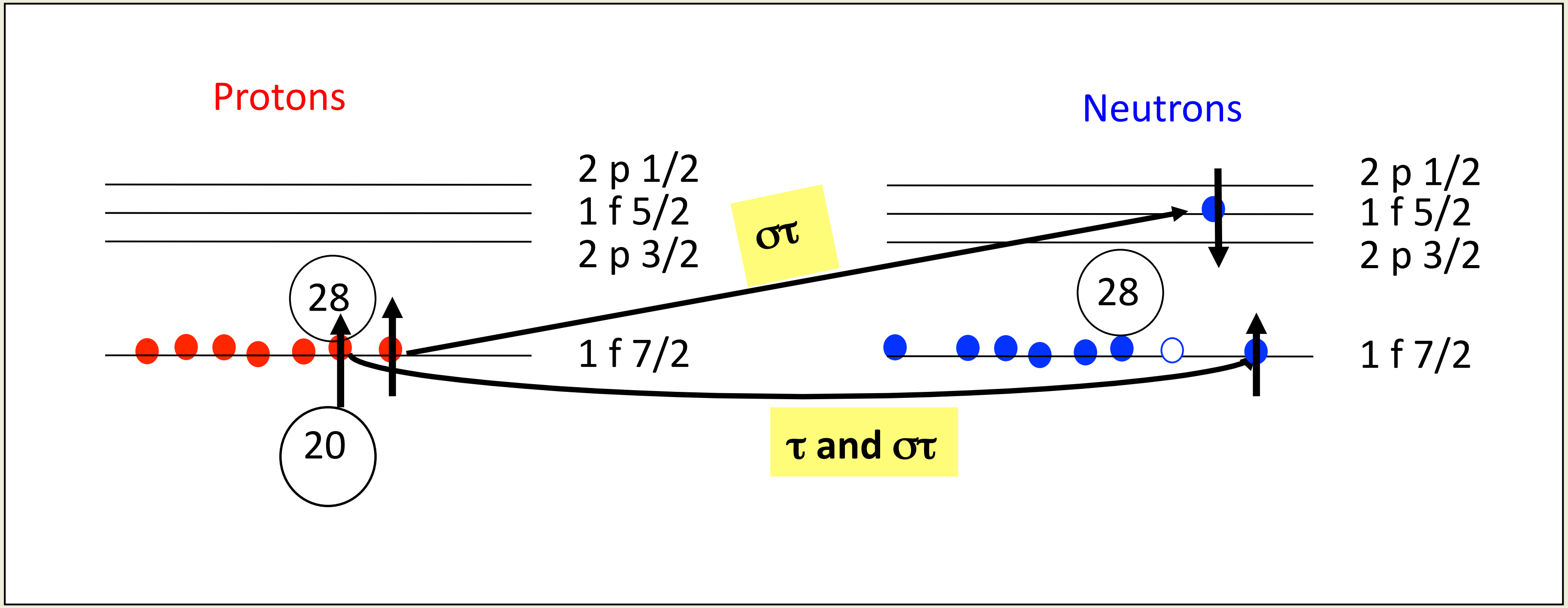
B. Rubio, F. Molina*, Y. Fujita,
W. Gelletly, S. Orrigo,
L. Kucuk et al

On behalf of the Valencia-Osaka
Surrey-Istambul-Santiago-GSI-Leuven-Bordeaux….
*P.h.D Thesis

Layout of my talk

- Motivation: B(GT) studies using the combined knowledge from beta decay and Charge Exchange reactions. Can one really combine them?
- Beta decay studies at GSI-FRS-Rising of Tz=-1 nuclei, comparison of Tz=+1 nuclei studied at Osaka
- Beta decay studies at GANIL-LISE-RIKEN

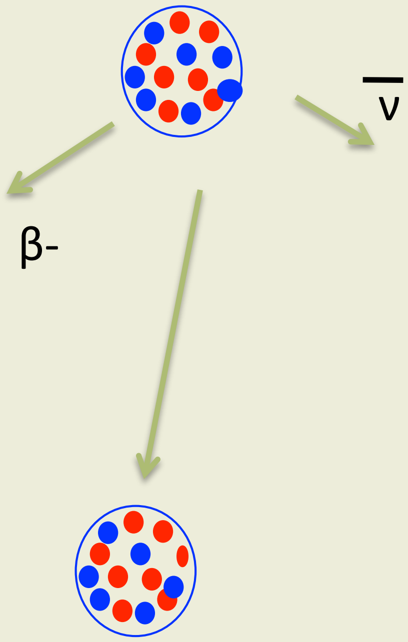
Beta decay and Charge Exchange are two processes governed by the same **στ (τ)** operator

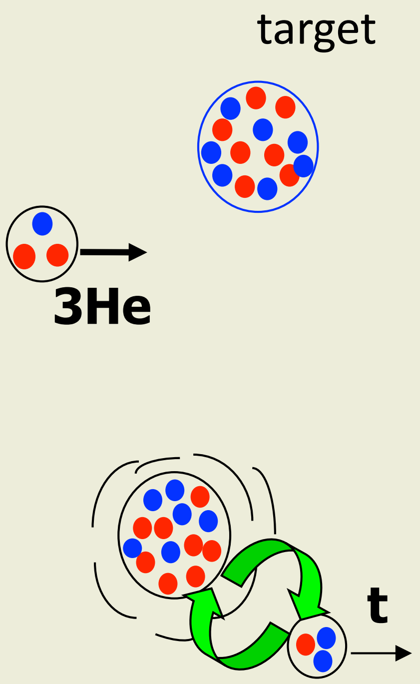


Beta decay and Charge Exchange are two processes governed by the same **στ (τ)** operator

Beta decay

Charge Exchange Reactions





$$B(GT) = \left| \left\langle \psi_f \right| \sum_k \sigma_k \tau_k^{\pm} \left| \psi_i \right\rangle \right|^2$$

Radioactive initial nucleus

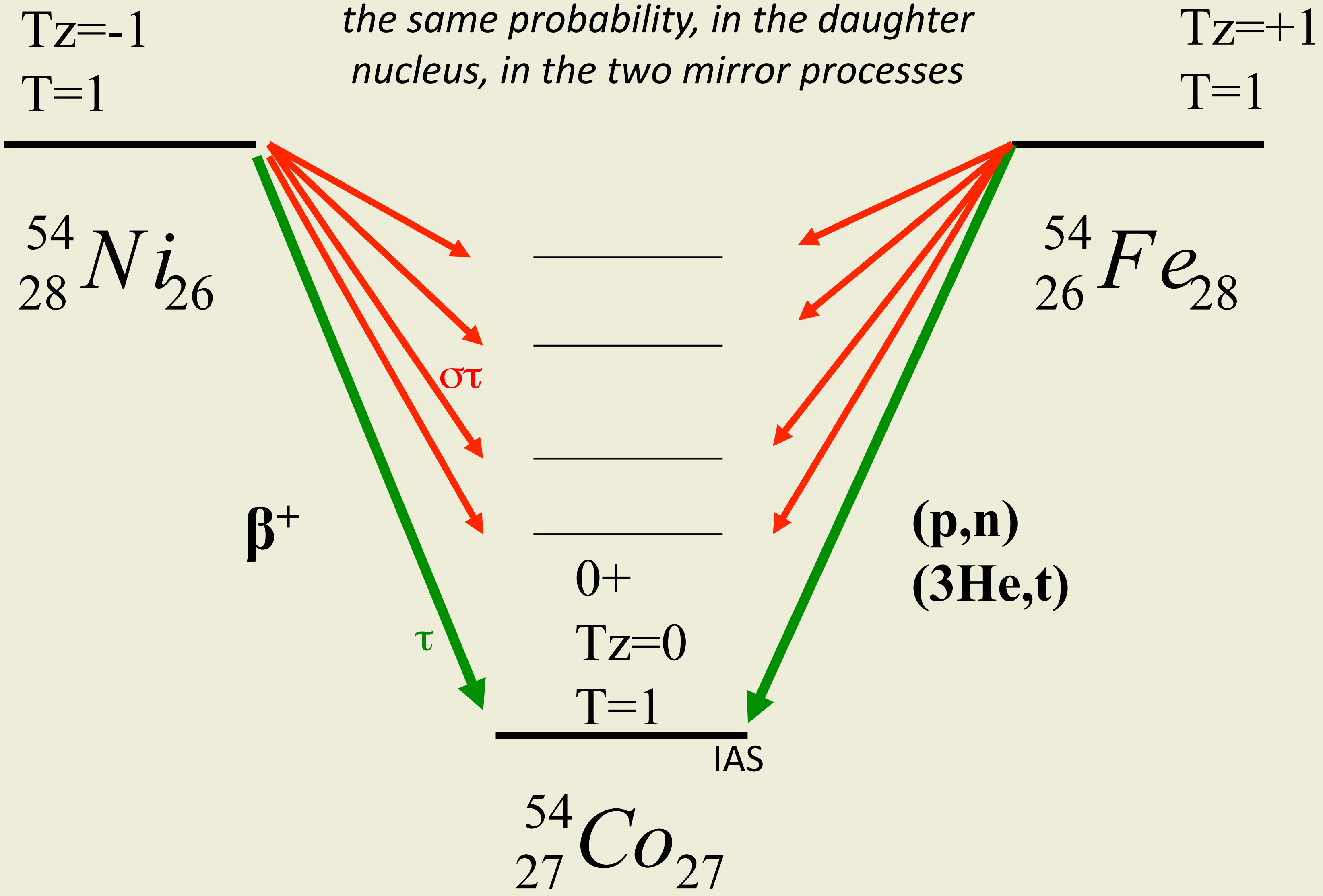
Stable Target

Beta Decay: Absolute Normalization of B(GT). Far from stability.

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

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



Tz=-1

T=1

${}^{54}_{28}Ni_{26}$

Tz=+1

T=1

${}^{54}_{26}Fe_{28}$

$\sigma\tau$

β^+

τ

(p,n)

(3He,t)

0+

Tz=0

T=1

IAS

${}^{54}_{27}Co_{27}$

Prior to our work……

Beta decay

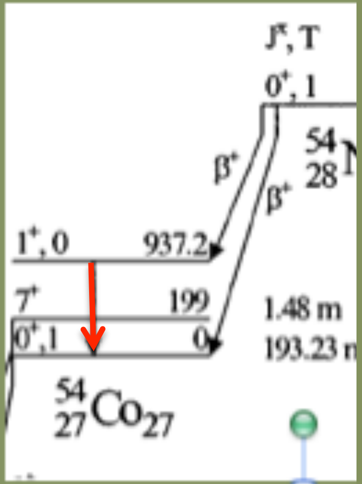
Charge Exchange Reactions

PHYSICAL REVIEW C VOLUME 59, NUM

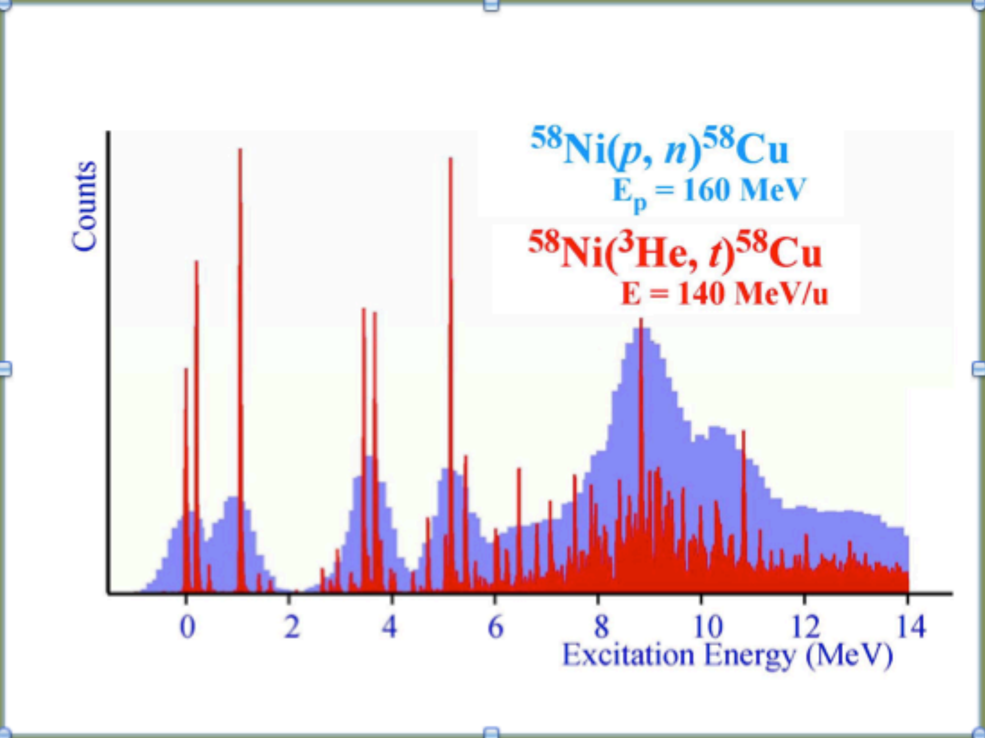
β-decay study of ^{54,55}Ni produced by an e

I. Reusen, A. Andreyev,* J. Andrzejewski,† N. Bijnens, S. Fr
W. F. Mueller, A. Piechaczek,‡ R. Raabe, K. Rykaczewski
J. Wauters,** and A

Instituut voor Kern- en Stralingsfysica, University of Leuven,
(Received 3 Decemb

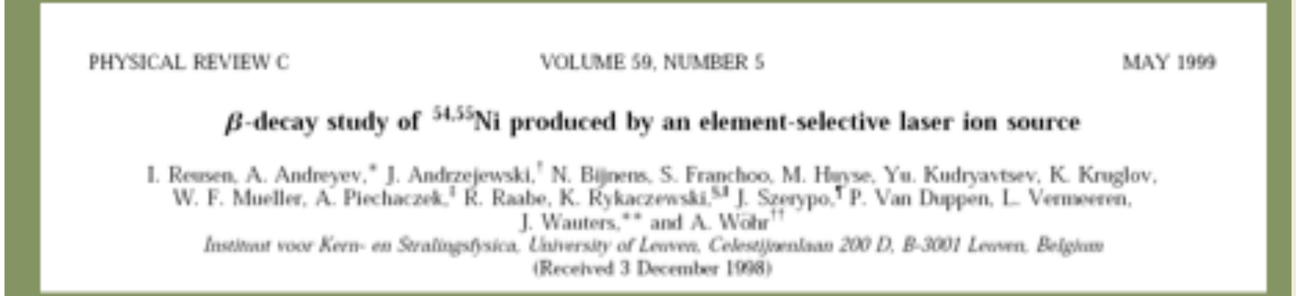


I. Reusen et al. Phys.Rev C 5



on energy of Gamow-Teller
states. At the stability.

The plan of the present experiments was to improve the beta decay side

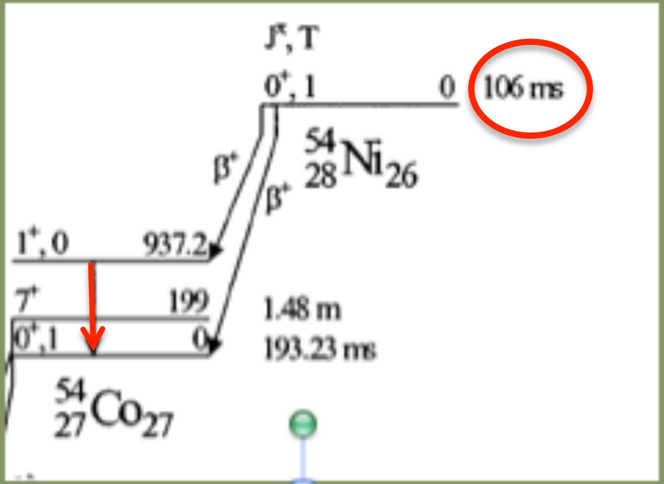


PHYSICAL REVIEW C VOLUME 59, NUMBER 5 MAY 1999

β-decay study of ^{54,55}Ni produced by an element-selective laser ion source

I. Reusen, A. Andreyev,* J. Andrzejewski,† N. Bijnens, S. Franchoo, M. Huyse, Yu. Kudryavtsev, K. Kruglov,
W. F. Mueller, A. Piechaczek,‡ R. Raabe, K. Rykaczewski,§∥ J. Szerypo,¶ P. Van Duppen, L. Vermeeren,
J. Wauters,** and A. Wöhr††
Instituut voor Kern- en Stralingsfysica, University of Leuven, Celestijnenlaan 200 D, B-3001 Leuven, Belgium

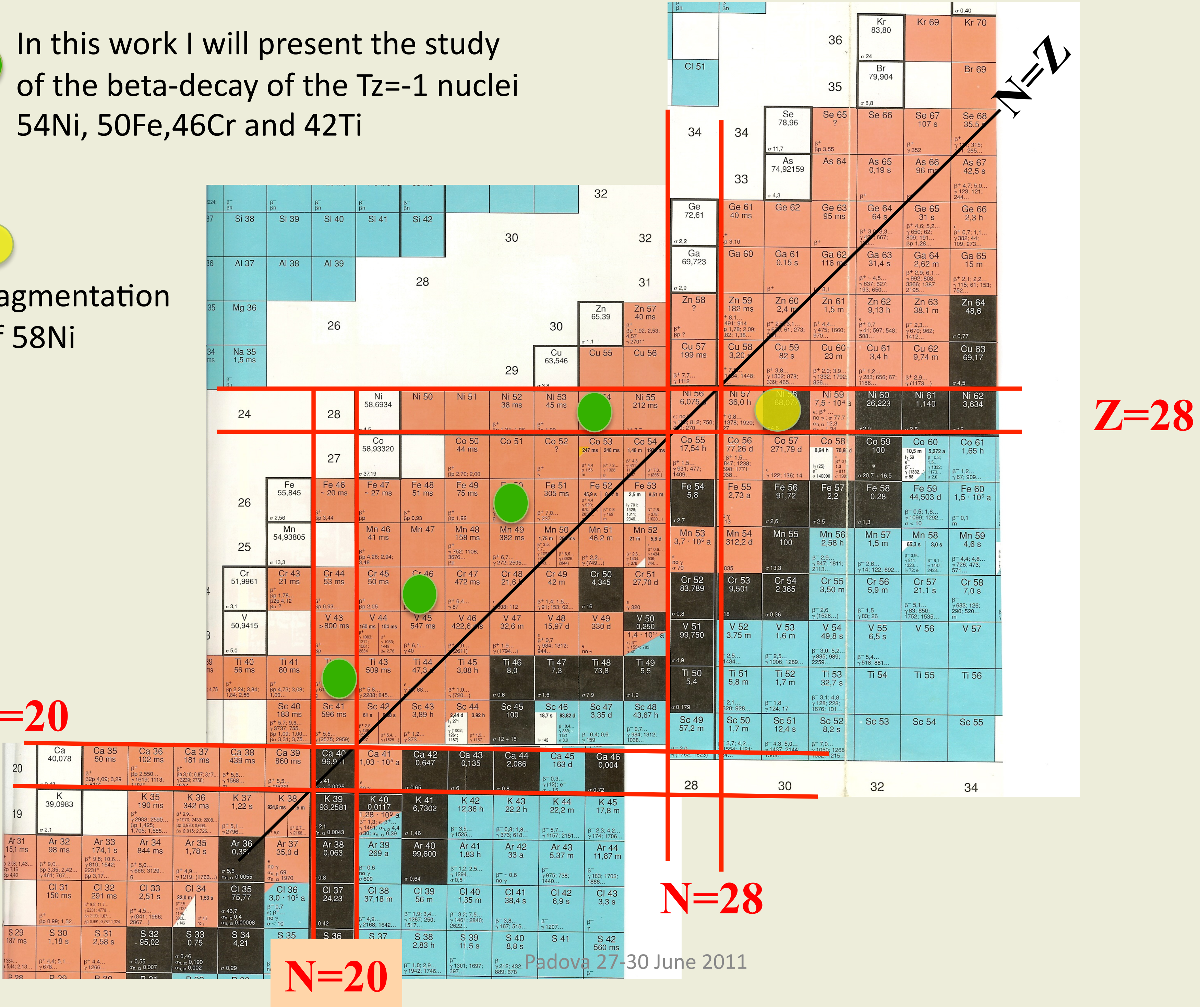
(Received 3 December 1998)



I. Reusen et al. Phys.Rev C 59, 2416-2421 (1999)

● In this work I will present the study of the beta-decay of the Tz=-1 nuclei 54Ni, 50Fe,46Cr and 42Ti

● Fragmentation of 58Ni



In this paper we are interested in extracting information about the B(GT) strength

Theoretically

$$B(GT) = \left| \langle \psi_f | \sum_k \sigma_k \tau_k^{\pm} | \psi_i \rangle \right|^2$$

Experimentally

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

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

Combined analysis
Fujita et al.,
PRL95(2005)212501

From the present experiment

☞ $\boxed{T_{1/2}}$ Parent half life

☞ $I_\beta(E)$ Beta feeding to states in the daughter nucleus

Not from the present experiments Q_β

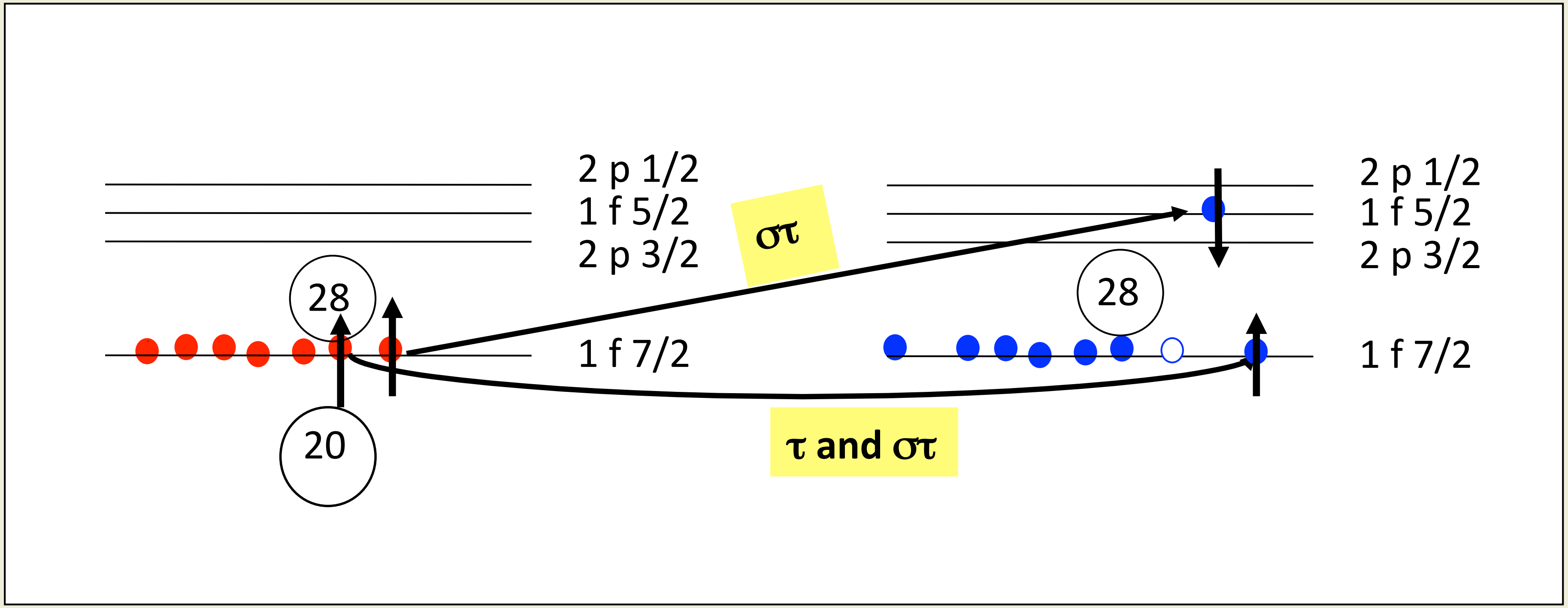
Simple scenario

We choose Tz=-1 nuclei with Z=22 to 28 because these cases are specially "clean" since they involve only

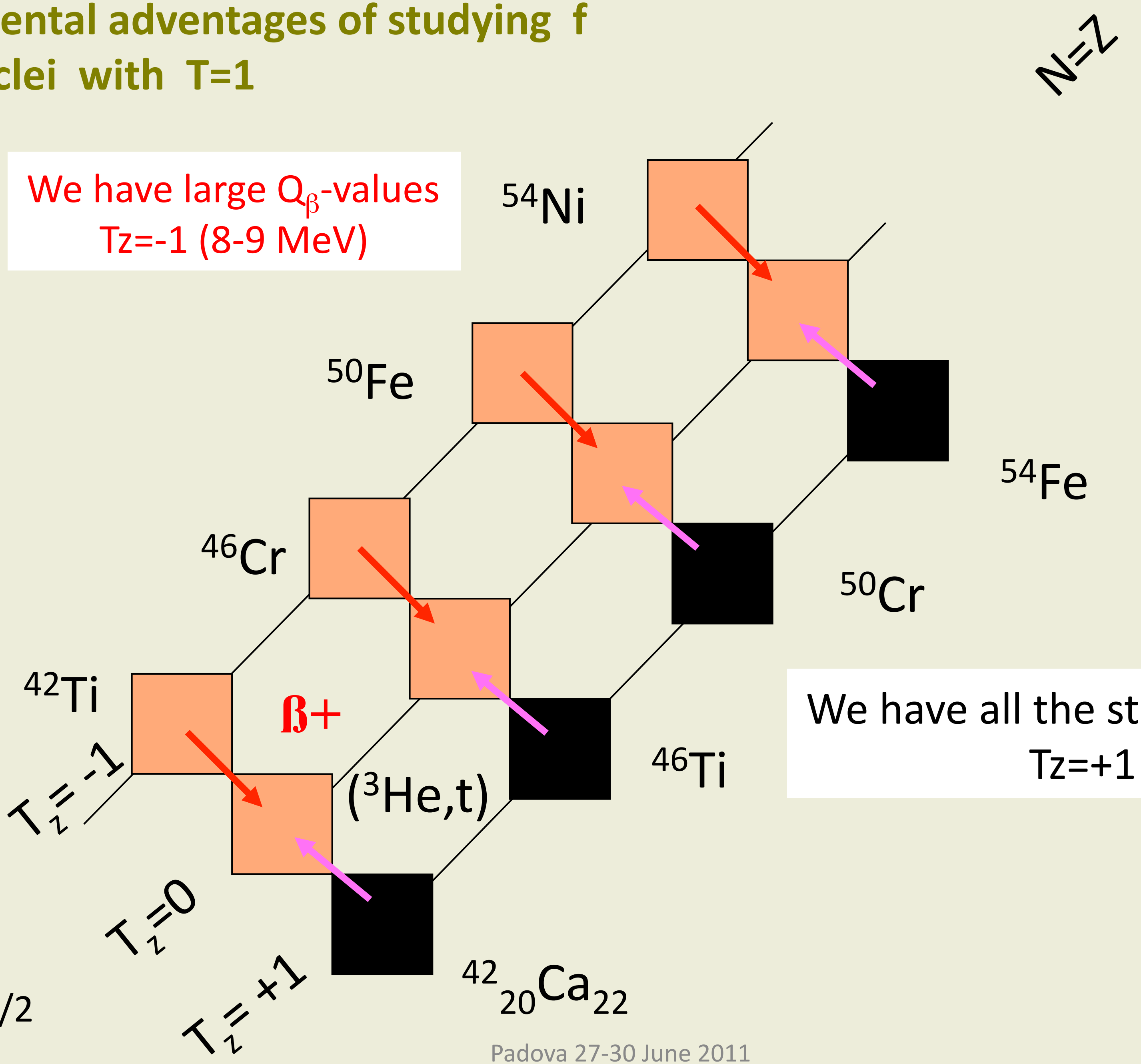
πf7/2 to νf7/2

and

πf7/2 to νf5/2



Experimental adventages of studying f shell nuclei with T=1



We have large Q_{β}-values
Tz=-1 (8-9 MeV)

N=Z

^{54}Ni

^{50}Fe

^{54}Fe

^{46}Cr

^{50}Cr

^{42}Ti

ß+

(^{3}He,t)

^{46}Ti

We have all the stable targets
Tz=+1

T_z= -1

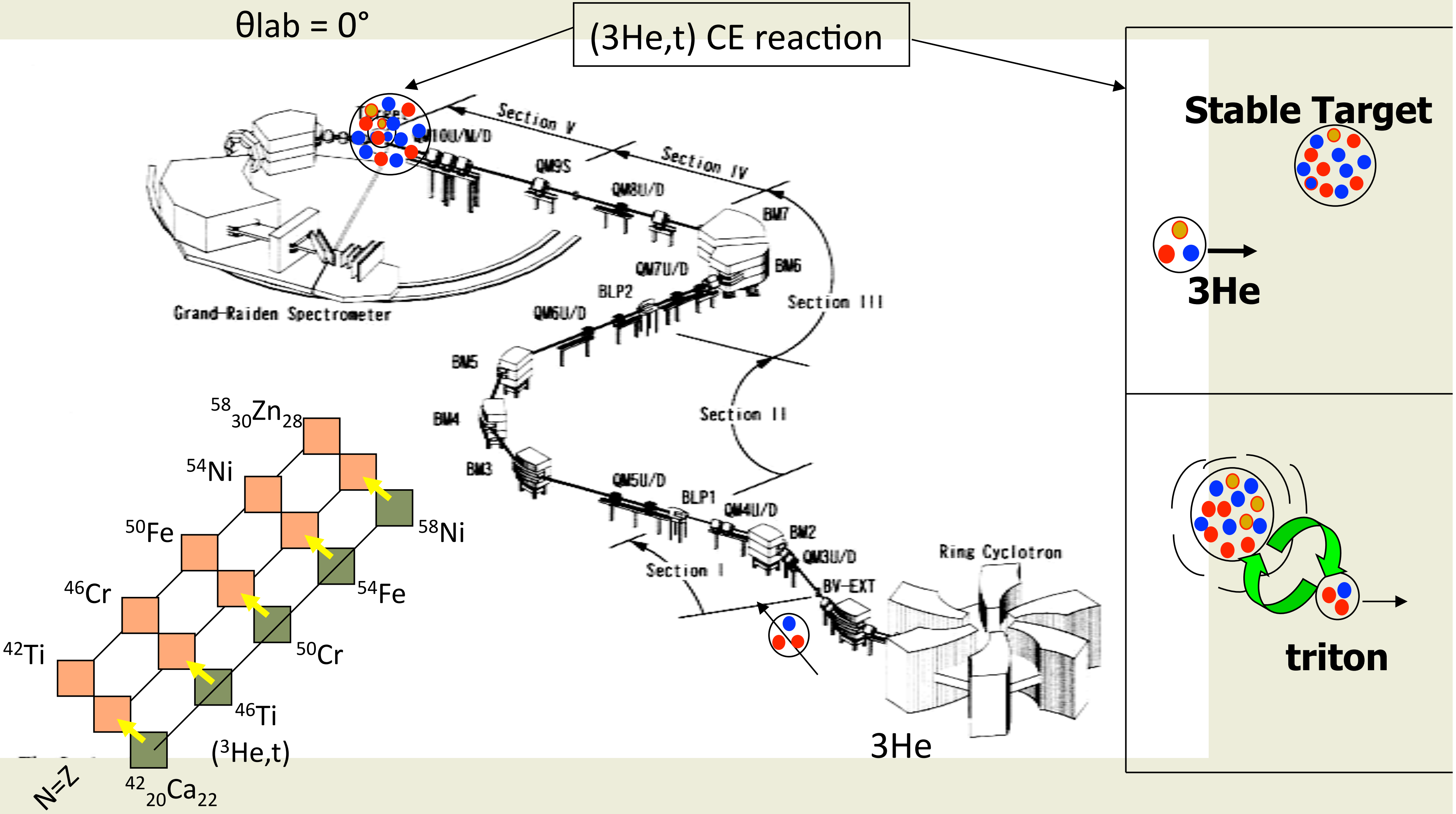
T_z=0

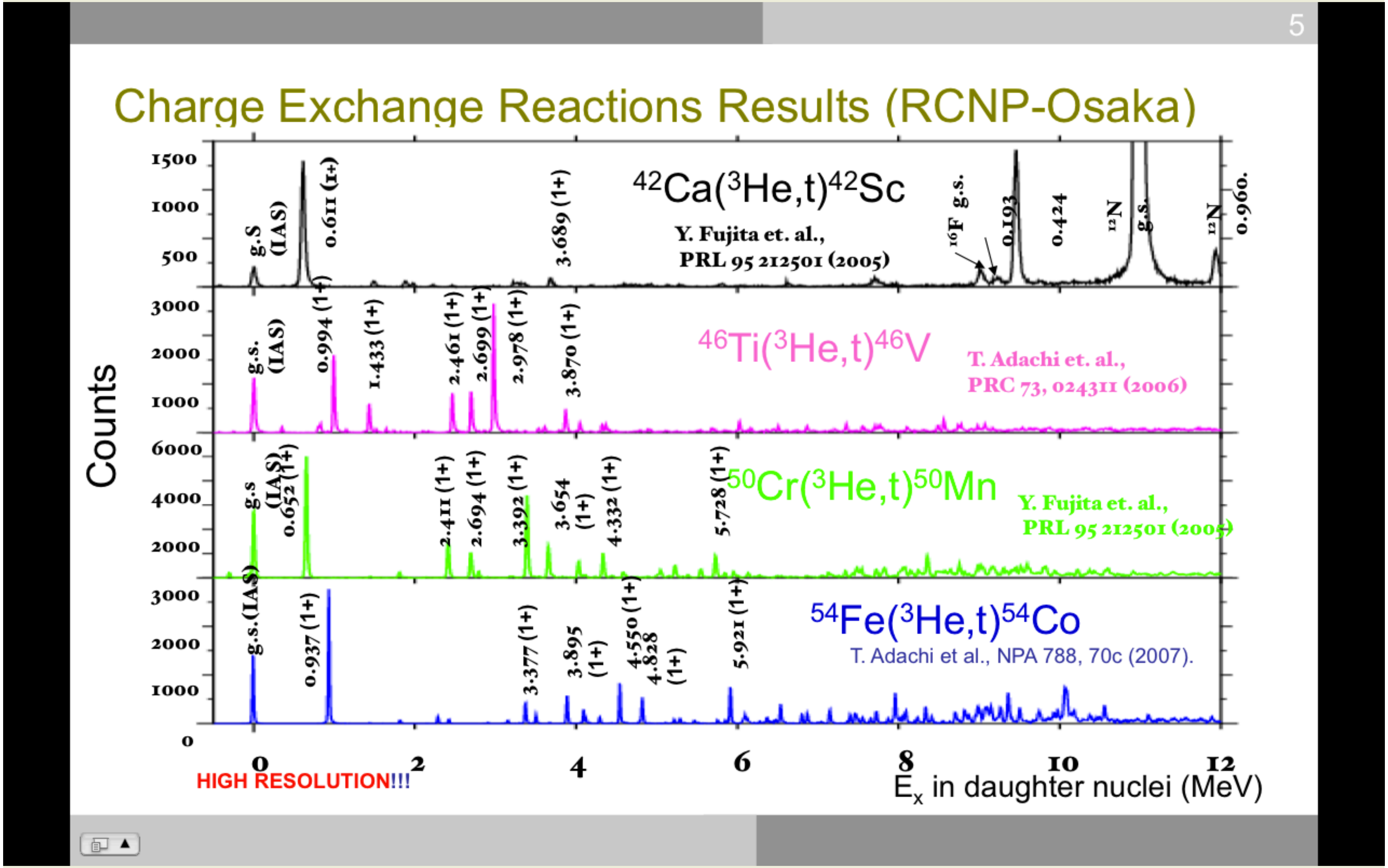
T_z= +1

$^{42}_{20}$Ca$_{22}$

Tz=(N-Z)/2

(3He,t) CE Reactions @ RCNP(Osaka)





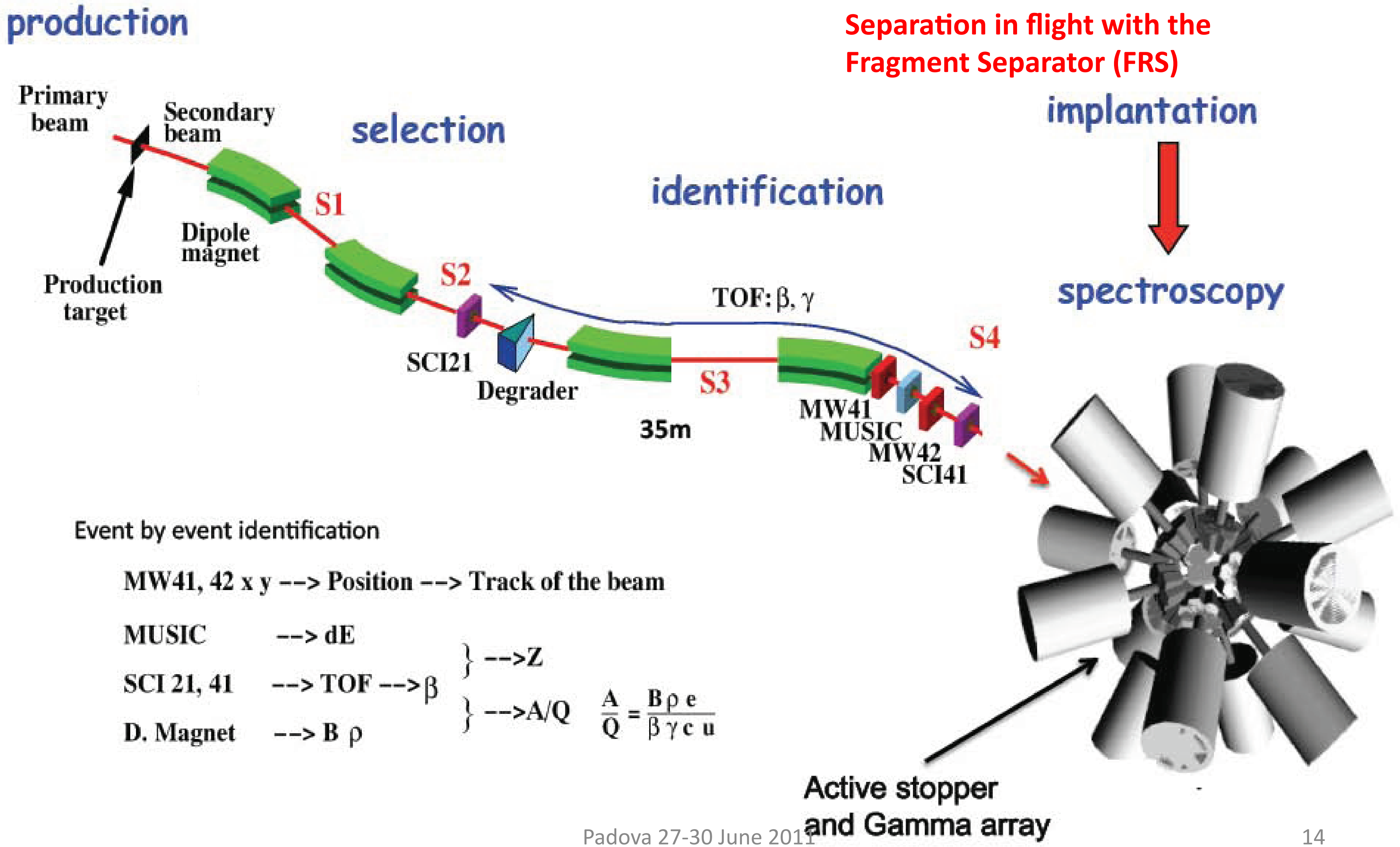
Charge Exchange Reactions Results (RCNP-Osaka)

HIGH RESOLUTION!!!

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)



Event by event identification

MW41, 42 x y --> Position --> Track of the beam

MUSIC --> dE

SCI 21, 41 --> TOF -->β

D. Magnet --> B ρ

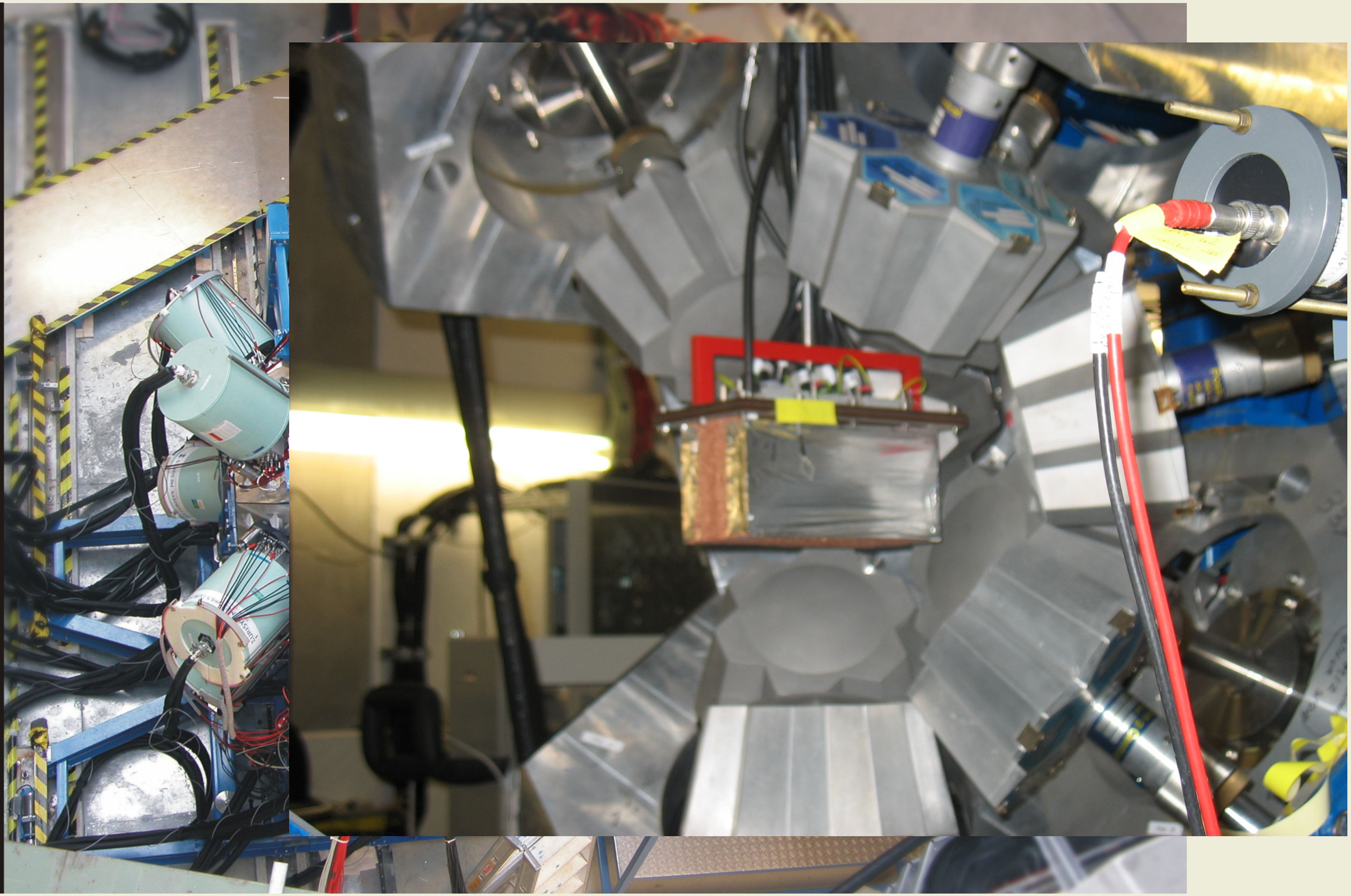
MUSIC and SCI 21, 41 } -->Z

SCI 21, 41 and D. Magnet } -->A/Q

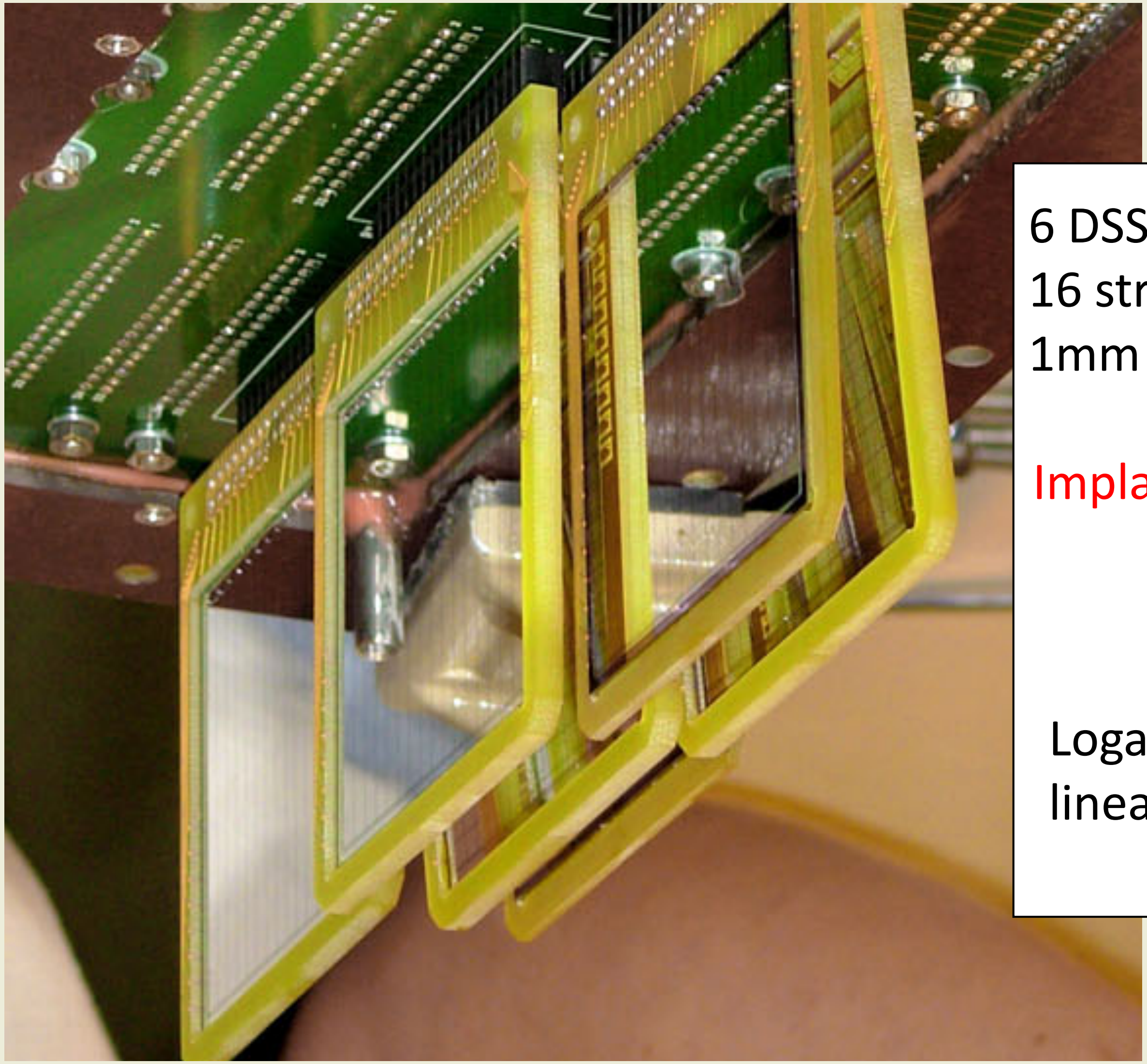
$$\frac{A}{Q} = \frac{B\rho\, e}{\beta\,\gamma\, c\, u}$$

RISING (Ge Array)

stopped beam setup



Detector Setup (Rising and DSSSD)

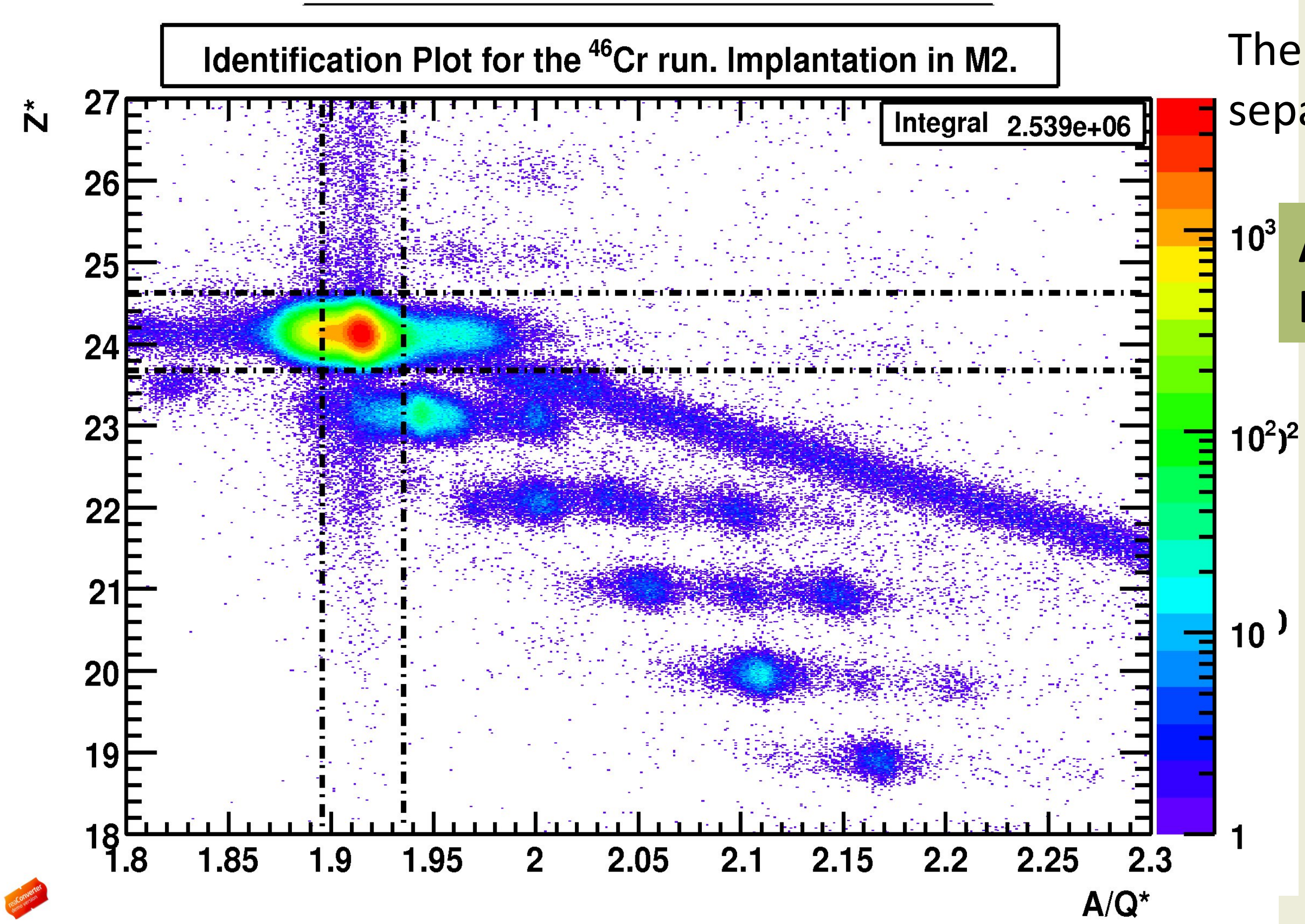


6 DSSSD detectors 1mm with 16 strips X and 16 strips Y, 1mm thick, 5 x 5 cm area

Implantations and Decay detectors

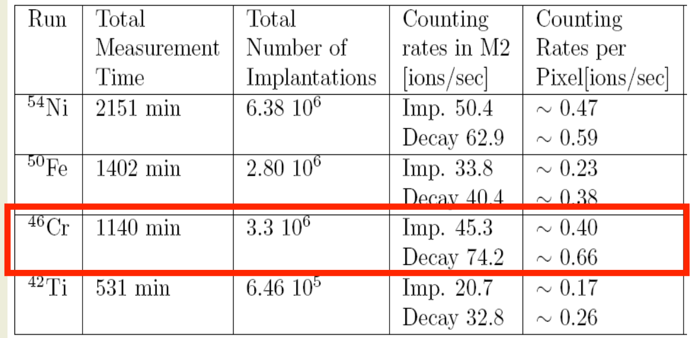
Logarithmic preamplifier linear up to 10 MeV.

46Cr Setting



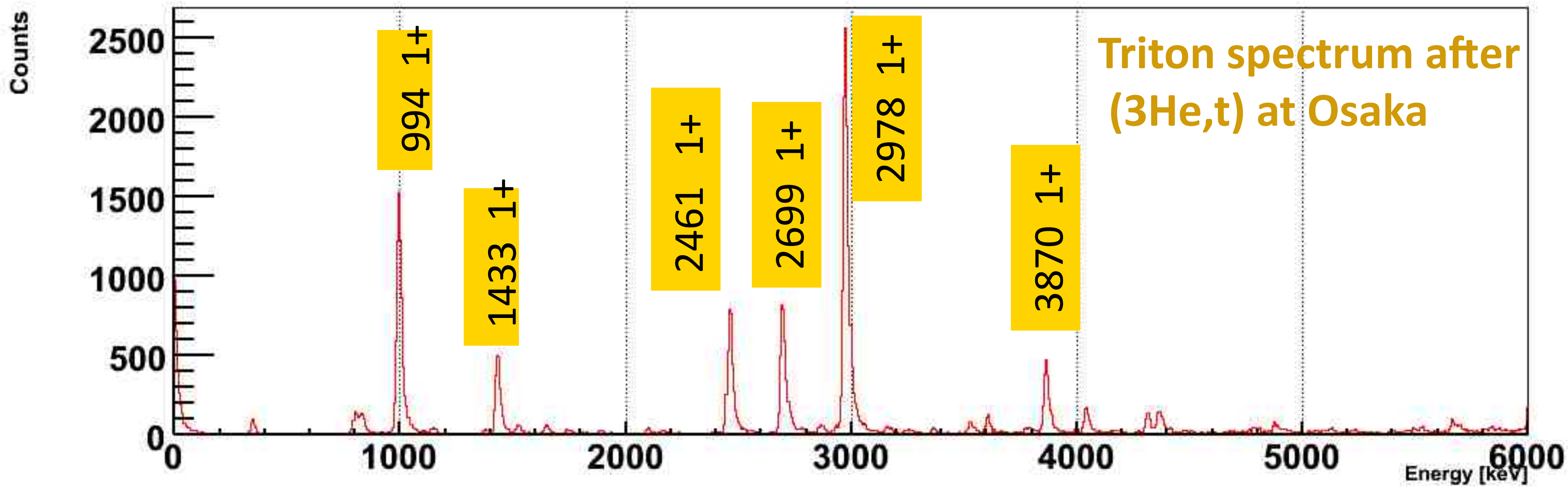
The most abundant nucleus produced, separated and identified up to sci41

And the most abundant nucleus Implanted in M2.



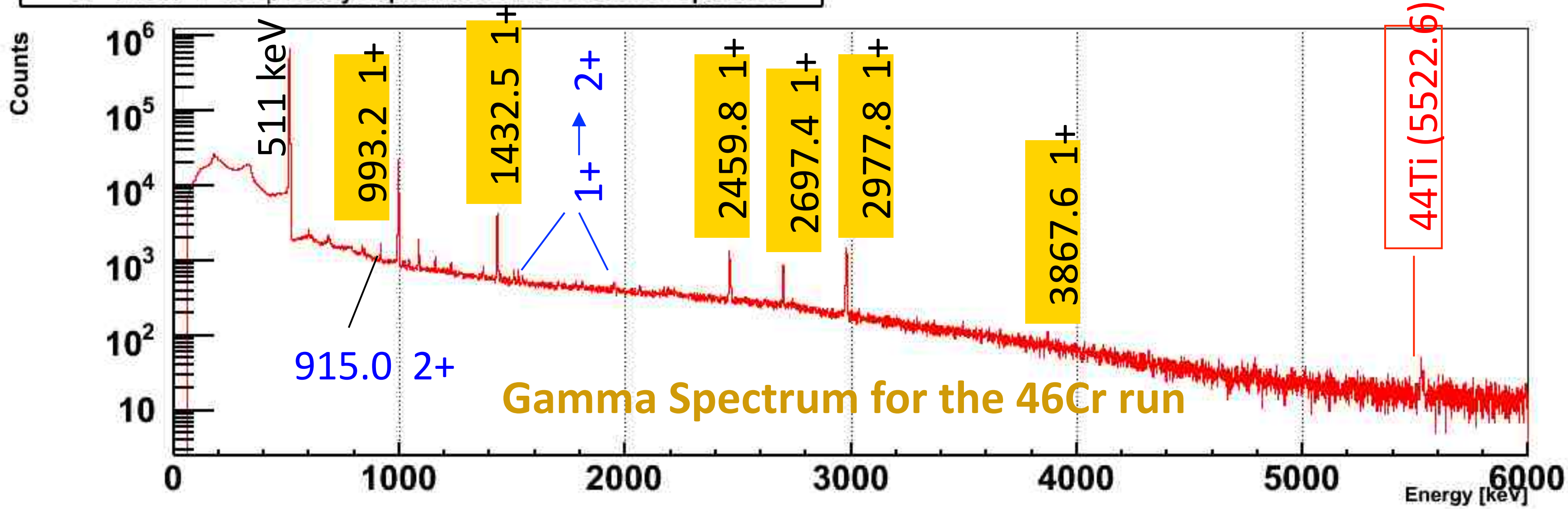
Run	Total Measurement Time	Total Number of Implantations	Counting rates in M2 [ions/sec]	Counting Rates per Pixel[ions/sec]
^{54}Ni	2151 min	$6.38\ 10^6$	Imp. 50.4 Decay 62.9	~ 0.47 ~ 0.59
^{50}Fe	1402 min	$2.80\ 10^6$	Imp. 33.8 Decay 40.4	~ 0.23 ~ 0.38
^{46}Cr	1140 min	$3.3\ 10^6$	Imp. 45.3 Decay 74.2	~ 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



Triton spectrum after (3He,t) at Osaka

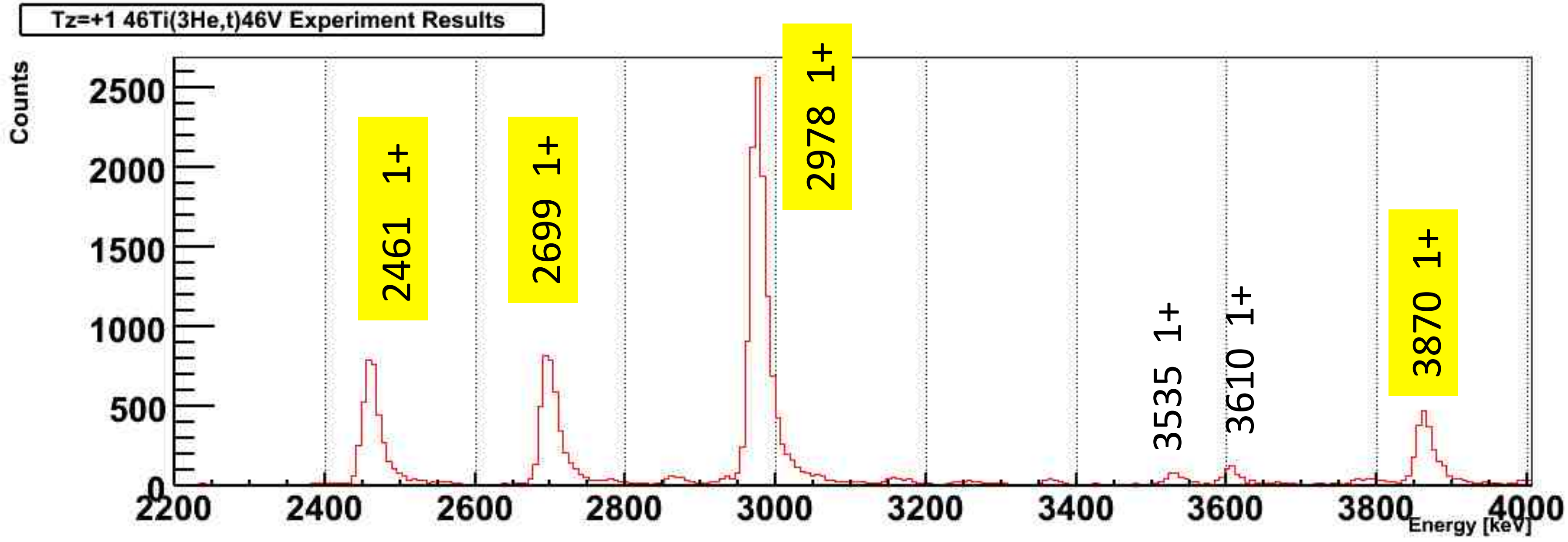
Tz=-1 46Cr → 46V β Decay Experiment. RISING Gamma Spectrum

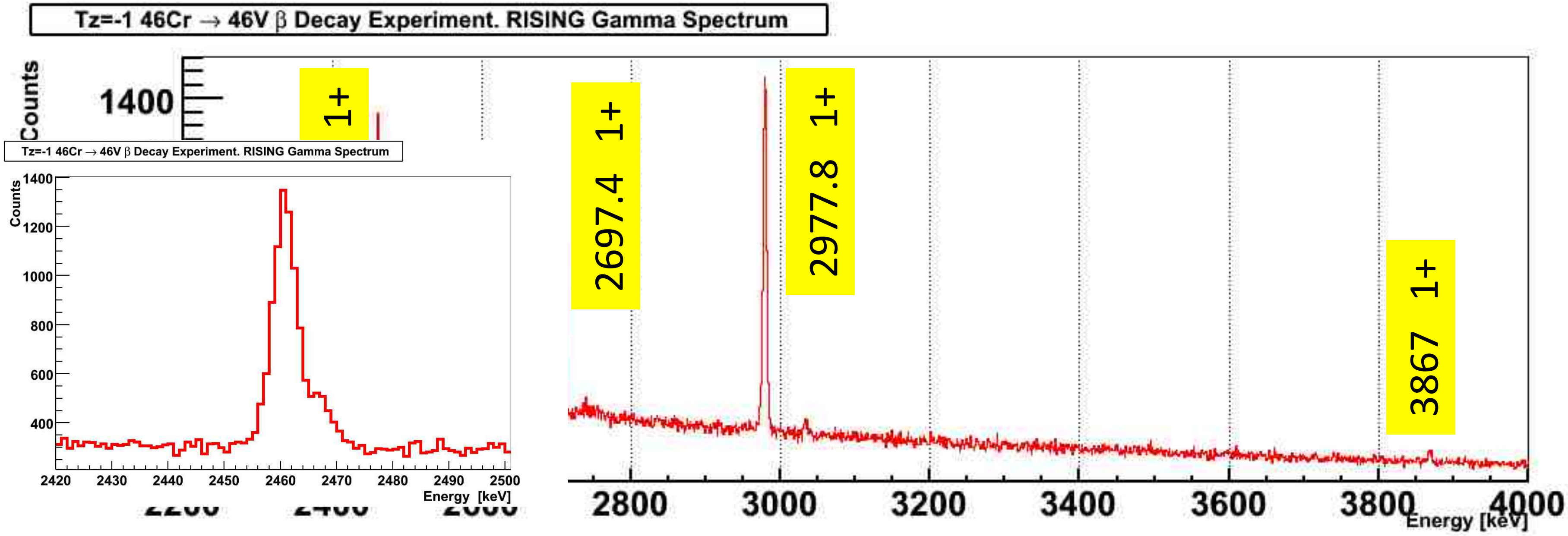


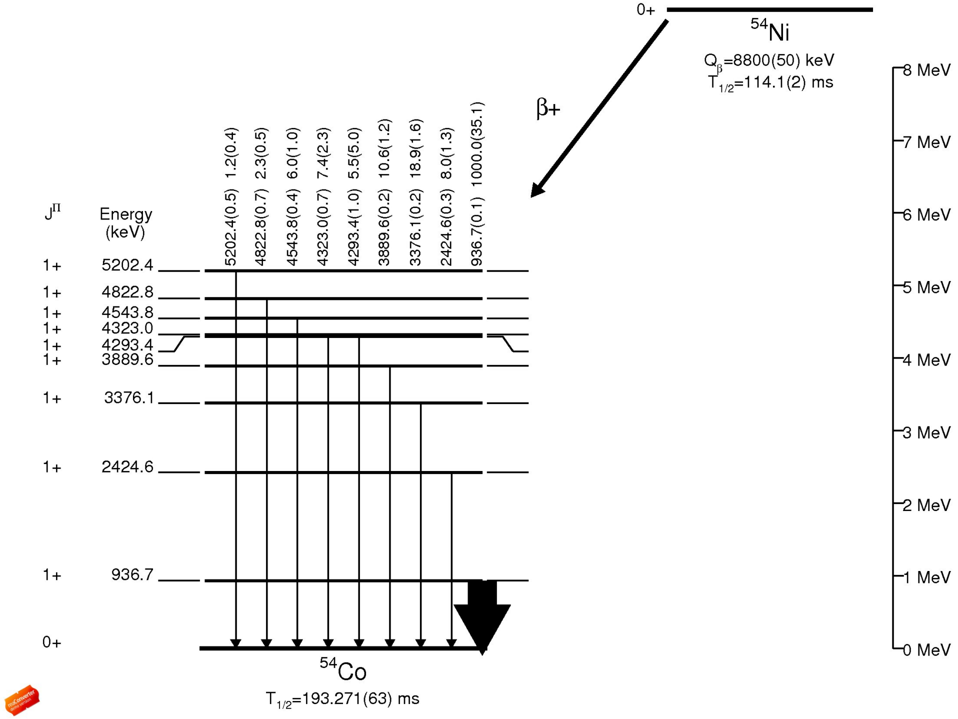
Gamma Spectrum for the 46Cr run

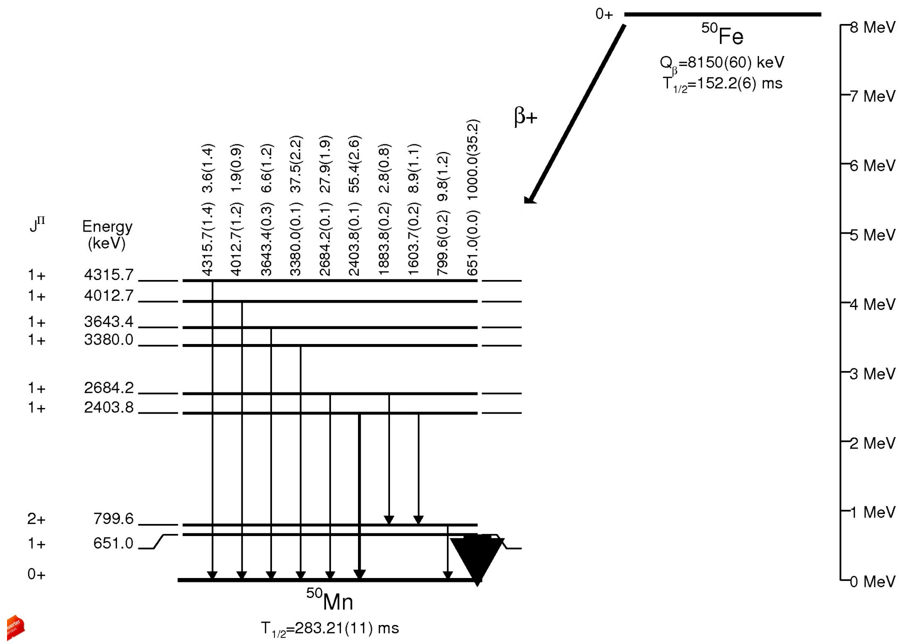
Gamma Spectrum for the 46Cr run

decay trigger

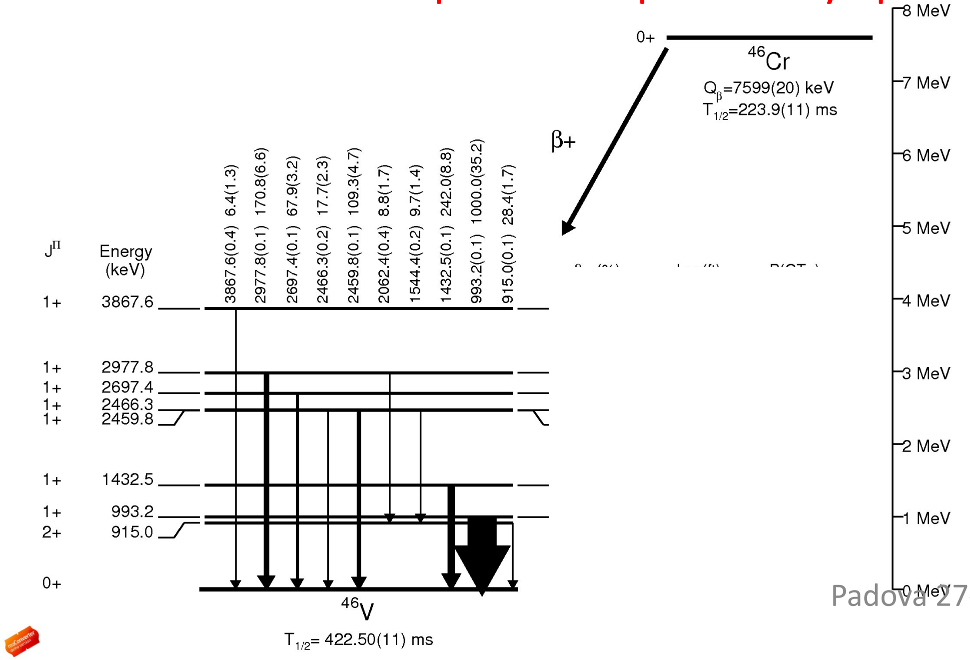


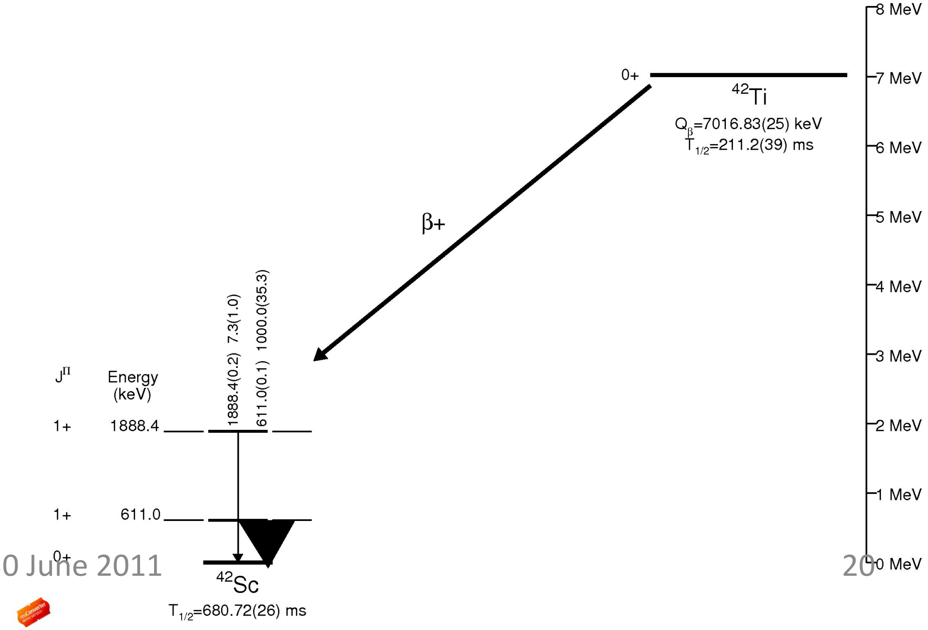




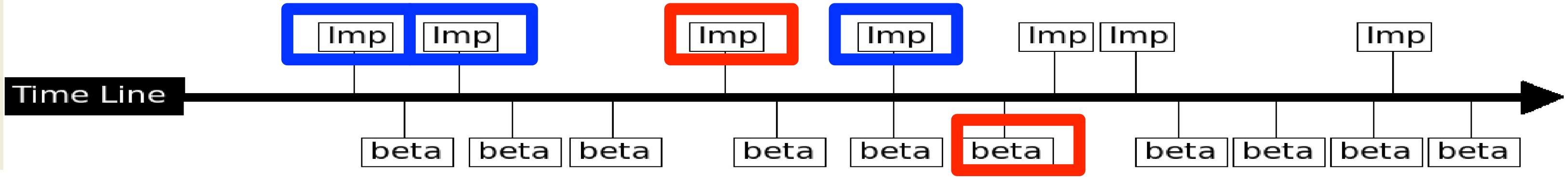


Results of this part: four previously “practically” unknown decay schemes

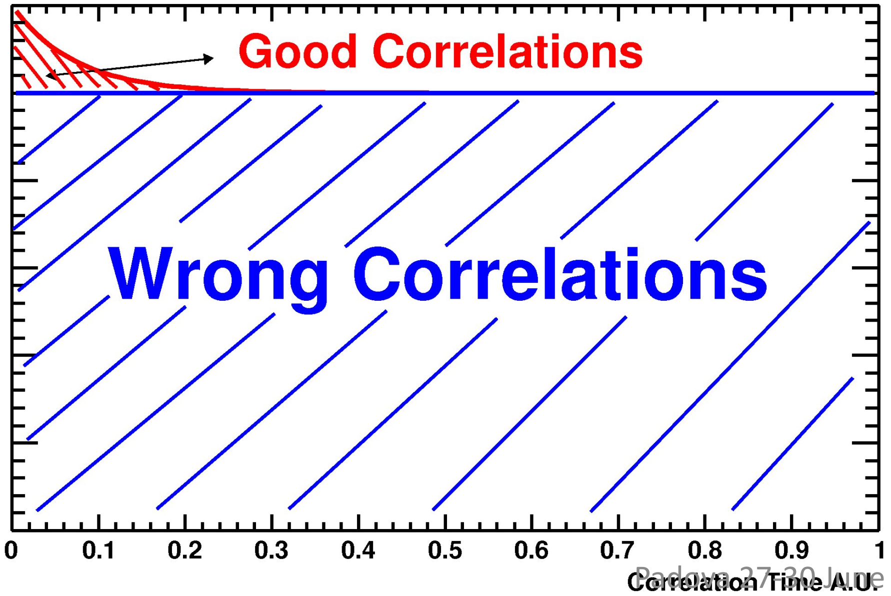


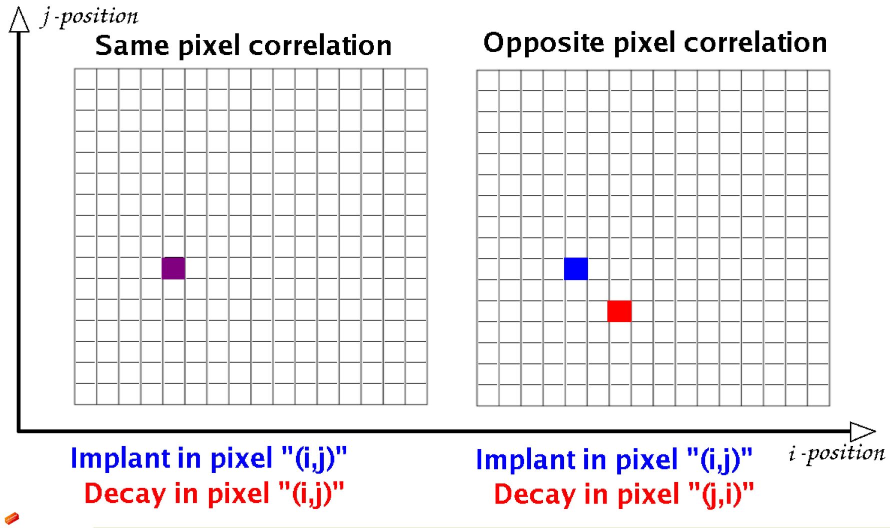


Half life analysis and background determination



One can correlate each beta decay with all previous implantation

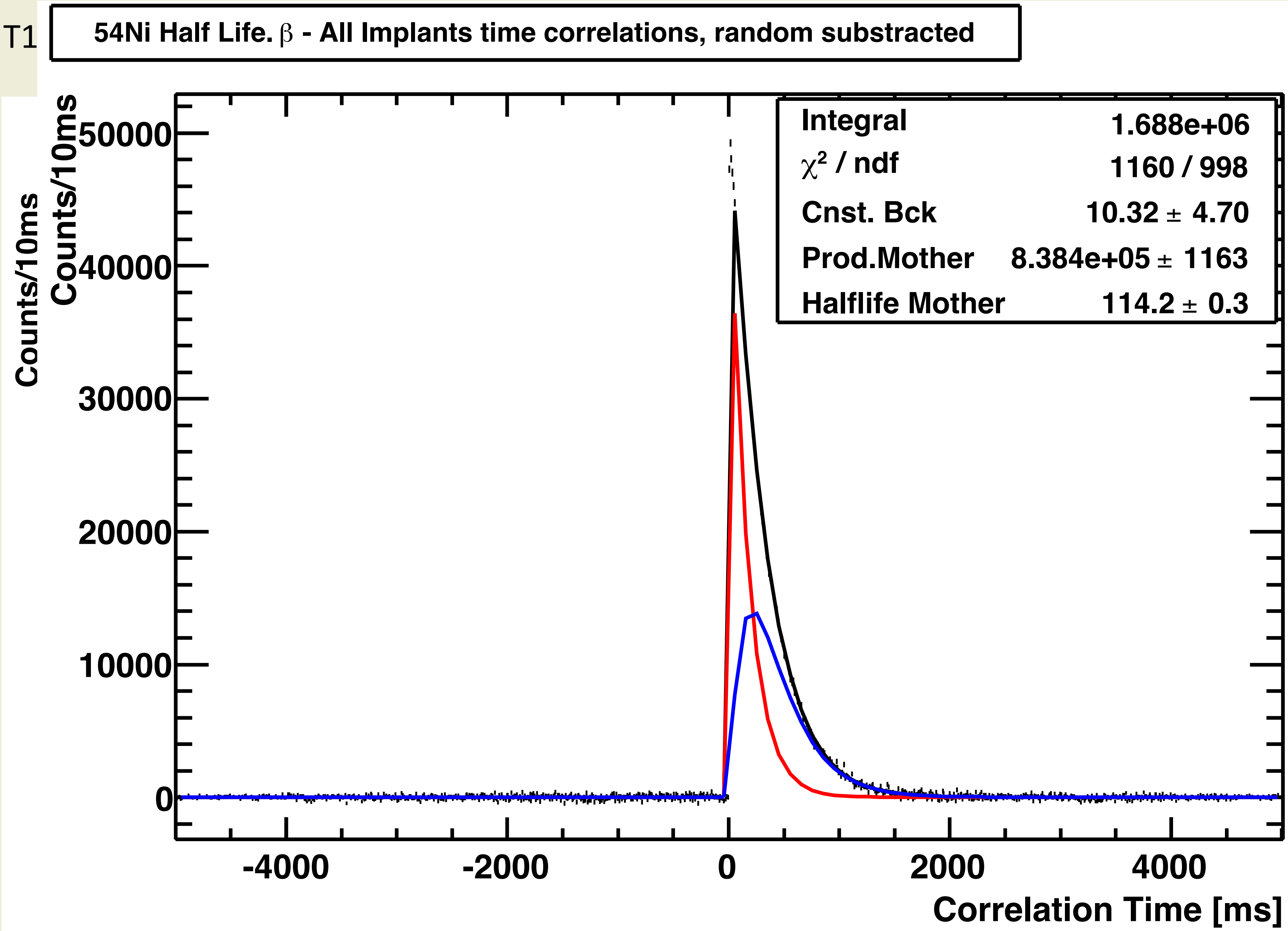




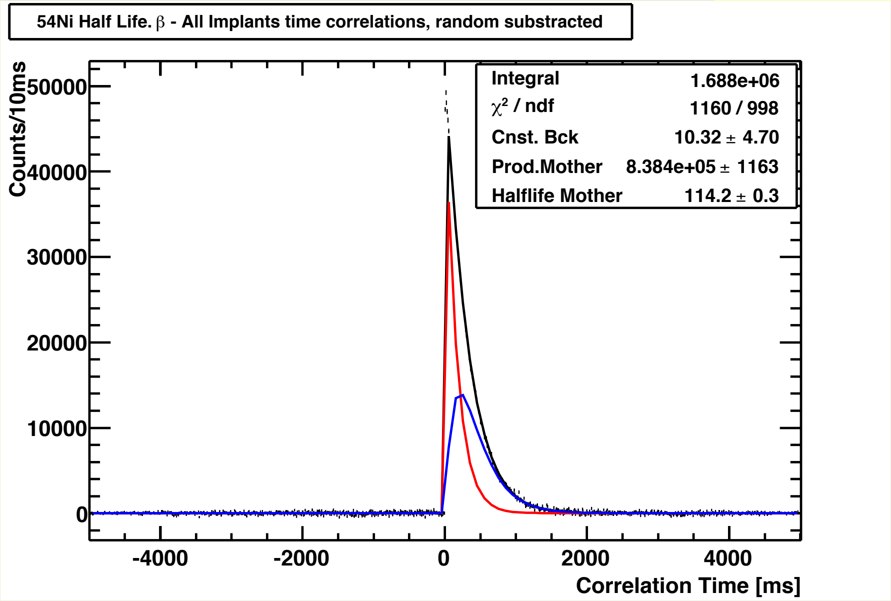
Implant in pixel "(i,j)"
Decay in pixel "(i,j)"

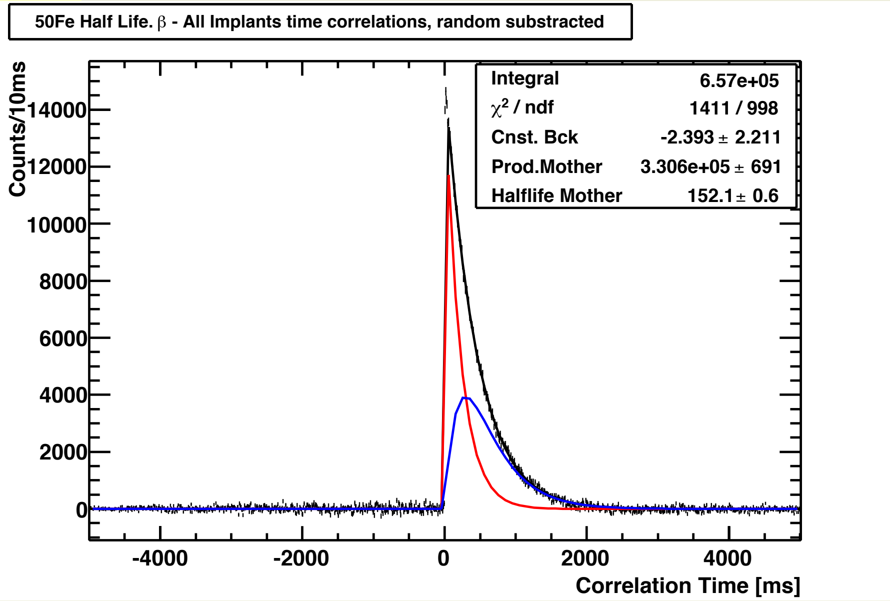
Implant in pixel "(i,j)"
Decay in pixel "(j,i)"

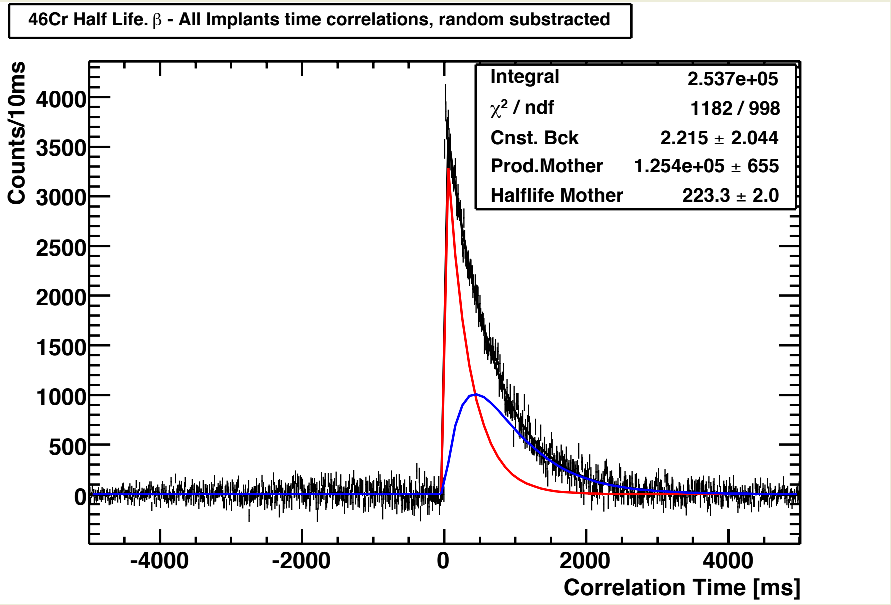
T1

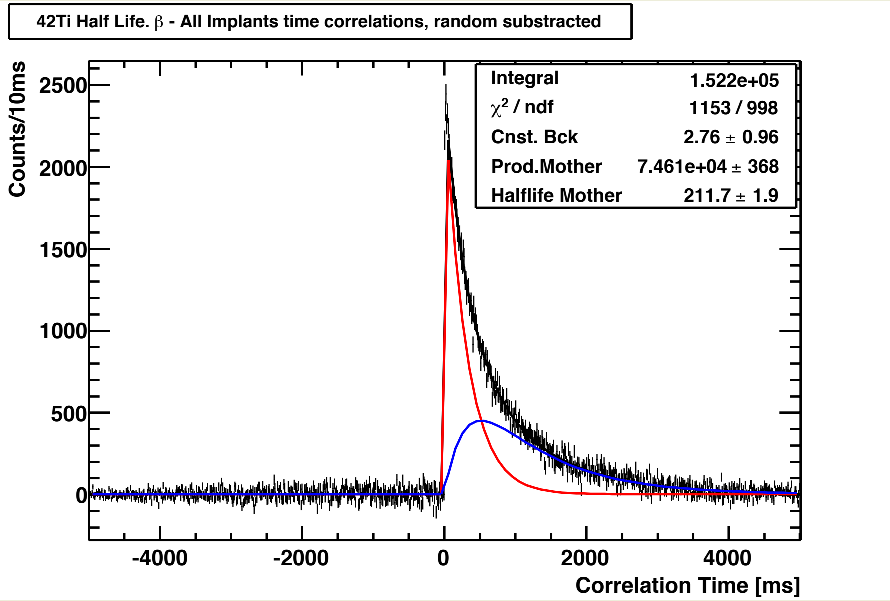

54Ni Half Life. β - All Implants time correlations, random substracted
Integral 1.688e+06
χ^2 / ndf 1160 / 998
Cnst. Bck 10.32 ± 4.70
Prod.Mother 8.384e+05 ± 1163
Halflife Mother 114.2 ± 0.3
Counts/10ms
Counts/10ms
50000
40000
30000
20000
10000
0
-4000
-2000
0
2000
4000
Correlation Time [ms]

Least square fit

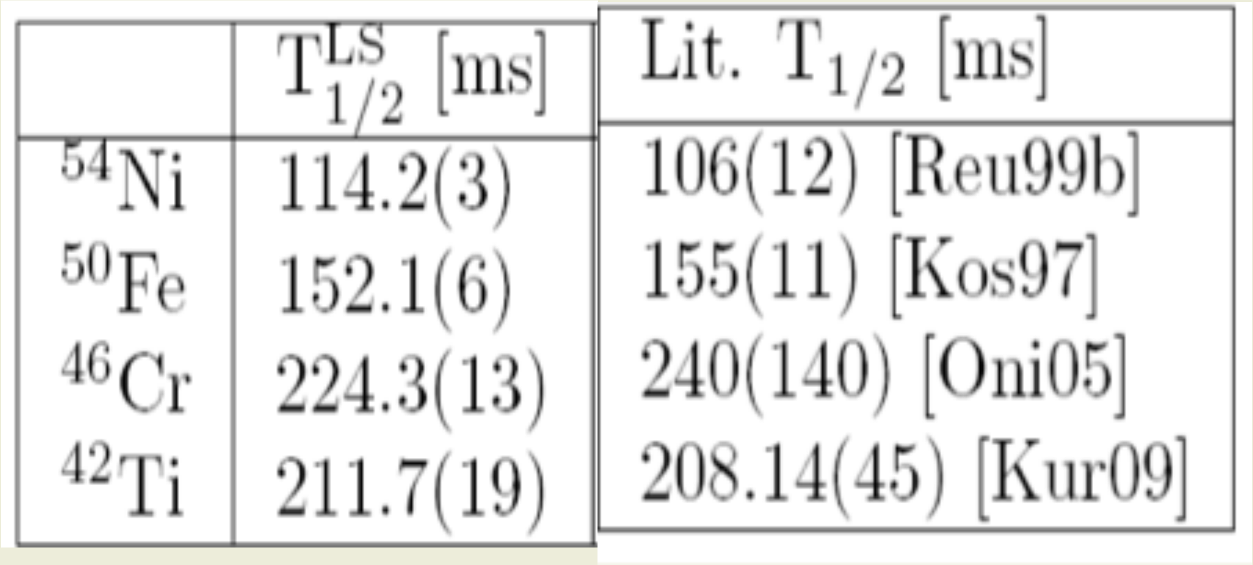








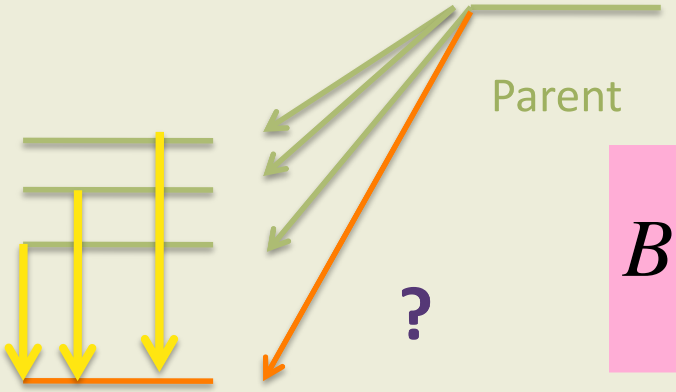
Summary of Half-life Analysis



	$T^{LS}_{1/2}$ [ms]	Lit. $T_{1/2}$ [ms]
^{54}Ni	114.2(3)	106(12) [Reu99b]
^{50}Fe	152.1(6)	155(11) [Kos97]
^{46}Cr	224.3(13)	240(140) [Oni05]
^{42}Ti	211.7(19)	208.14(45) [Kur09]

For three out the four cases, we improved in two orders of magnitude the accuracy of the half-life.

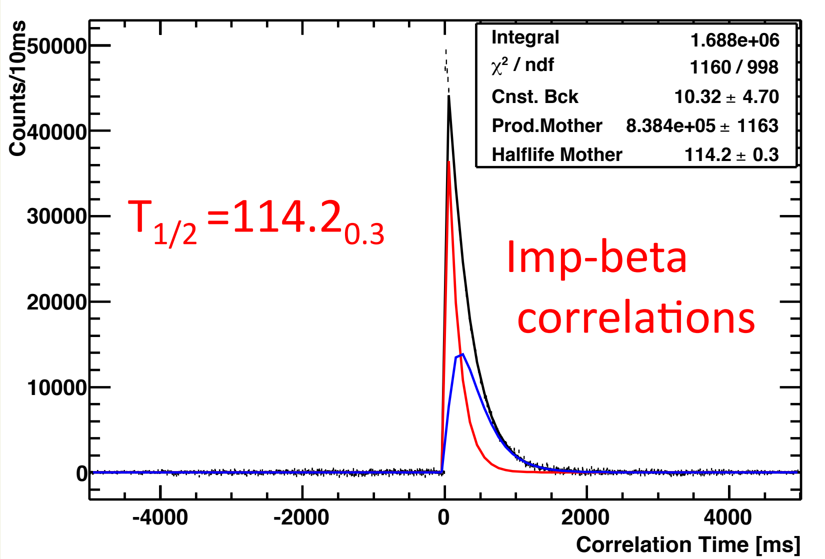
42Ti case, most accurate half-life measurement:
T.Kurtukian et al., Phys. Rev. C 80, 035502 (2009)



Absolute beta feeding: estimation of absolute feeding to the first excited state

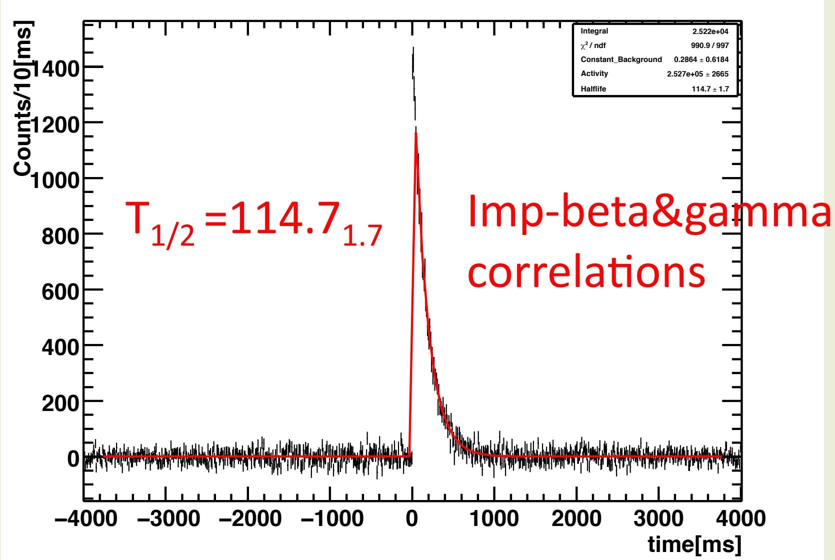
$$B(GT)^{\beta} = k\frac{\boxed{I_{\beta}(E)}}{f(Q_{\beta}-E,Z)T_{1/2}}$$

Estimation of absolute feeding to the first excited state



$T_{1/2}=114.2_{0.3}$

Imp-beta correlations

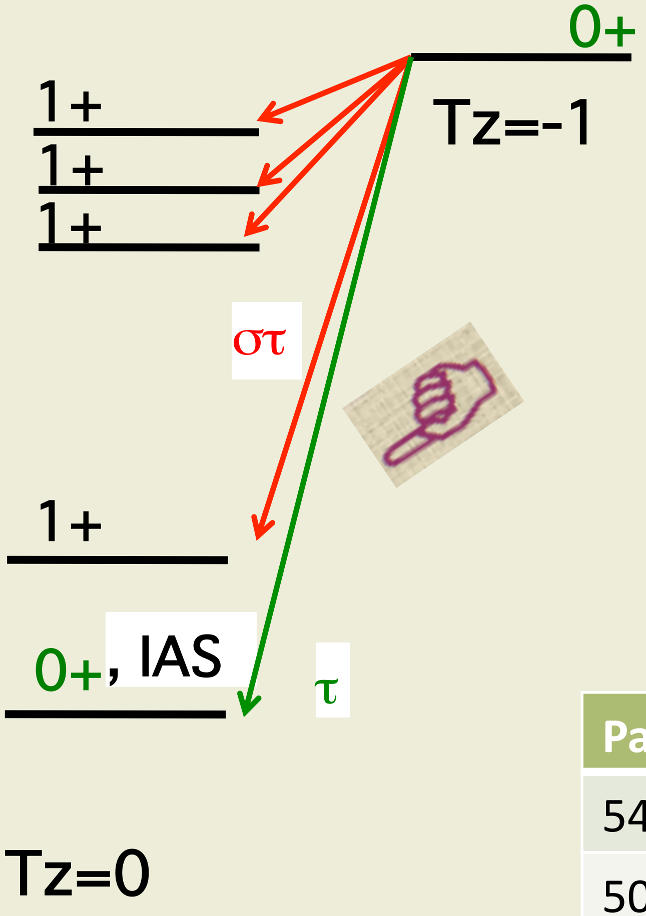


$T_{1/2}=114.7_{1.7}$

Imp-beta&gamma correlations

Systematic errors such as beta efficiency error or survival probability errors cancels!, only gamma efficiency counts!!!

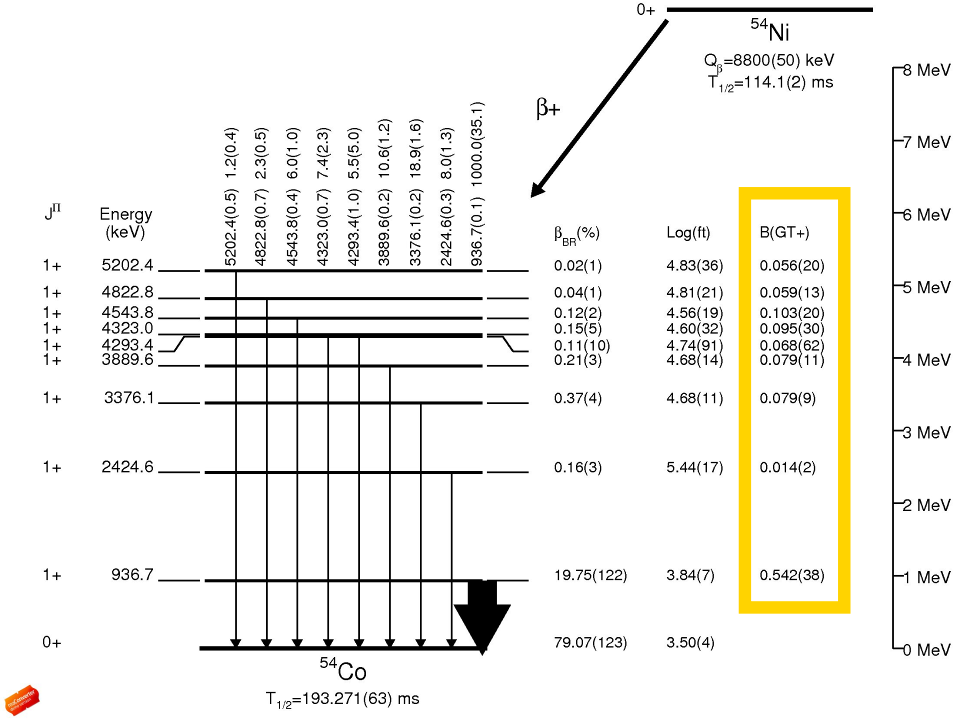
Comparison of "g.s to g.s feeding" estimated from Fermi transition probability and our experimental result

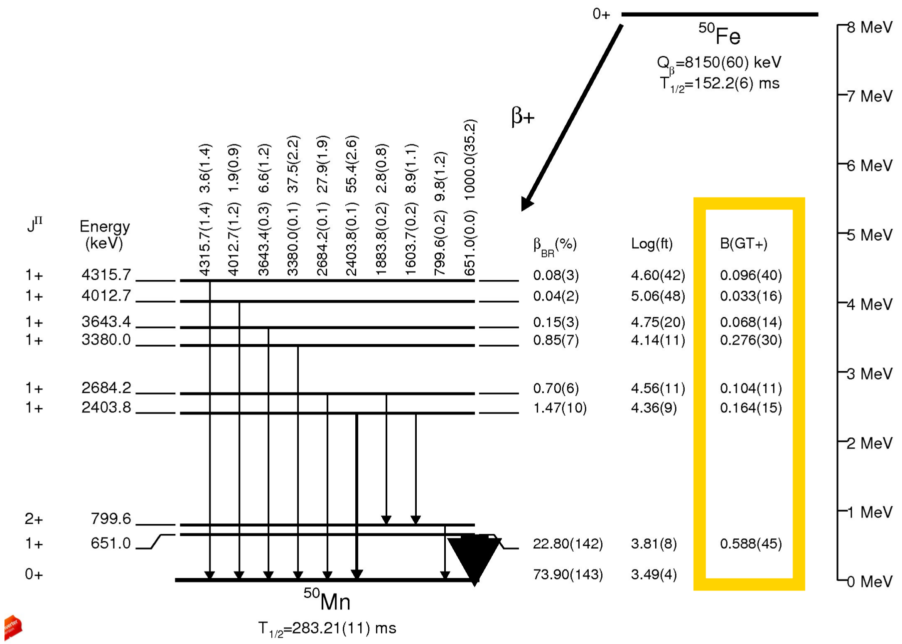


This is a super-allowed 0+➔0+ Fermi transition with B(F)=N-Z
And hence

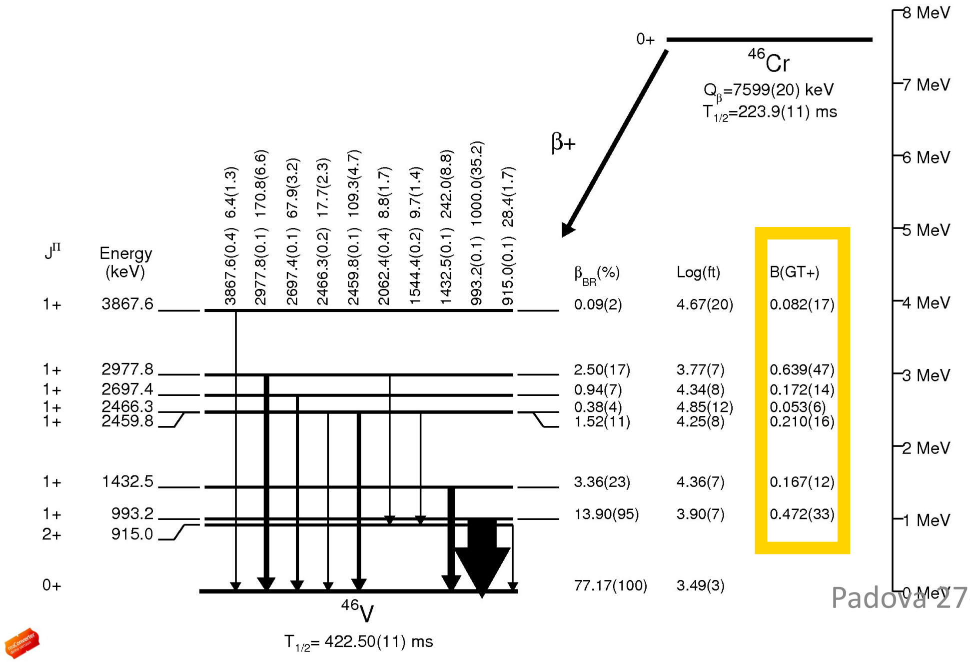
$$T_F = \frac{6144.0(16)}{2(1-\delta c)f}$$

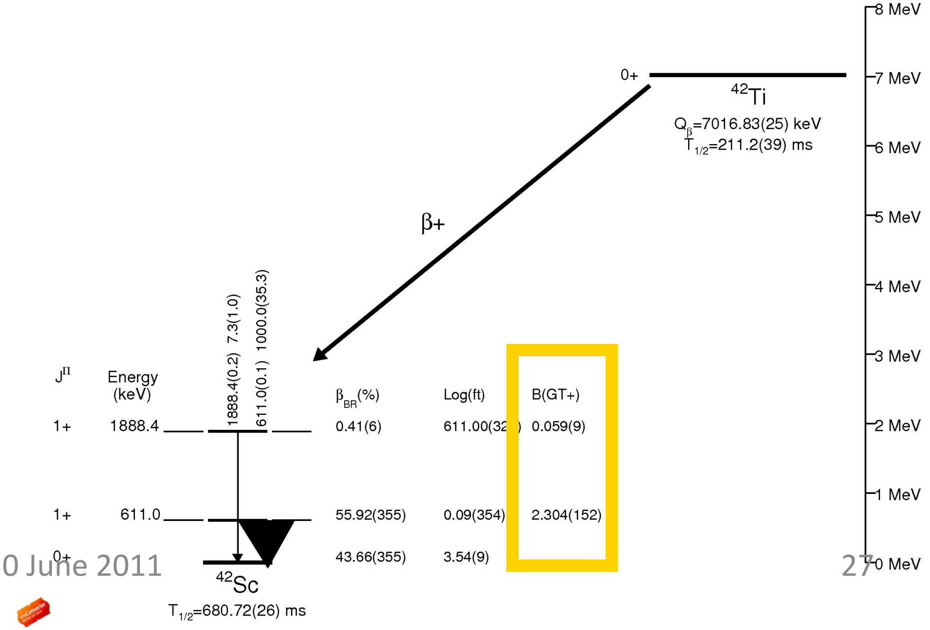
Parent	Fermi estim	Exp. G.s feed
54Ni	0.82(3)	0.79(2)
50Fe	0.74(4)	0.74(2)
46Cr	0.78(1)	0.77(2)
42Ti	0.49(1)	0.44(4)



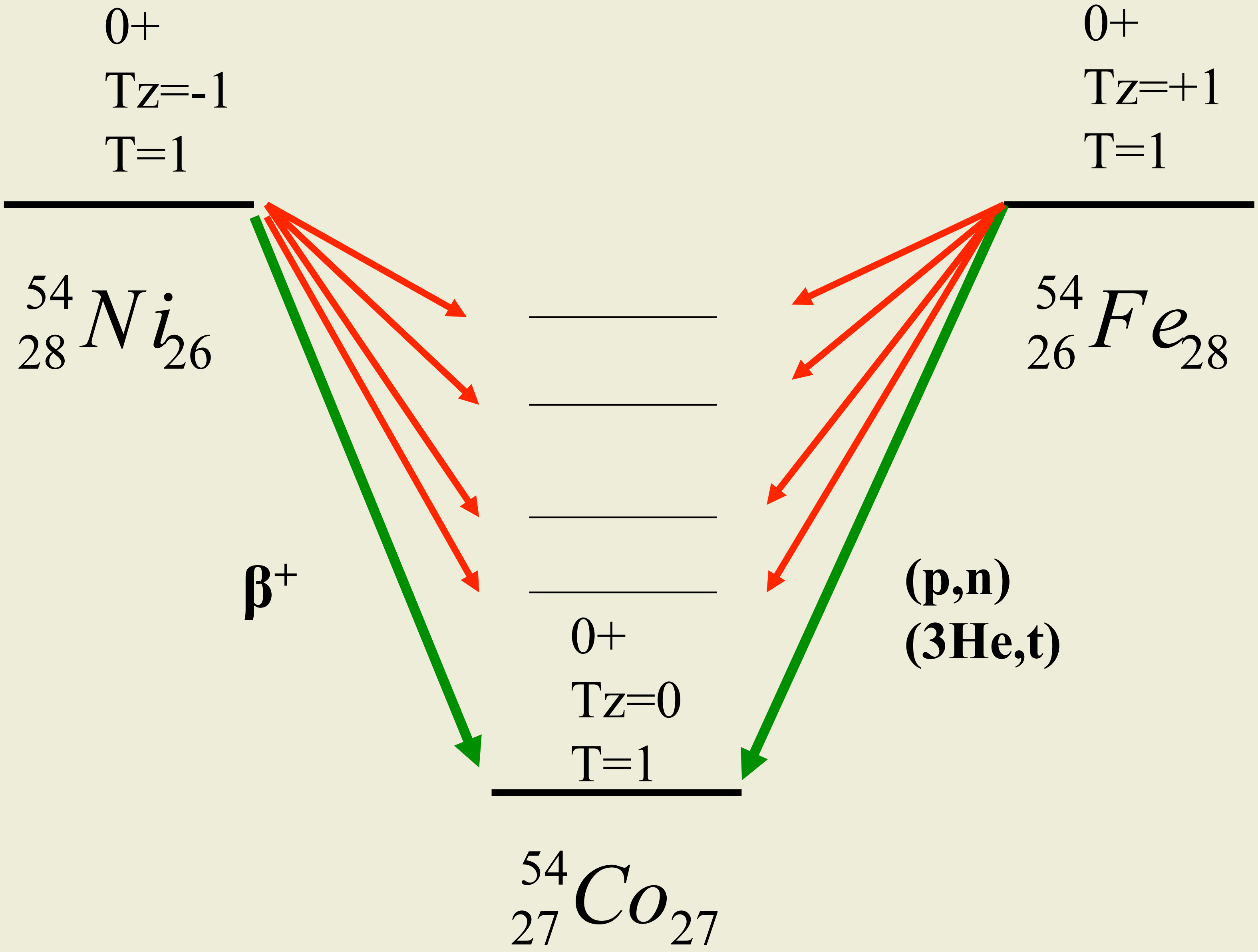


Result of this part: absolute B(GT) values for all the levels observed in the beta decay





B(GT) comparison



0+
Tz=-1
T=1

$^{54}_{28}Ni_{26}$

0+
Tz=+1
T=1

$^{54}_{26}Fe_{28}$

β^{+}

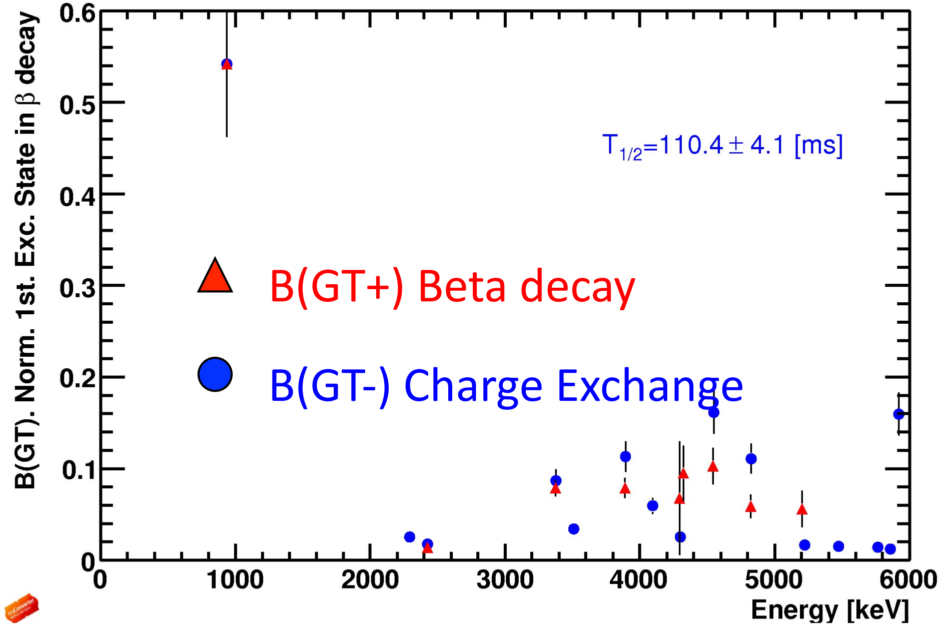
(p,n)
(3He,t)

0+
Tz=0
T=1

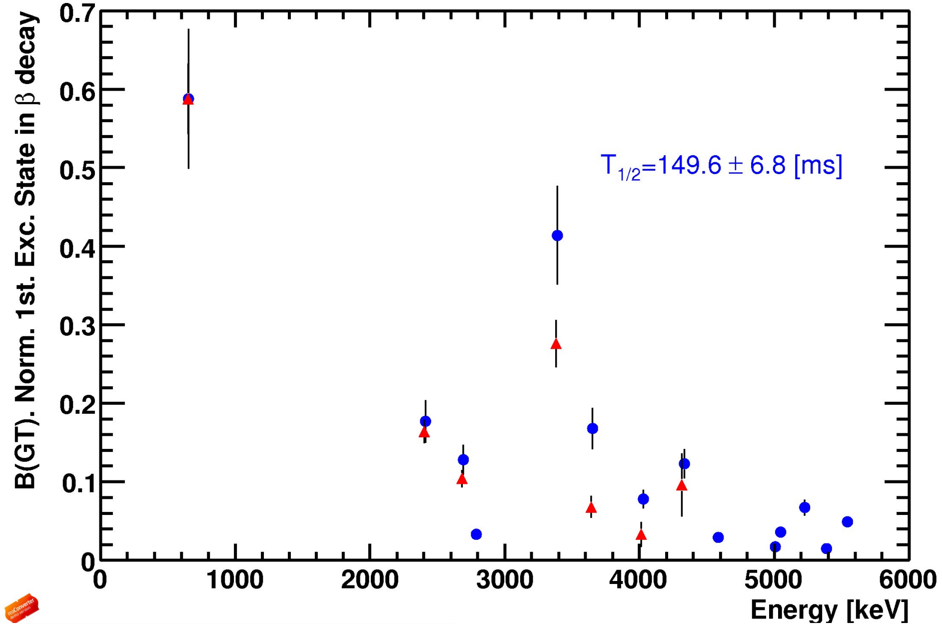
$^{54}_{27}Co_{27}$

Comparison of beta decay and CE reactions (Normalised to the 1st excited state)

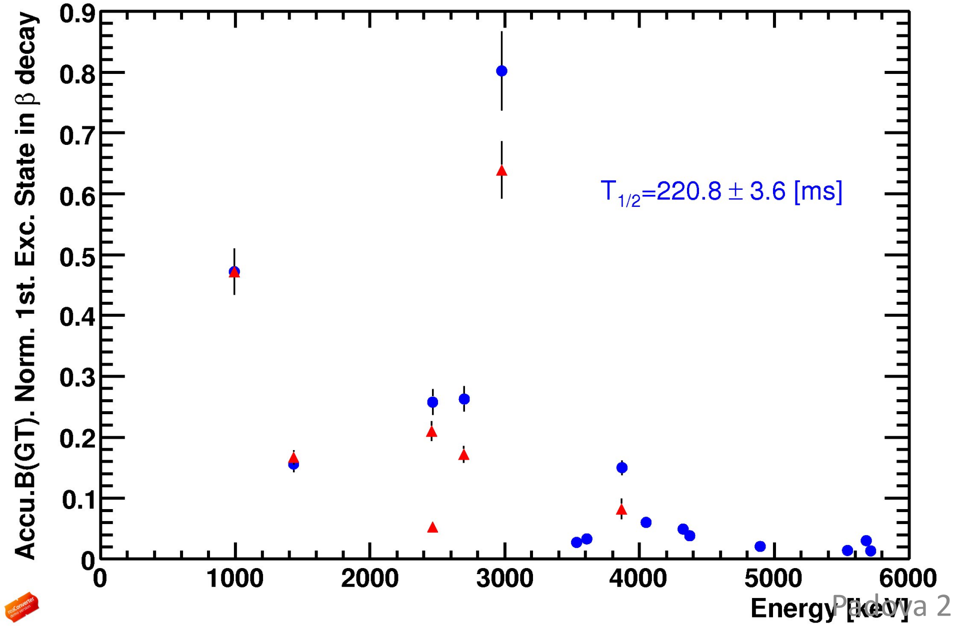
Mass 54 B(GT) Comparison



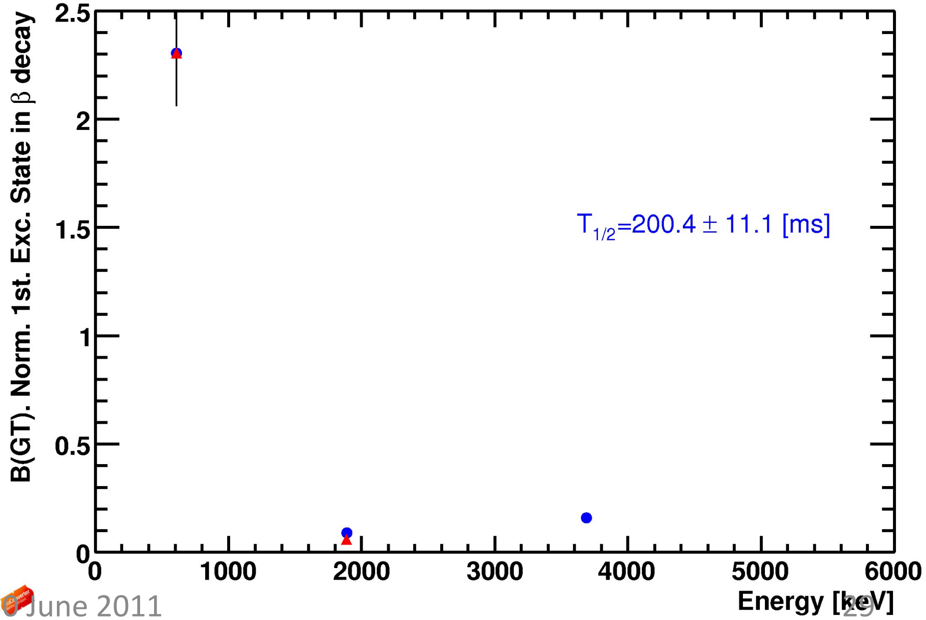
Mass 50 B(GT) Comparison



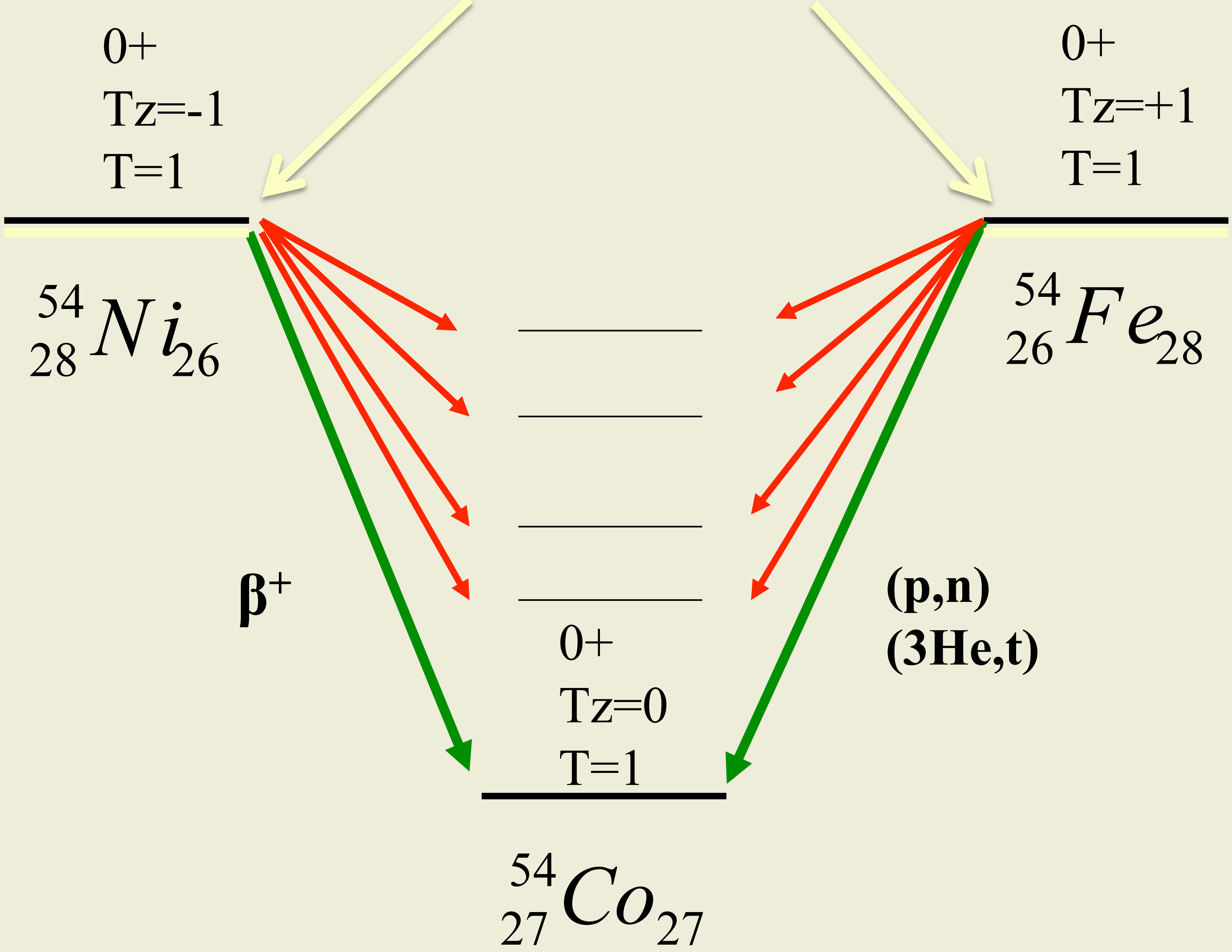
Mass 46 B(GT) Comparison



Mass 42 B(GT) Comparison

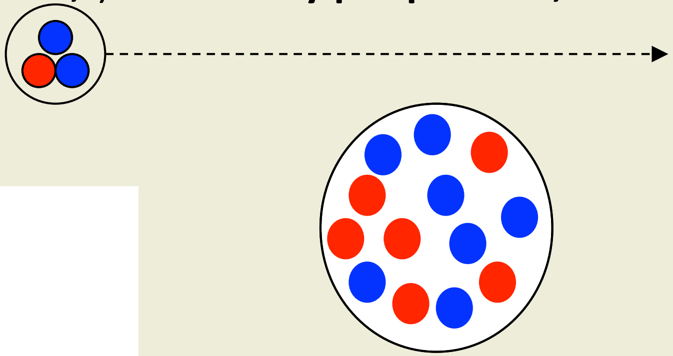


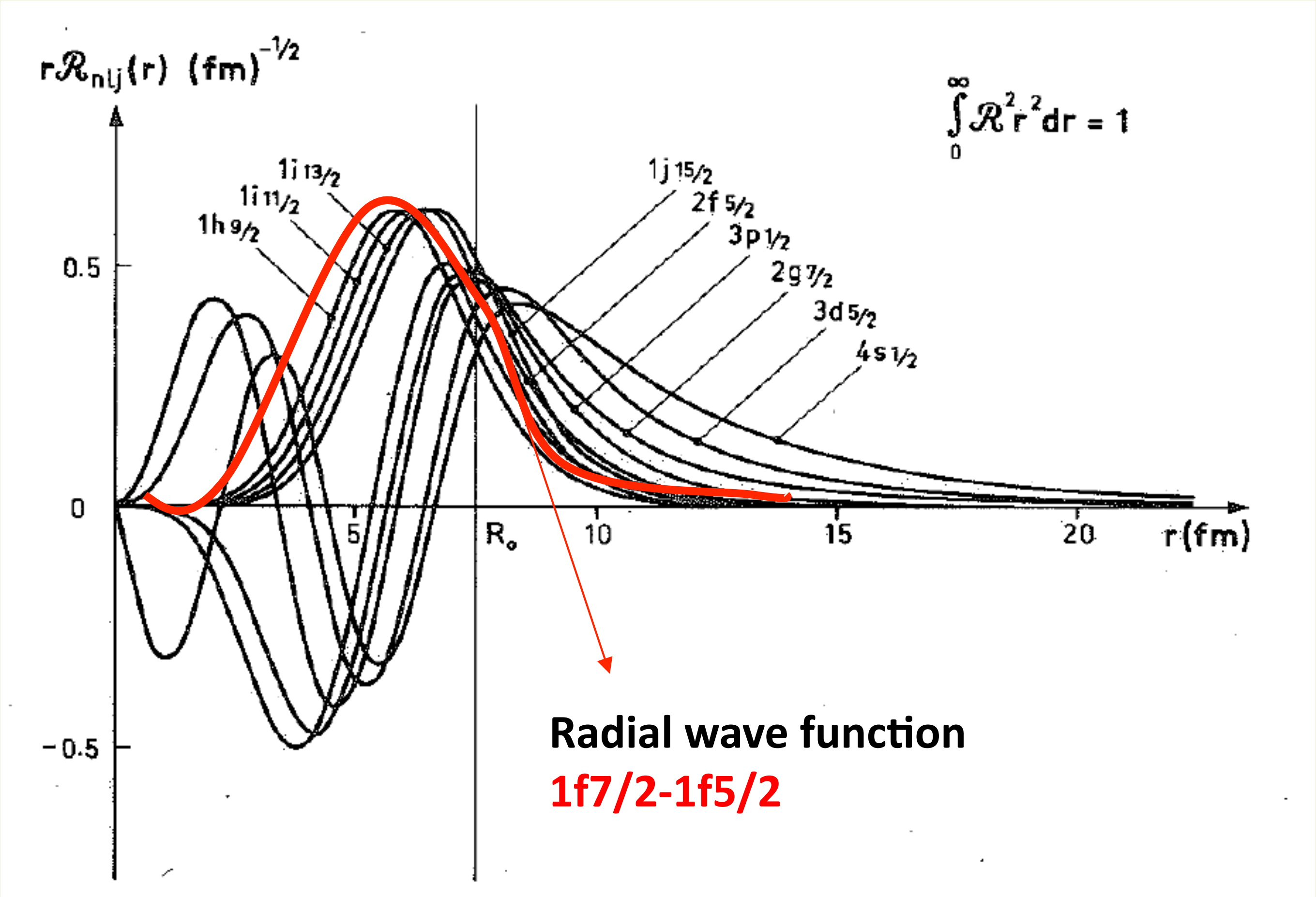
Possible reasons: Maybe the two mirror ground states are not identical



Maybe the two processes are not identical

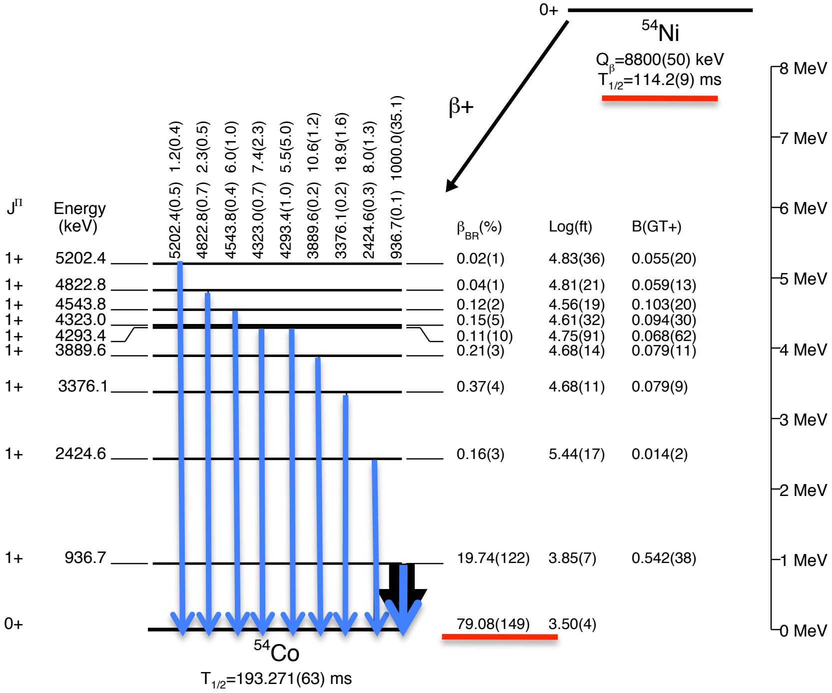
Hadronic reactions such as (3He,t) are mainly peripherical,

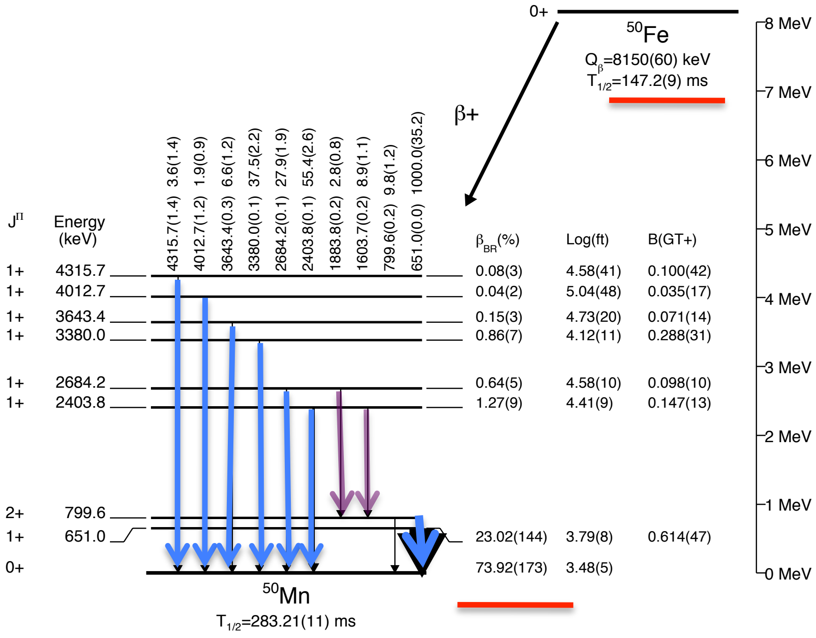




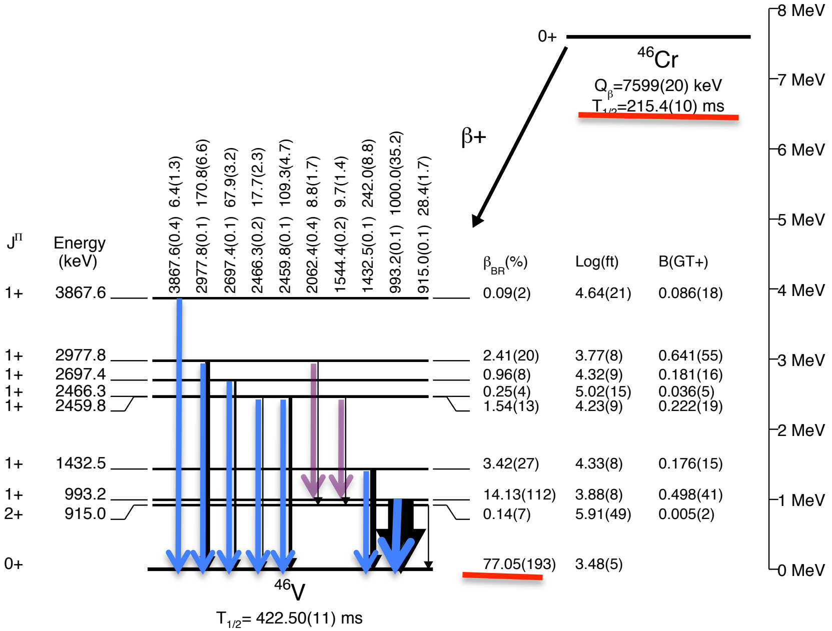
Radial wave function

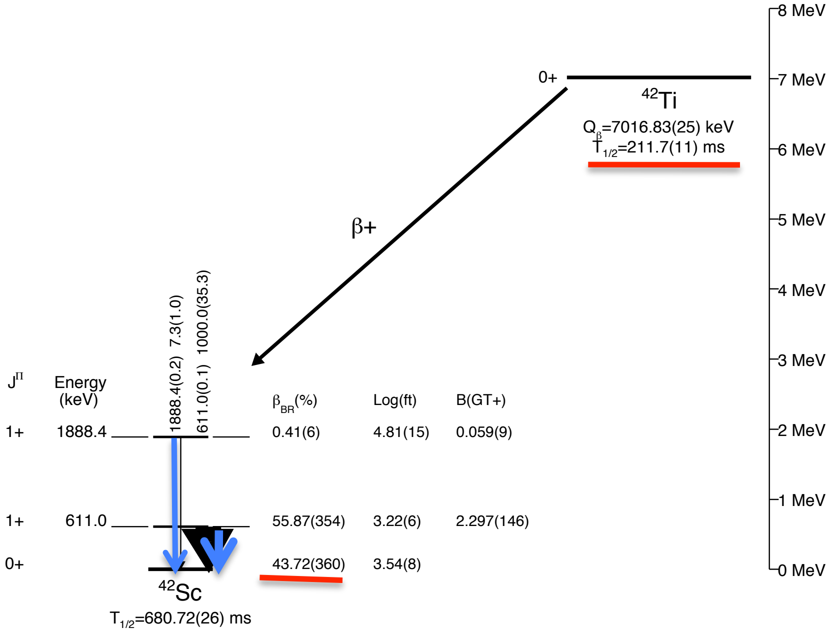
1f7/2-1f5/2



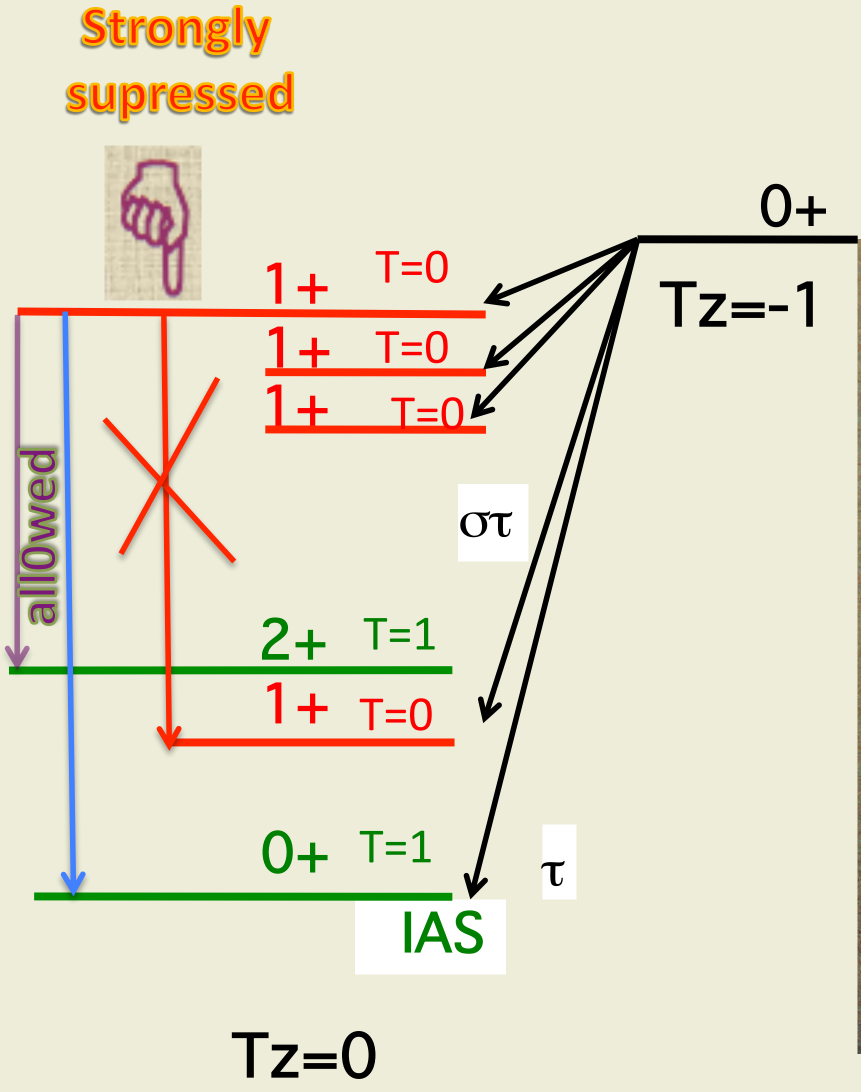


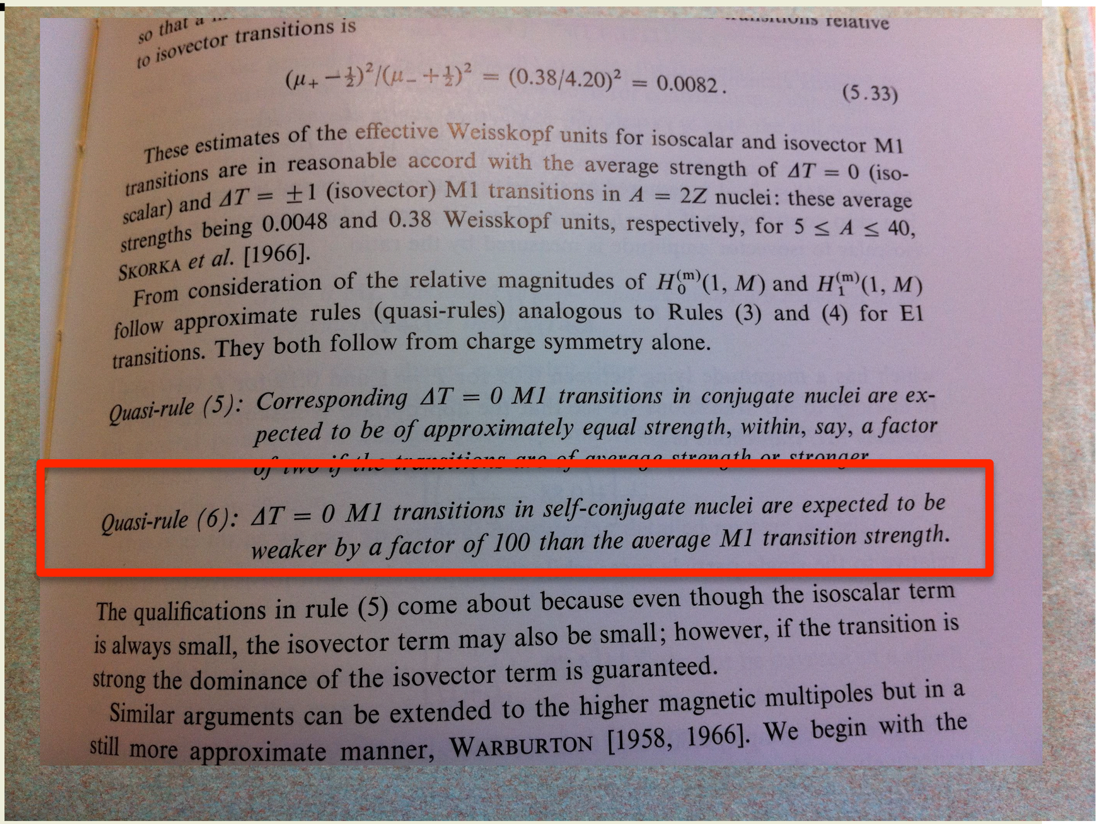
Many 1+➔ 0+ , few 1+ ➔2+, but never 1+➔ 1+ M1 transitions were observed!!!!





M1 transitions from T=0 to T=0 are strongly suppressed!!!!




so that a
transitions relative
to isovector transitions is

$$(\mu_+ - \tfrac{1}{2})^2/(\mu_- + \tfrac{1}{2})^2 = (0.38/4.20)^2 = 0.0082\,. \qquad (5.33)$$

These estimates of the effective Weisskopf units for isoscalar and isovector M1 transitions are in reasonable accord with the average strength of $\Delta T = 0$ (isoscalar) and $\Delta T = \pm 1$ (isovector) M1 transitions in $A = 2Z$ nuclei: these average strengths being 0.0048 and 0.38 Weisskopf units, respectively, for $5 \leq A \leq 40$, Skorka *et al.* [1966].

From consideration of the relative magnitudes of $H_0^{(m)}(1, M)$ and $H_1^{(m)}(1, M)$ follow approximate rules (quasi-rules) analogous to Rules (3) and (4) for E1 transitions. They both follow from charge symmetry alone.

Quasi-rule (5): Corresponding $\Delta T = 0$ M1 transitions in conjugate nuclei are expected to be of approximately equal strength, within, say, a factor of two if the transitions are of average strength or stronger.

Quasi-rule (6): $\Delta T = 0$ M1 transitions in self-conjugate nuclei are expected to be weaker by a factor of 100 than the average M1 transition strength.

The qualifications in rule (5) come about because even though the isoscalar term is always small, the isovector term may also be small; however, if the transition is strong the dominance of the isovector term is guaranteed.

Similar arguments can be extended to the higher magnetic multipoles but in a still more approximate manner, Warburton [1958, 1966]. We begin with the

summary

We have studied the beta decay of four Tz=-1 nuclei in the f7/2 shell

They were all “well” produced in fragmentation of 58Ni beams (but difficult at isol facilities)

In spite of the complex set-up we could get extremely clean results

Very precise T1/2, g.s beta feeding and feeding to the excited states were obtained

The four decay schemes and the corresponding B(GT)
values for all observed levels could be determined where only Q-beta was taking from the literature.

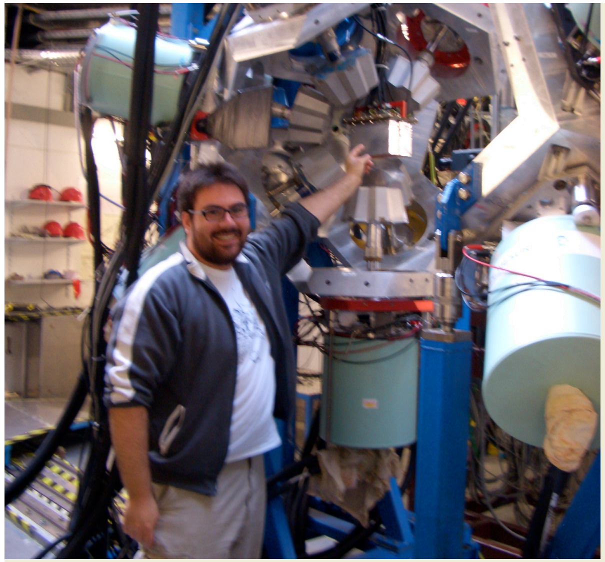
A very selective isospin Quasi selection rule was observed for the first time in f-shell nuclei

The results were compared with the mirror CE reaction process.
All “expected levels” were observed
The isospin symmetry works well for the strong transitions but small transitions show differences up to 50% which still have to be understood.

CONCLUSION, ONE CAN PERFORME DELICATE SPECTROSCOPY STUDIES IN FRAGMENTATION REACTIONS IF ONE ACHIEVES CLEAN IMPLANTATION

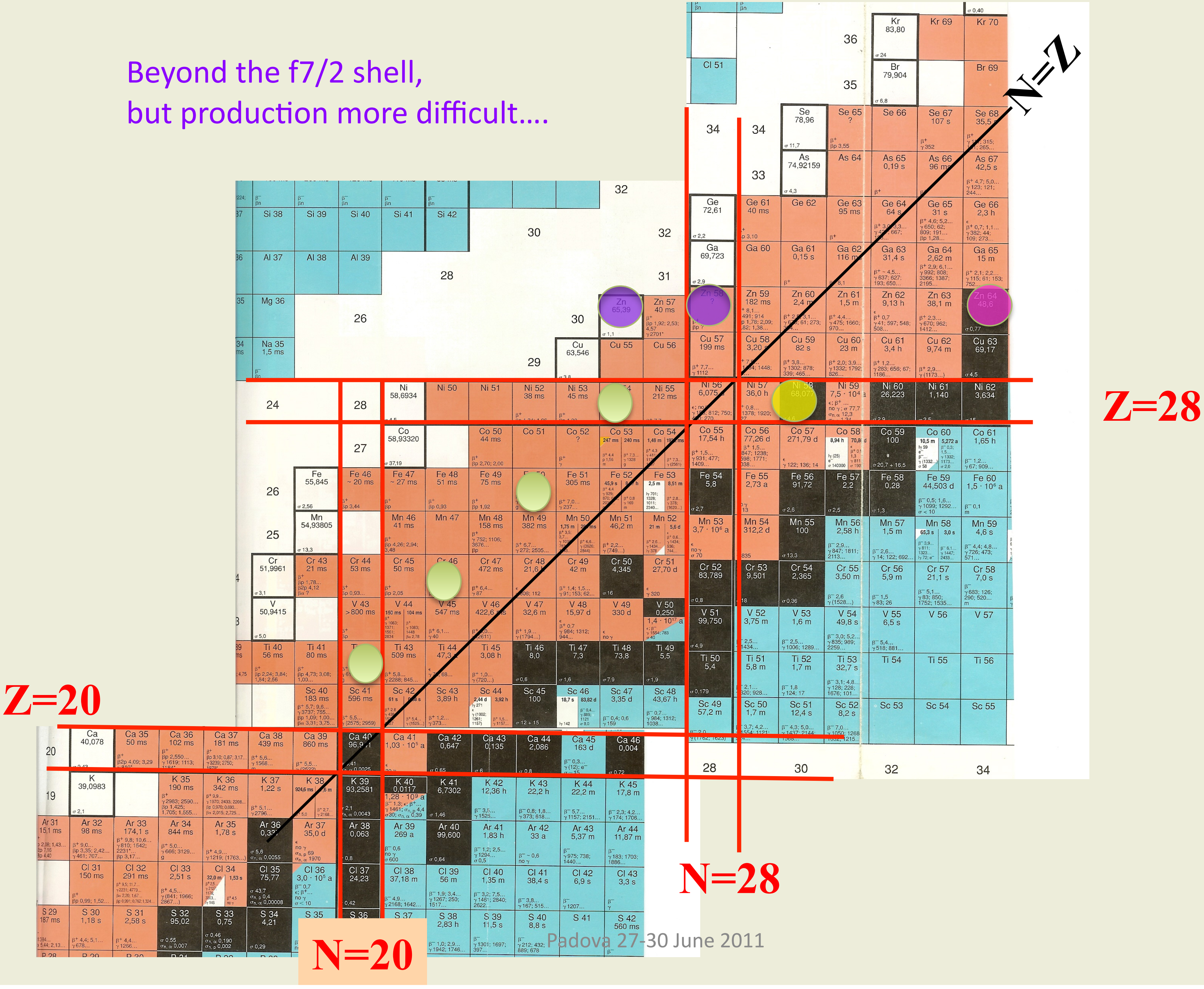
F. Molina,[1,*] B. Rubio,[1] Y. Fujita,[2,†] J. Agramunt,[1] A. Algora,[1,‡] L. Amon,[3] J. Benlliure,[4]
P. Boutachkov,[5] L. Cáceres,[5,6] R.B. Cakirli,[3] E. Casarejos,[4] C. Domingo-Pardo,[7] P. Doornenbal,[5]
A. Gadea,[1,8] E. Ganioğlu,[3] M. Gascón,[4] W. Gelletly,[9] H. Geissel,[5] J. Gerl,[5] M. Górska,[5] J. Grębosz,[5,10]
R. Hoischen,[5,11] R. Kumar,[12] N. Kurz,[5] I. Kojouharov,[5] H. Matsubara,[13] A.I. Morales,[4] Y. Oktem,[3]
D. Pauwels,[14] D. Pérez-Loureiro,[4] S. Pietri,[9] Zs. Podolyák,[9] W. Prokopowicz,[5] D. Rudolph,[11] H. Schaffner,[5]
S.J. Steer,[9] J.L. Tain,[1] A. Tamii,[13] S. Tashenov,[5] J.J. Valiente-Dobón,[8] S. Verma,[4] and H-J. Wollersheim[5]

[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] *Department of Physics, Istanbul University, Istanbul, Turkey*
[4] *Universidad de Santiago de Compostela, E-15782 Santiago de Compostela, Spain*
[5] *Gesellschaft für Schwerionenforschung, Planckstrasse 1, D-64291 Darmstadt, Germany*
[6] *Universidad Autonma de Madrid, E-28049 Madrid, Spain*
[7] *Forschungszentrum Karlsruhe, D-76344 Eggenstein-Leopoldshafen, Germany*
[8] *INFN-Laboratorio Nazionale di Legnaro, 35020 Legnaro (PD), Italy*
[9] *Department of Physics, University of Surrey, Guildford GU2 7XH, Surrey, UK*
[10] *The Henryk Niewodniczanski Institute of Nuclear Physics, (IFJ PAN), Kraków, Poland*
[11] *Department of Physics, Lund University, S-22100 Lund, Sweden*
[12] *Inter University Accelerator Centre, Post Box No. 10502, New Delhi 110067, India*
[13] *Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan*
[14] *Instituut voor Kern- en Stralingsfysica, K.U. Leuven, B-3001 Leuven, Belgium*



Encouraged by these results………

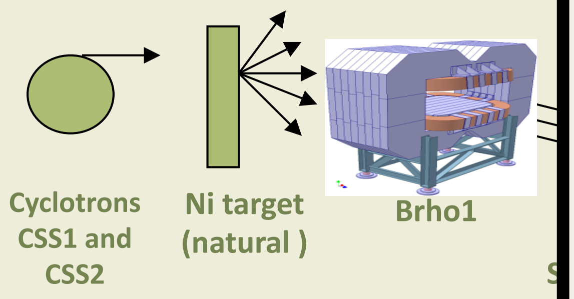
Beyond the f7/2 shell,
but production more difficult….



Reaction: ^{64}Zn^{29+} (79 MeV.A) + ^{nat}Ni @ GANIL 2008

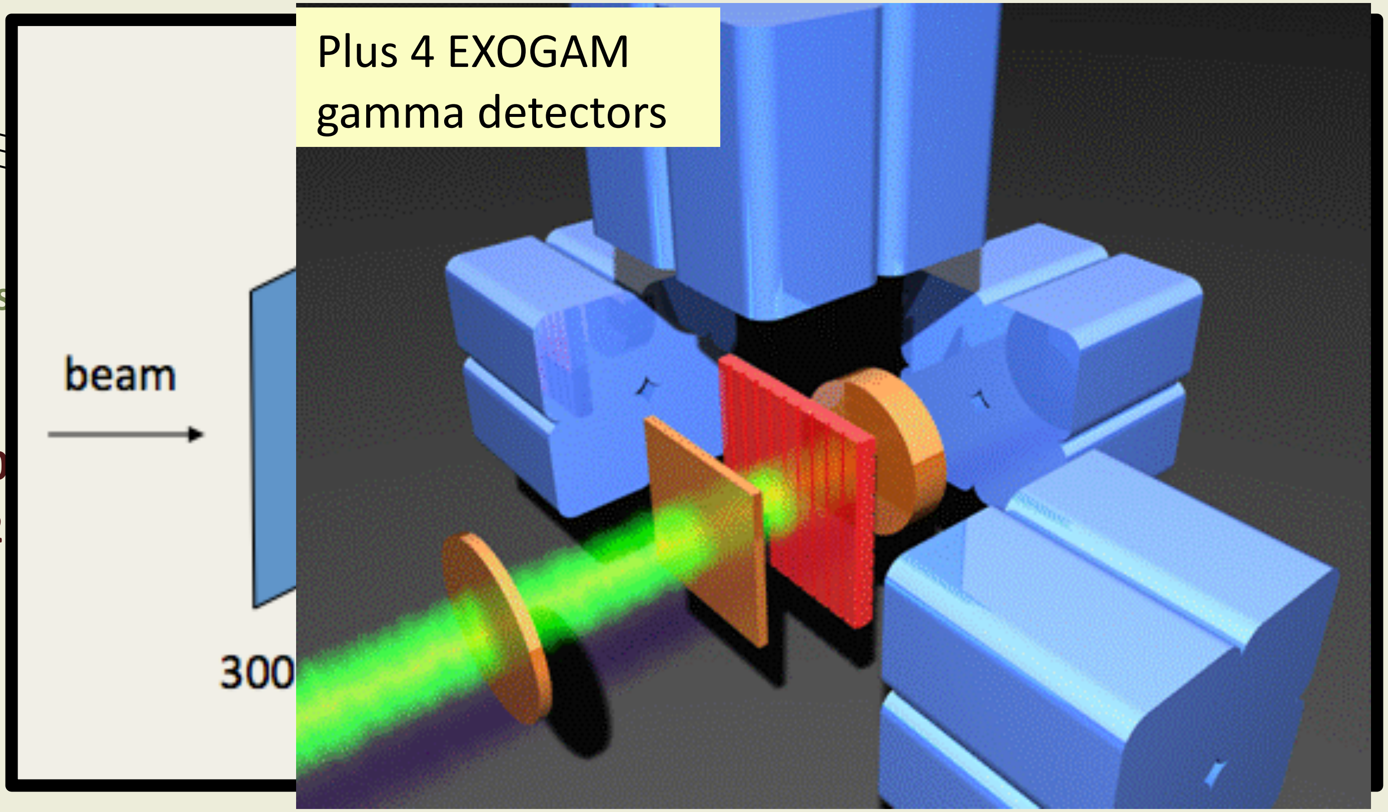
79 MeV / nucleon

Incoming ^{64}Zn $^{29+}$

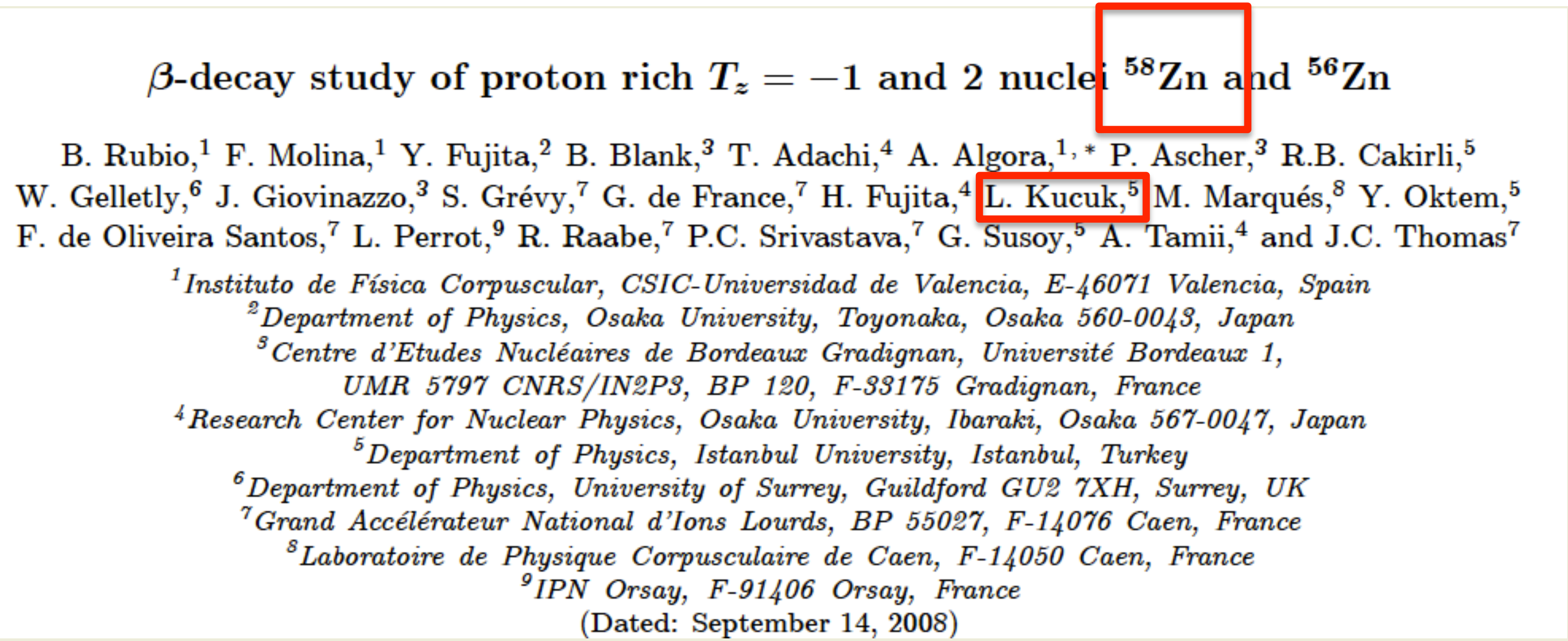


Incoming beam intensity : 500

Target Thickness:1.8 mgr/cm2



Plus 4 EXOGAM gamma detectors

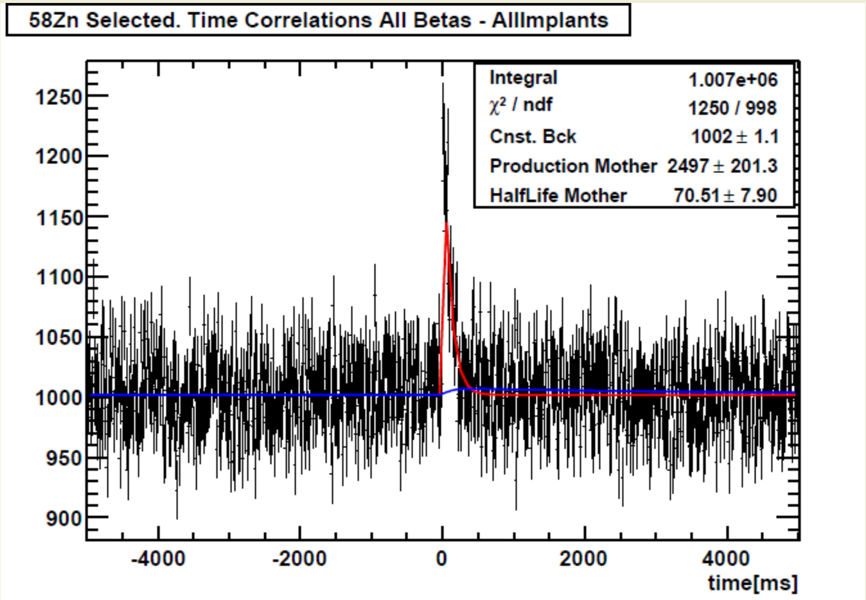


β-decay study of proton rich $T_z = -1$ and 2 nuclei ^{58}Zn and ^{56}Zn

B. Rubio,[1] F. Molina,[1] Y. Fujita,[2] B. Blank,[3] T. Adachi,[4] A. Algora,[1,*] P. Ascher,[3] R.B. Cakirli,[5]
W. Gelletly,[6] J. Giovinazzo,[3] S. Grévy,[7] G. de France,[7] H. Fujita,[4] L. Kucuk,[5] M. Marqués,[8] Y. Oktem,[5]
F. de Oliveira Santos,[7] L. Perrot,[9] R. Raabe,[7] P.C. Srivastava,[7] G. Susoy,[5] A. Tamii,[4] and J.C. Thomas[7]

[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] *Centre d'Etudes Nucléaires de Bordeaux Gradignan, Université Bordeaux 1,*
UMR 5797 CNRS/IN2P3, BP 120, F-33175 Gradignan, France
[4] *Research Center for Nuclear Physics, Osaka University, Ibaraki, Osaka 567-0047, Japan*
[5] *Department of Physics, Istanbul University, Istanbul, Turkey*
[6] *Department of Physics, University of Surrey, Guildford GU2 7XH, Surrey, UK*
[7] *Grand Accélérateur National d'Ions Lourds, BP 55027, F-14076 Caen, France*
[8] *Laboratoire de Physique Corpusculaire de Caen, F-14050 Caen, France*
[9] *IPN Orsay, F-91406 Orsay, France*

(Dated: September 14, 2008)



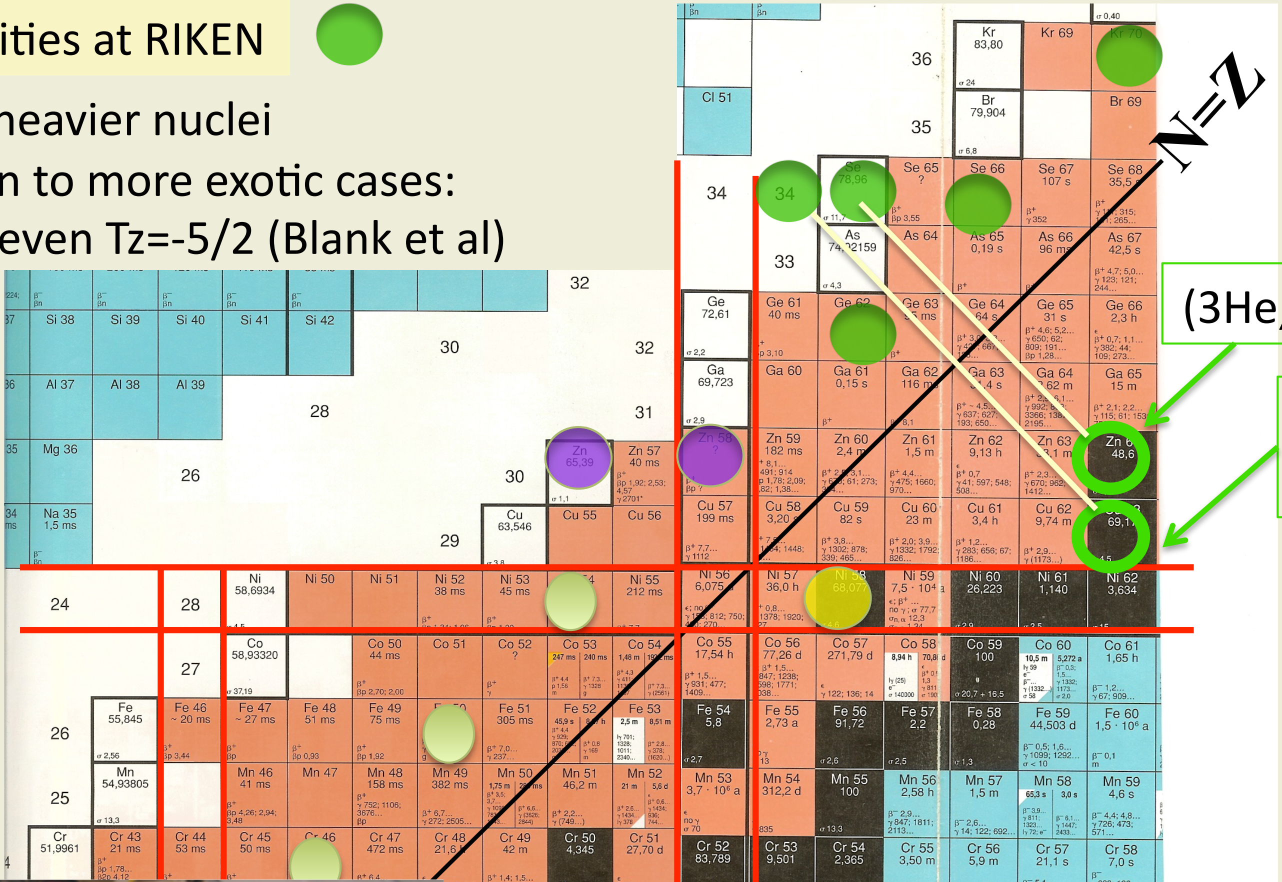
Kucuk et al, preliminary analysis

Opportunities at RIKEN

Tz=-1 in heavier nuclei

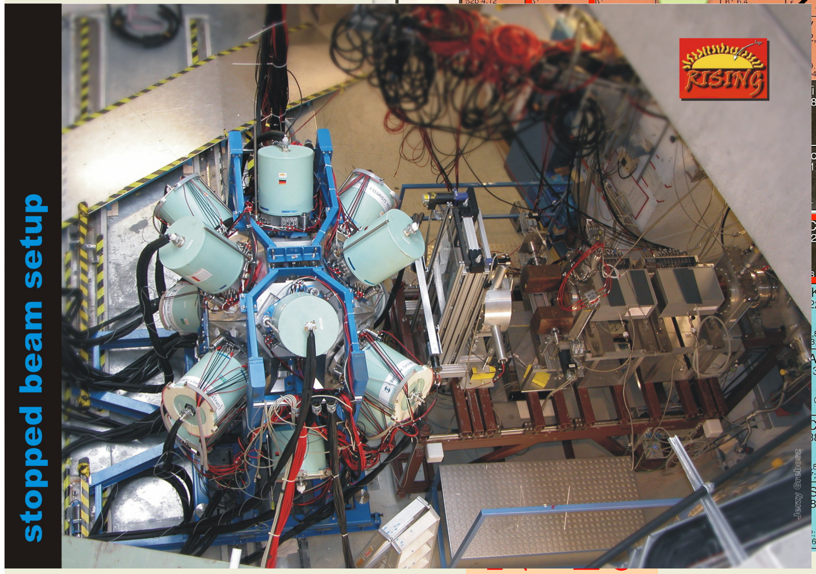
Extension to more exotic cases:

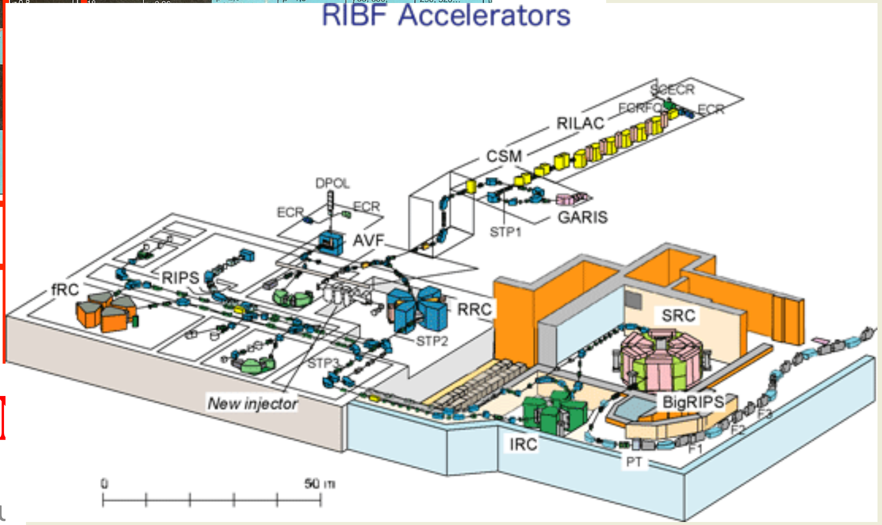
Tz=-2 or even Tz=-5/2 (Blank et al)

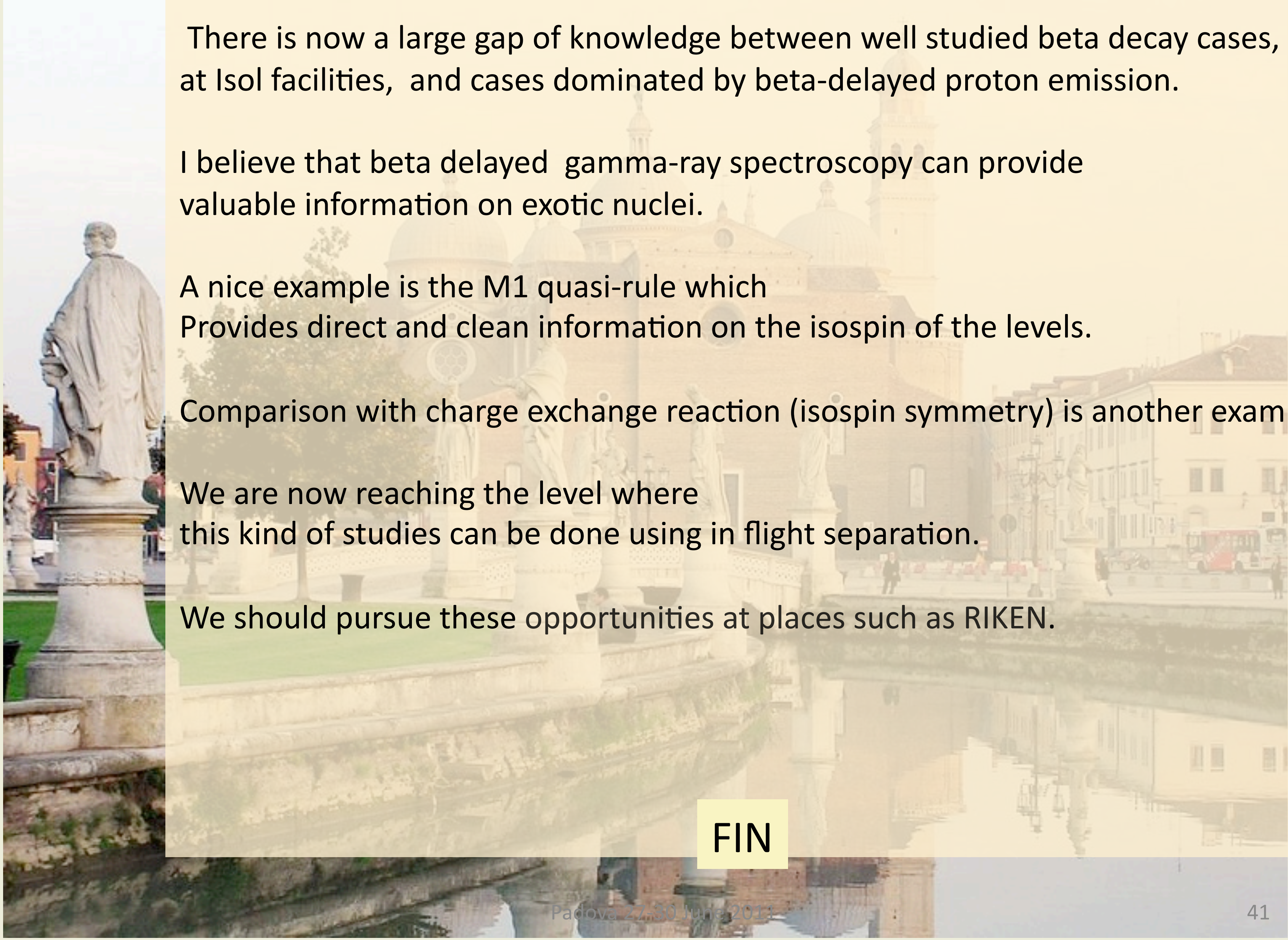


(3He,t) data available

(3He,t) being considered







There is now a large gap of knowledge between well studied beta decay cases, at Isol facilities, and cases dominated by beta-delayed proton emission.

I believe that beta delayed gamma-ray spectroscopy can provide valuable information on exotic nuclei.

A nice example is the M1 quasi-rule which
Provides direct and clean information on the isospin of the levels.

Comparison with charge exchange reaction (isospin symmetry) is another example.

We are now reaching the level where
this kind of studies can be done using in flight separation.

We should pursue these opportunities at places such as RIKEN.

FIN