Beta-decay spectroscopy with spin-polarized radioactive nuclei

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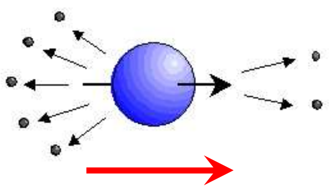
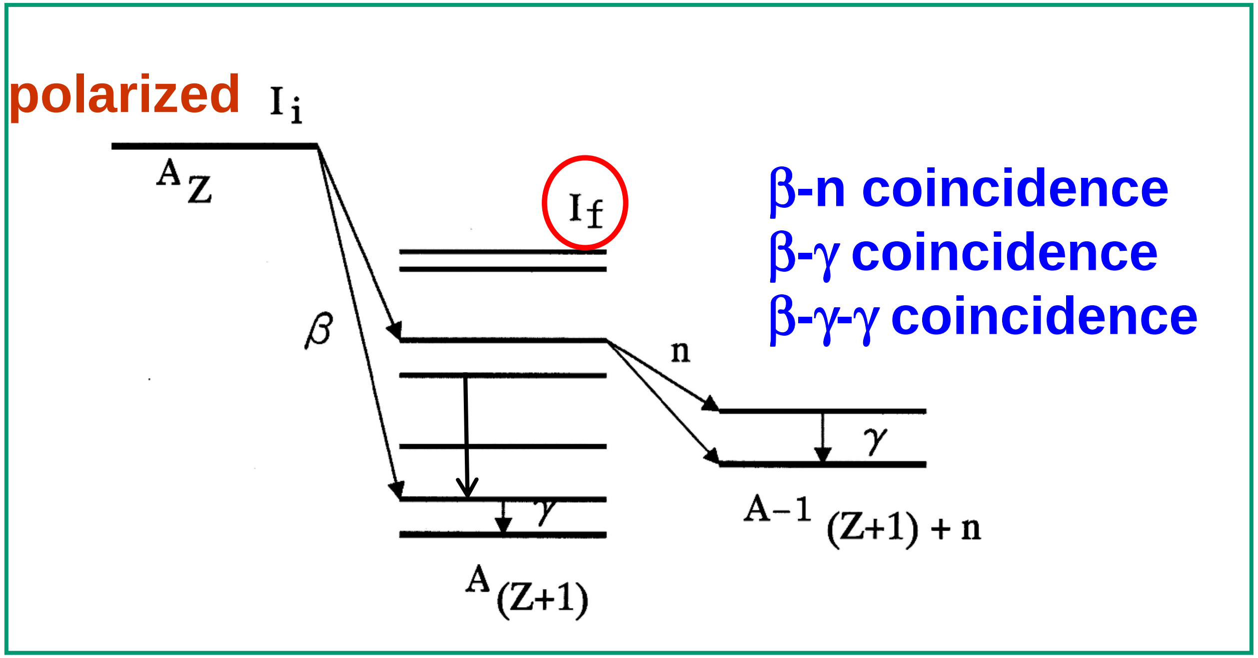
β-delayed decay spectroscopy

very effective method to assign spin-parity of daughter states



polarization



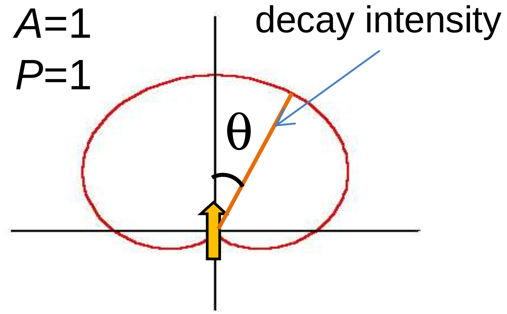
β-decay from a spin-polarized nucleus

β-decay angular distribution

$$W(\theta) \simeq 1 + AP\cos\theta$$

allowed transition

A: asymmetry parameter of allowed β-decay
P: polarization of the parent nucleus



	I_i^π (Na)	I_f^π (Mg)	$A(I_i, I_f)$
^{28}Na	1^+	2^+	$+0.5$
		1^+	-0.5
		0^+	-1.0
^{29,31}Na	$3/2^+$	$5/2^+$	$+0.6$
		$3/2^+$	-0.4
		$1/2^+$	-1.0
^{30}Na	2^+	3^+	$+0.67$
		2^+	-0.33
		1^+	-1.0
^{32}Na	(4^-)	5^-	$+0.8$
		4^-	-0.2
		3^-	-1.0
	(3^-)	4^-	$+0.75$
		3^-	-0.25
		2^-	-1.0

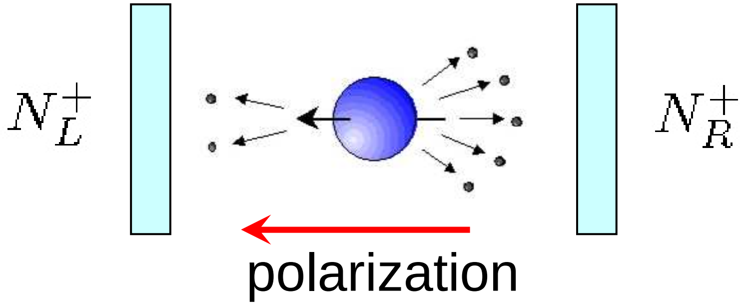
initial → final

$$A(I_i, I_f) = \begin{cases} \pm 1 & \text{for } I_f = I_i - 1, \\ \dfrac{\pm 1/(I_i+1) - 2\tau\sqrt{I_i/(I_i+1)}}{1+\tau^2} & \text{for } I_f = I_i, \\ \mp \dfrac{I_i}{I_i+1} & \text{for } I_f = I_i + 1. \end{cases}$$

$$\tau = C_V \langle 1 \rangle / C_A \langle \sigma \rangle \sim 0$$

+: β^+
-: β^-

A takes very different values
depending on the final state spin.



β-ray detection

$$N_R^+ = \epsilon_R \times (1 + AP) \text{ x}N_0$$
$$N_L^+ = \epsilon_L \times (1 - AP) \text{ x}N_0$$

ε: detection efficiency

$$N_R^- = \epsilon_R \times (1 - AP) \text{ x}N_0$$
$$N_L^- = \epsilon_L \times (1 + AP) \text{ x}N_0$$

spin reversed

$$AP = \frac{\sqrt{R} - 1}{\sqrt{R} + 1} \quad \left(R = \frac{N_R^+}{N_L^+} \Big/ \frac{N_R^-}{N_L^-} \right)$$

free from instrumental asymmetry

P can be evaluated from ***AP*** value for a transition to the known spin state.

↓

A → spin assignment

where to perform the experiment?

$$\frac{\Delta(AP)}{AP} = \frac{\sqrt{1-(AP)^2}}{AP\sqrt{Y_{\beta\gamma}}}$$

$Y_{\beta\gamma}$

Large polarization is important

TRIUMF ISAC in Canada

first beam in 2000

polarized radioactive beam line

very high polarization

TRIUMF ISAC
Polarized Beam Line

collinear optical pumping

Kiefl **80% pol**
^{8}Li: transverse
β-NMR
condensed
matter physics

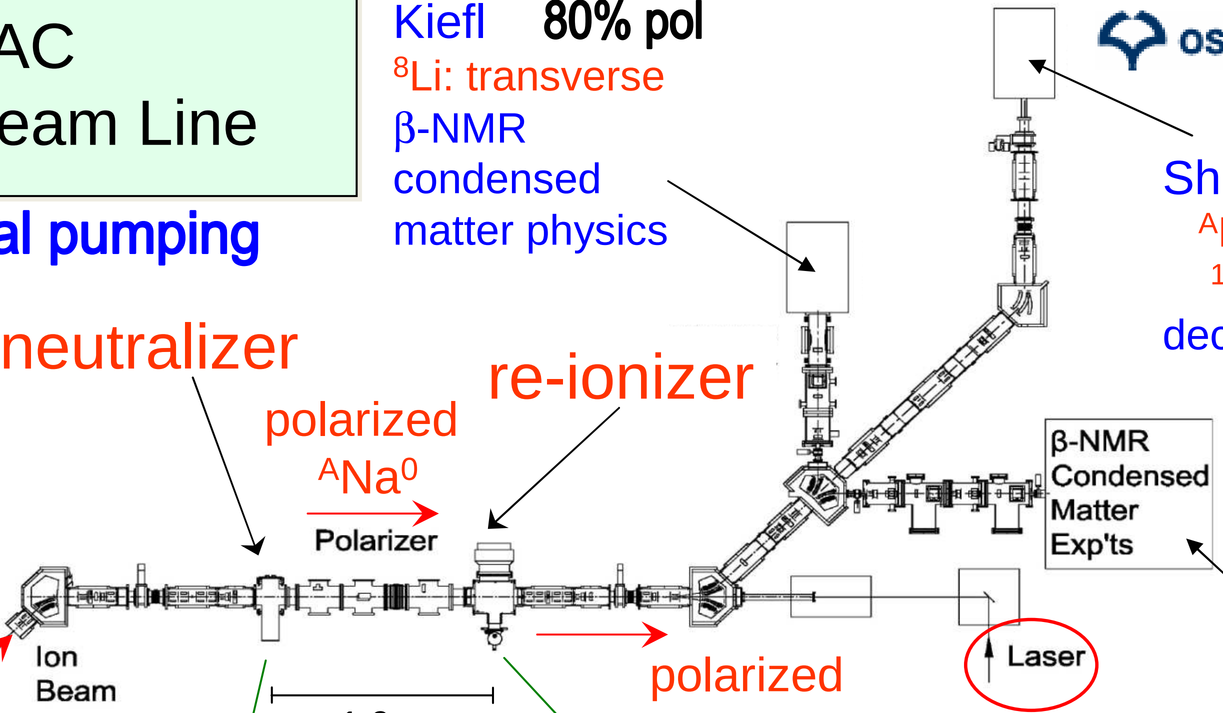
OSAKA UNIVERSITY

Shimoda **30-50% pol**
^{A}Na: transverse
^{11}Li: transverse
decay spectroscopy

neutralizer

polarized
$^{A}Na^{0}$

re-ionizer



Kiefl **80% pol**
^{8}Li: longitudinal
β-NMR
condensed
matter physics

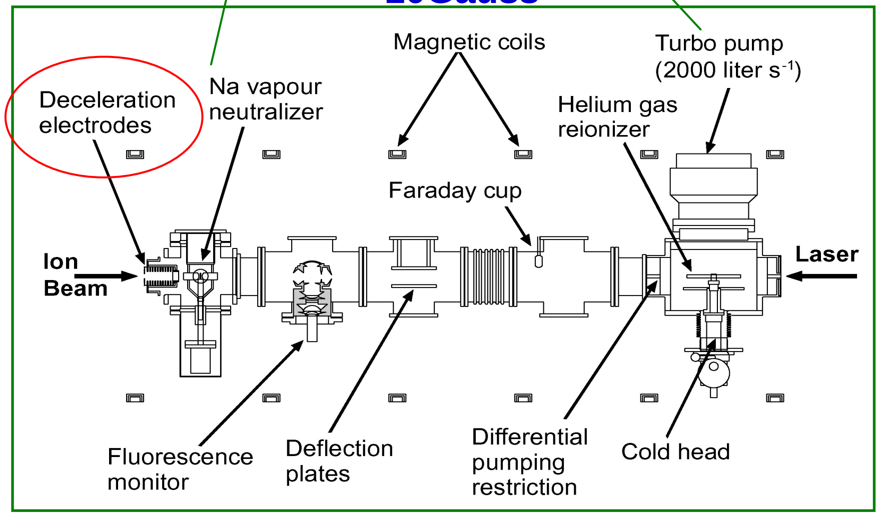
polarized
$^{A}Na^{+1}$

two frequency
laser beams

unpolarized $^{A}Na^{+1}$
30 keV

B →
10Gauss

beam velocity
tuning

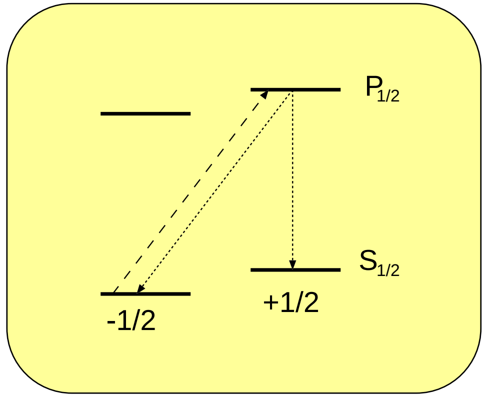


pumping within 2.6μs

C.D.P. Levy et al.
Nucl. Instr. and Meth.
B204 (2003) 689

pumping the two ground-state hyperfine levels in order to achieve high polarization

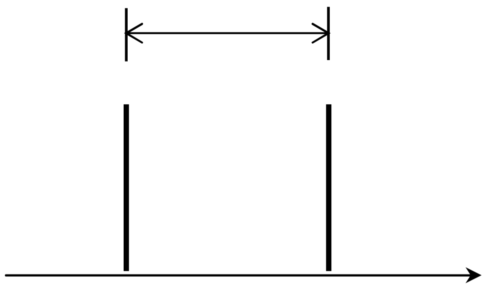
without hyperfine int.



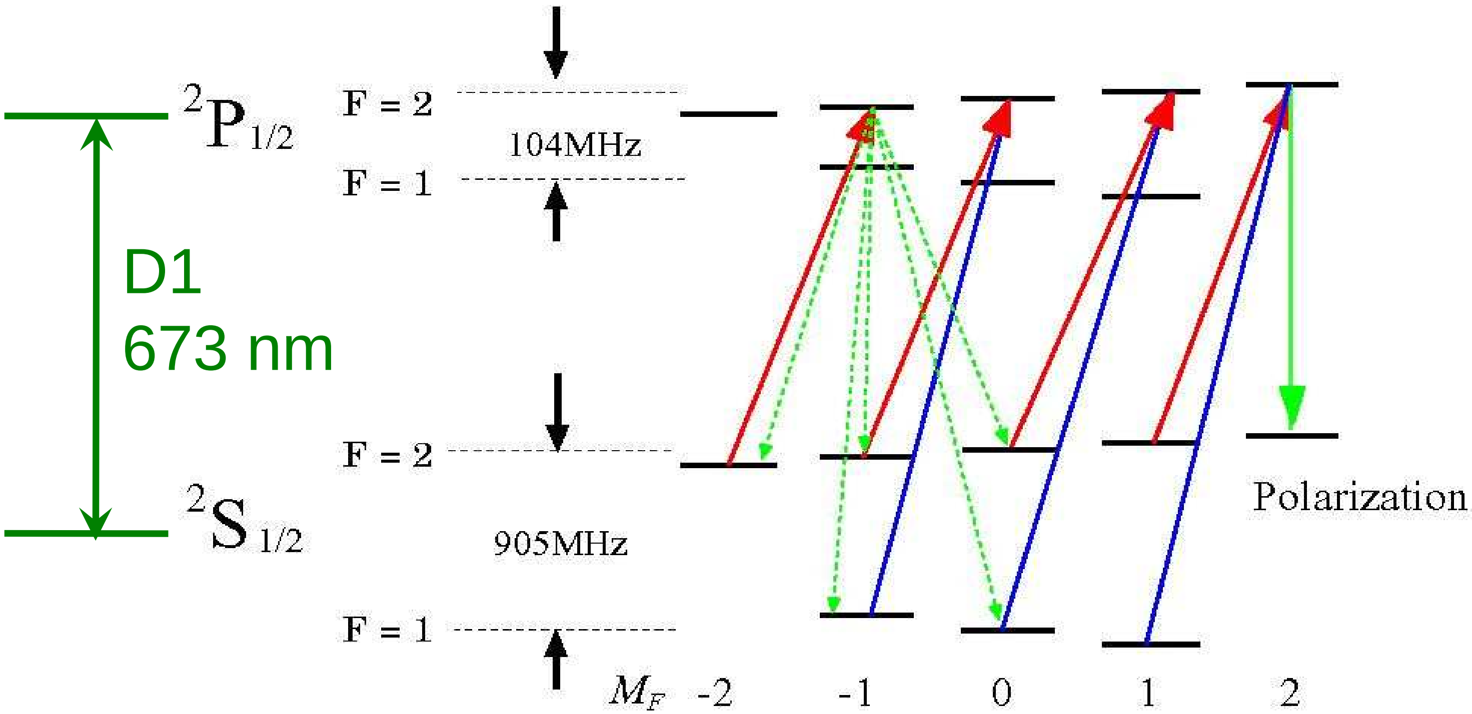
with hyperfine int.

$$\vec{F} = \vec{J} + \vec{I}$$

atom 1/2 nucleus 3/2



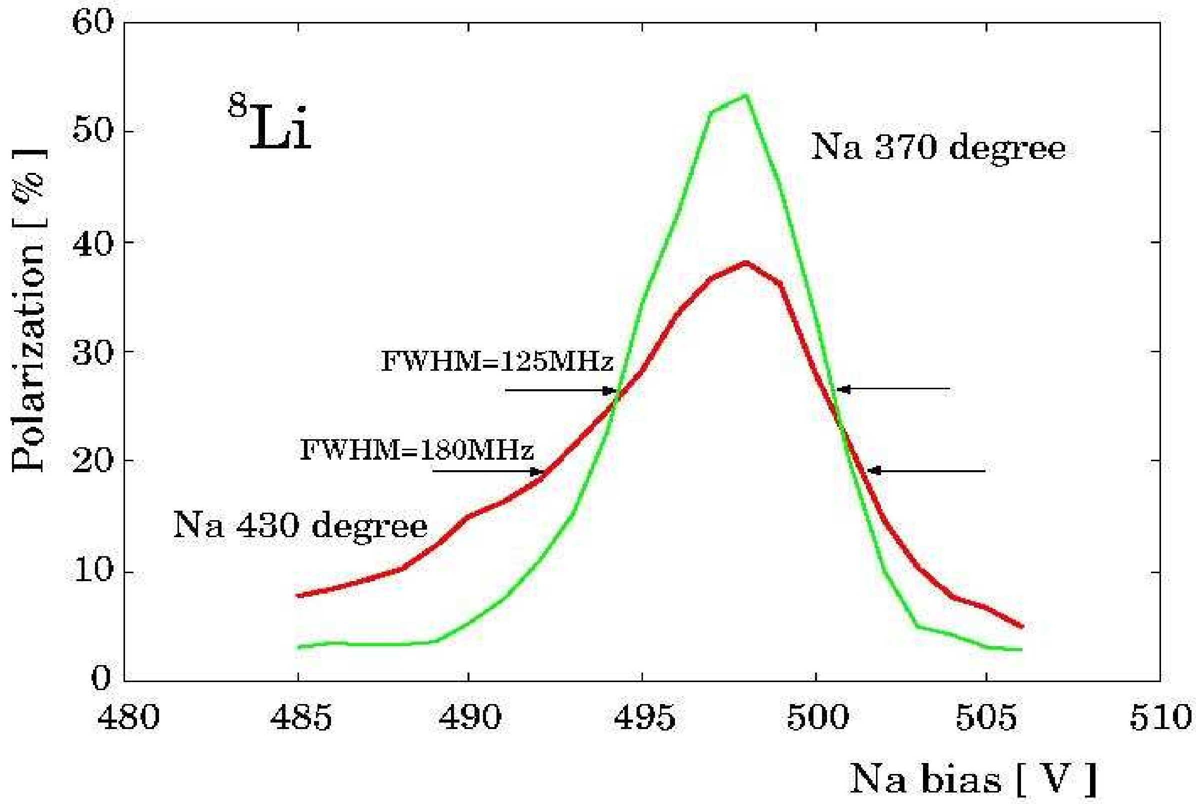
905 MHz EOM was used



^{11}Li(I=3/2$^-$)

unexpectedly low polarization

energy (Doppler) broadening of the neutralized beam

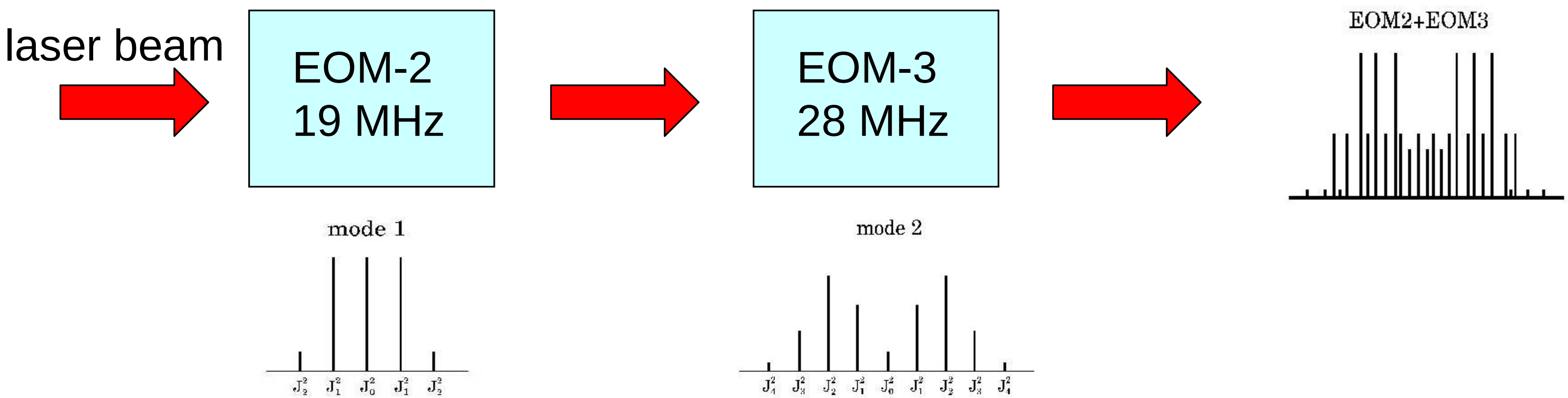


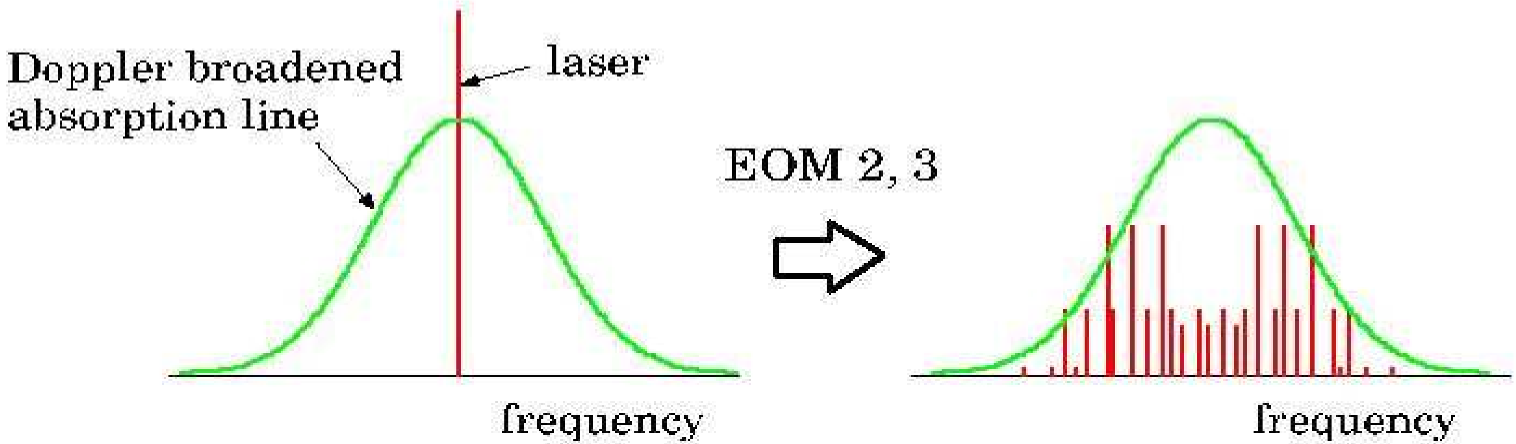
>> laser line width
~ 1 MHz

multiple collisions with Na atoms in the neutralizer

broadening the laser line width

two EOMs in series





^{8}Li

P ~ 20%

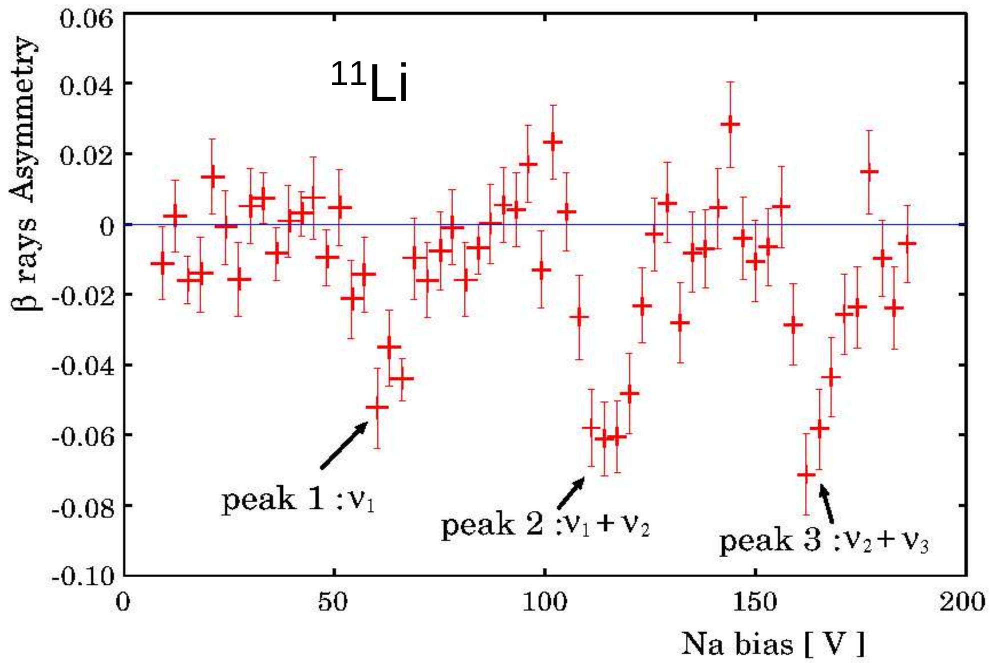
↓

P ~ 70%

Doppler-shift tuning

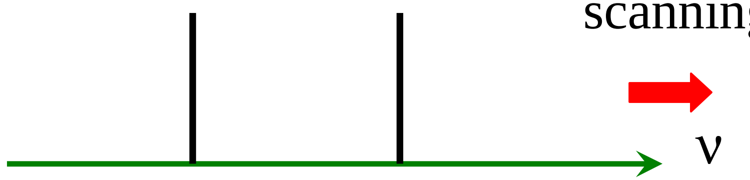
deceleration bias (Na vapor cell)
tuning to adjust ion beam velocity
so as to meet the Doppler shift

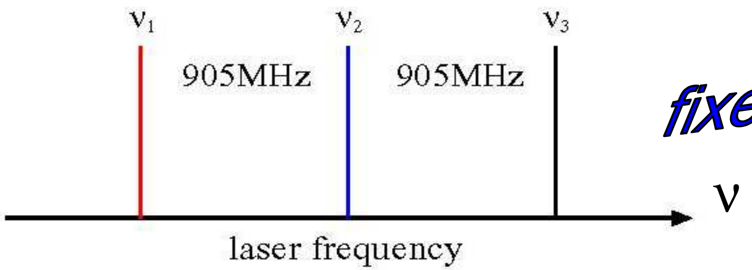
beta-decay asymmetry



absorption line

scanning velocity





fixed

Achieved polarization

Phil Levy @TRIUMF

^{8}Li: 80%, ^{9}Li: 56%, ^{11}LI: 55%,

^{20}Na: 57%, ^{21}Na: 56%, ^{26}Na: 55%,
^{27}Na: 51%, ^{28}Na: 45%,

Corrected for spin-relaxation
K. Minamisonno et al.,
Nucl. Phys. A746(2004)673c

^{28}Na: 28%, ^{29}Na: 36%

Uncorrected for spin-relaxation
Preset work

Pumping for $^{11}Be^{+}$ beam is in progress.

3

$\overrightarrow{^{11}Li_{gs}} \Rightarrow$ $\mathbf{^{11}Be^*}+\beta$

↳ $^{10}Be^* + n$

↳ $^{10}Be_{gs} + \gamma$

July 2002
Aug 2004

neutron halo
N=8
cluster

1

$\overrightarrow{^{28}Na_{gs}} \Rightarrow$ $\mathbf{^{28}Mg^*}+\beta$

↳ $^{28}Mg^* + \gamma$

↳ $^{28}Mg_{gs} + \gamma$

Nov 2007

system check
new level search
island of inversion
N=20

2

$\overrightarrow{^{29}Na_{gs}} \Rightarrow$ $\mathbf{^{29}Mg^*}+\beta$

↳ $^{29}Mg^* + \gamma$

↳ $^{29}Mg_{gs} + \gamma$

Nov 2007

island of inversion
Intruder
N=20

$\overrightarrow{^{30}Na_{gs}} \Rightarrow$ $\mathbf{^{30}Mg^*}+\beta$

↳ $^{30}Mg^* + \gamma$

↳ $^{30}Mg_{gs} + \gamma$

Aug 2010

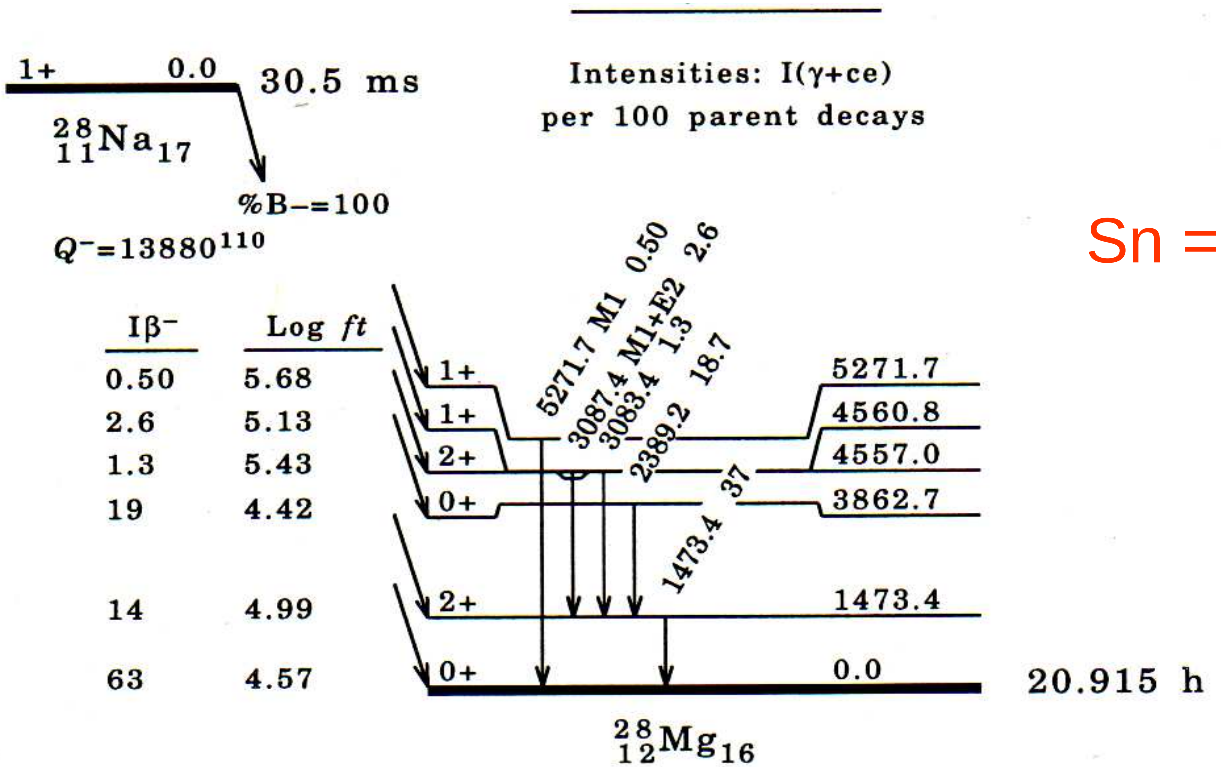
island of inversion
Intruder
N=20

system check with polarized ^{28}Na beam and search for something new

800 particles per sec

^{28}Mg

- test of the experimental methods
- confirm I^{π} assignments
- high E_x levels

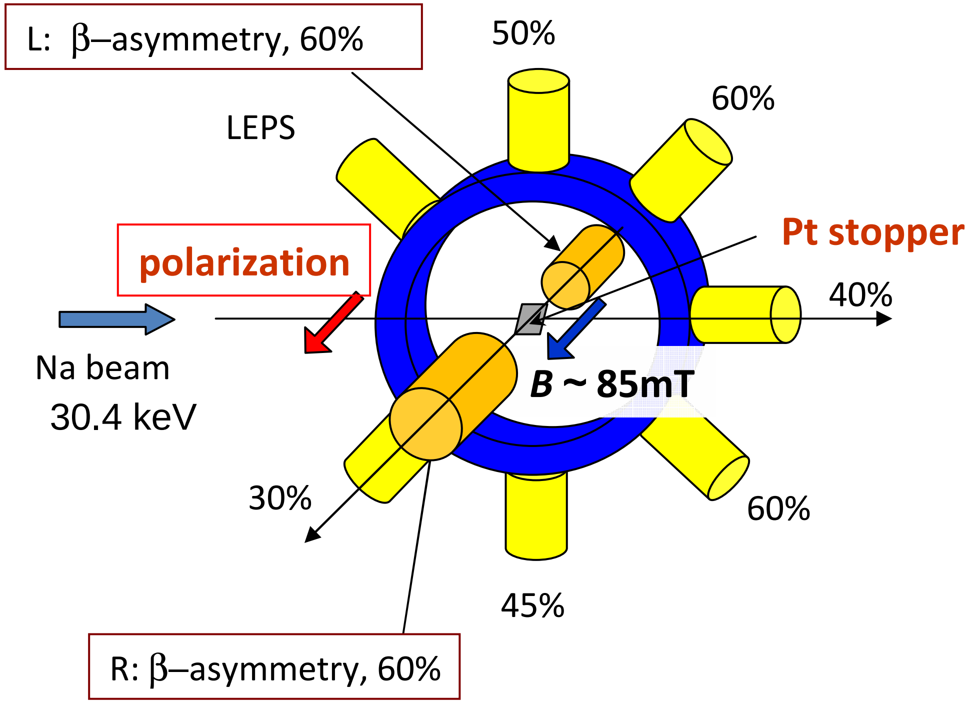


Sn = 8.503 MeV

9 HPGe detectors + plastic scintillator telescopes

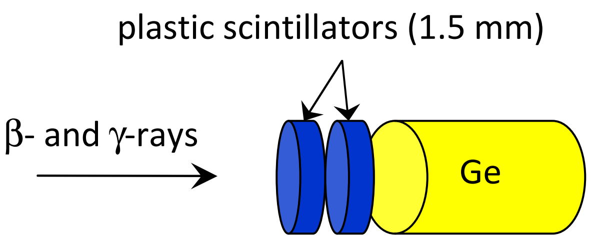
^{28,29,30,31,32}Na decay at TRIUMF

β-asymmetry: β–γ, β–γ–γ, γ–γ



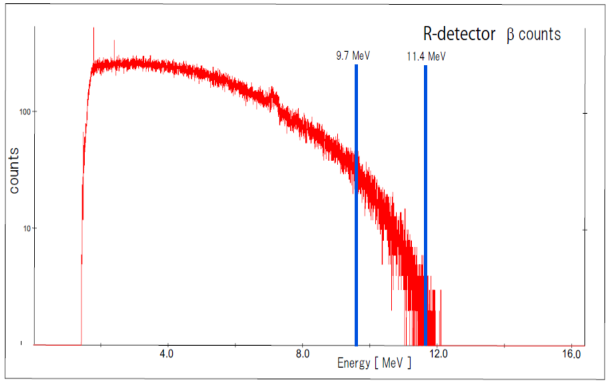
total efficiency
1.7% @1333keV

28Na and 29Na in Nov. 2007



β energy threshold: eliminates Al contaminants from trigger
β energy : assigns β-decay branch

β-ray energy spectrum



selecting ground-state transition.

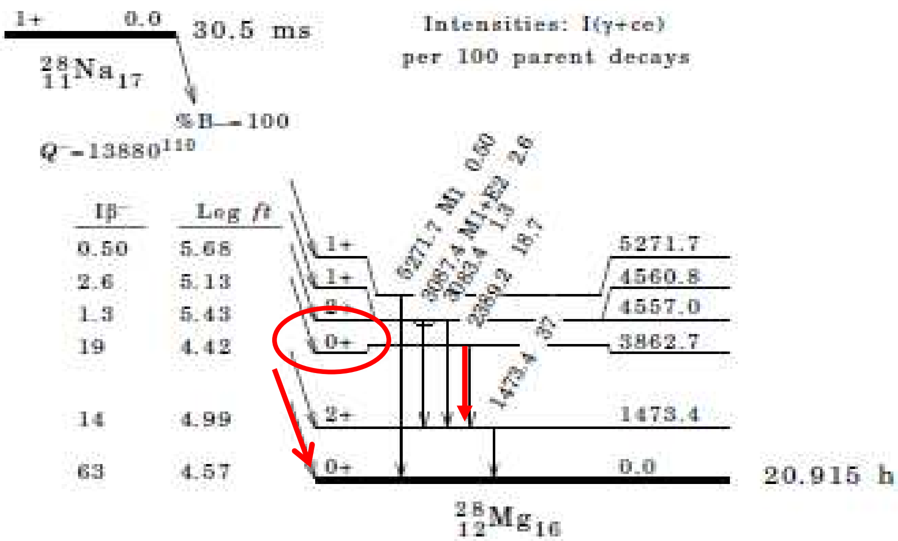
AP **= -0.283(5)** $\Rightarrow$ ***P* = 0.283(5)**

uncorrected for spin-relaxation

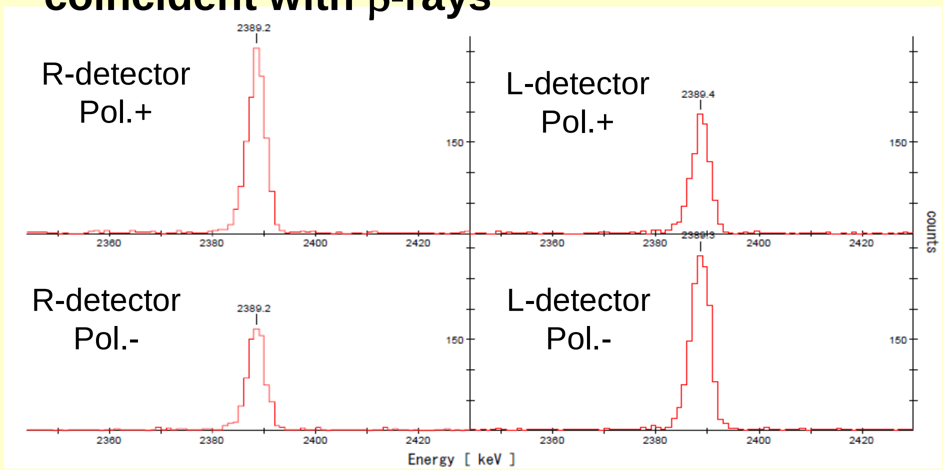
1+ → 0+ : *A* = -1.0

spin assignments of the levels in ^{28}Mg

	I_i^π (Na)	I_f^π (Mg)	$A(I_i, I_f)$
^{28}Na	1^+	2^+	$+0.5$
		1^+	-0.5
		0^+	-1.0



2389 keV γ-ray peaks (3862 ⇨ 1473) coincident with β-rays



***AP* = -0.25±0.01** ⇨ ***A* = -0.89±0.05** ⇨ ***I*$^\pi$ = 0$^+$**

Revised Decay Scheme of ^{28}Na and New Levels in ^{28}Mg

Levels and gamma rays

Red : newly observed ones

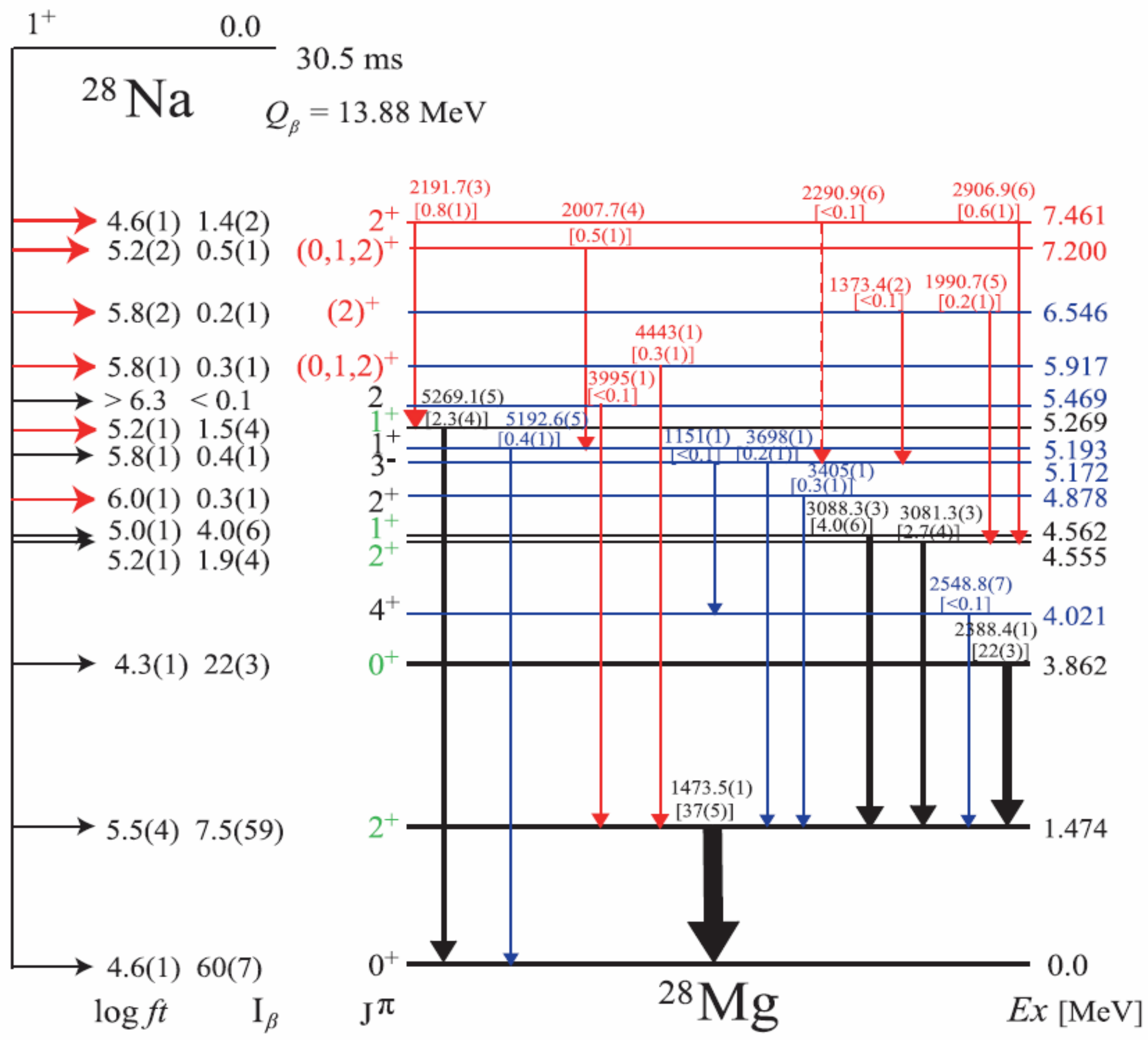
Blue : previously observed in (t, p) reaction
and newly observed in 28Na β decay

Spins and parities

Red : newly assigned

Green : previously reported,
and confirmed by present work

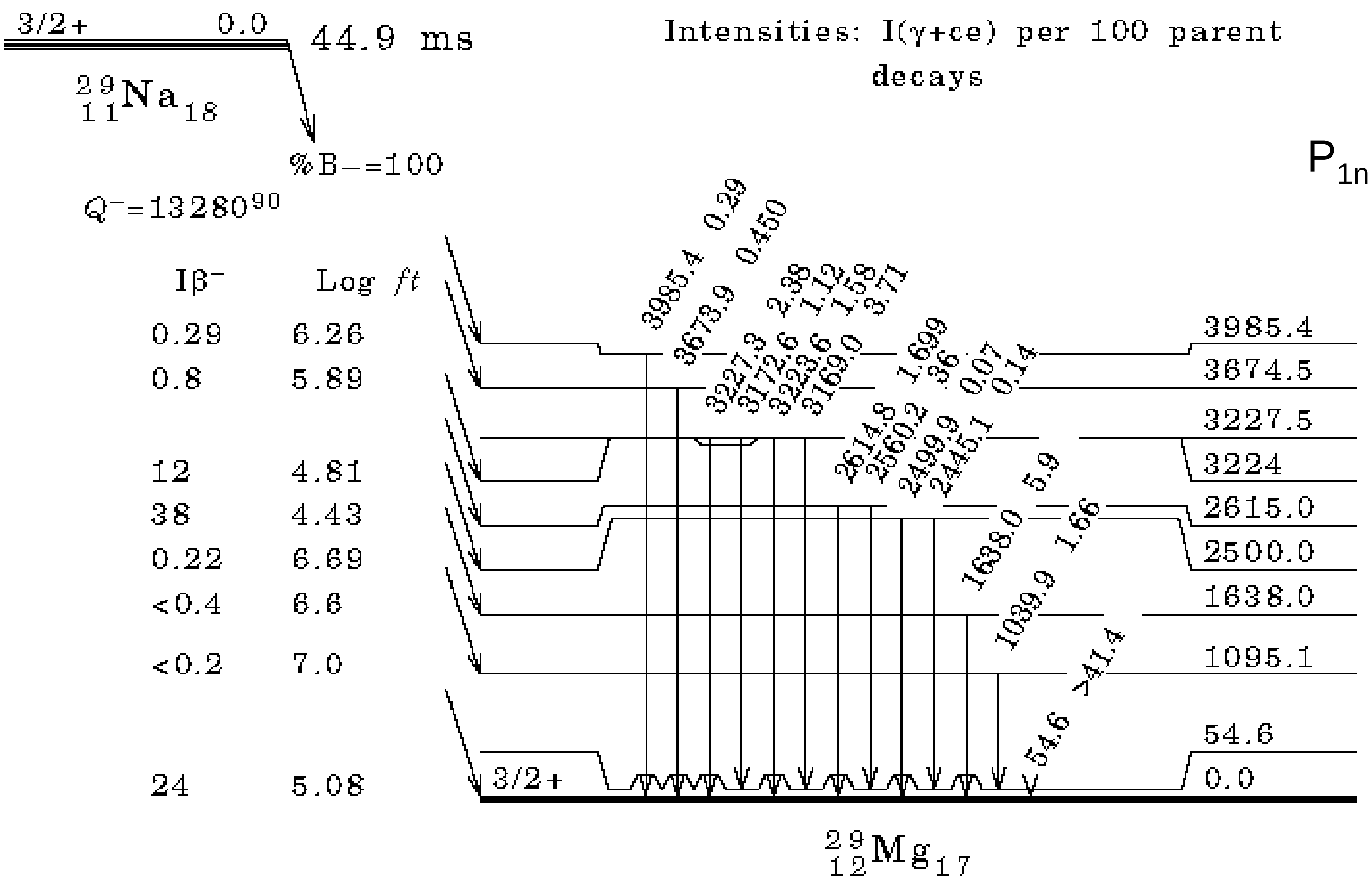
Black : previously reported



^{29}Na decay spin-parity assignments of ^{29}Mg levels

200 particles per sec

^{29}Na β-decay (NNDC 1998)



P$_{1n}$ = 21.5%

essentially no spin-parity assignments

Revised Decay Scheme of ^{29}Na and Spin-Parity Assignments of ^{29}Mg Levels

Levels and gamma rays

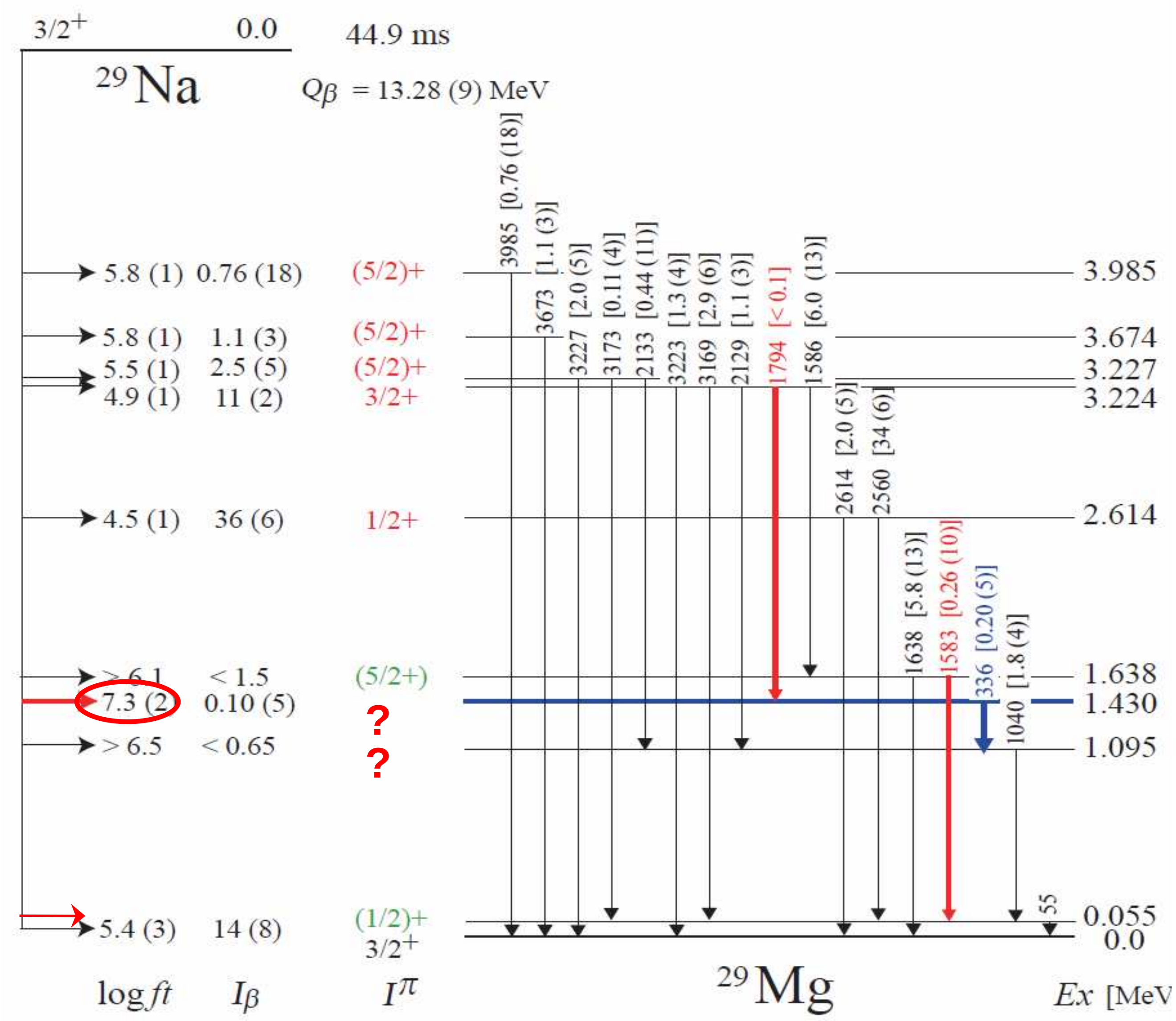
Red : newly observed

Blue : previously observed in 30Na β-n decay and transfer reactions ; newly observed in 29Na β decay

Spins and parities

Red : newly assigned

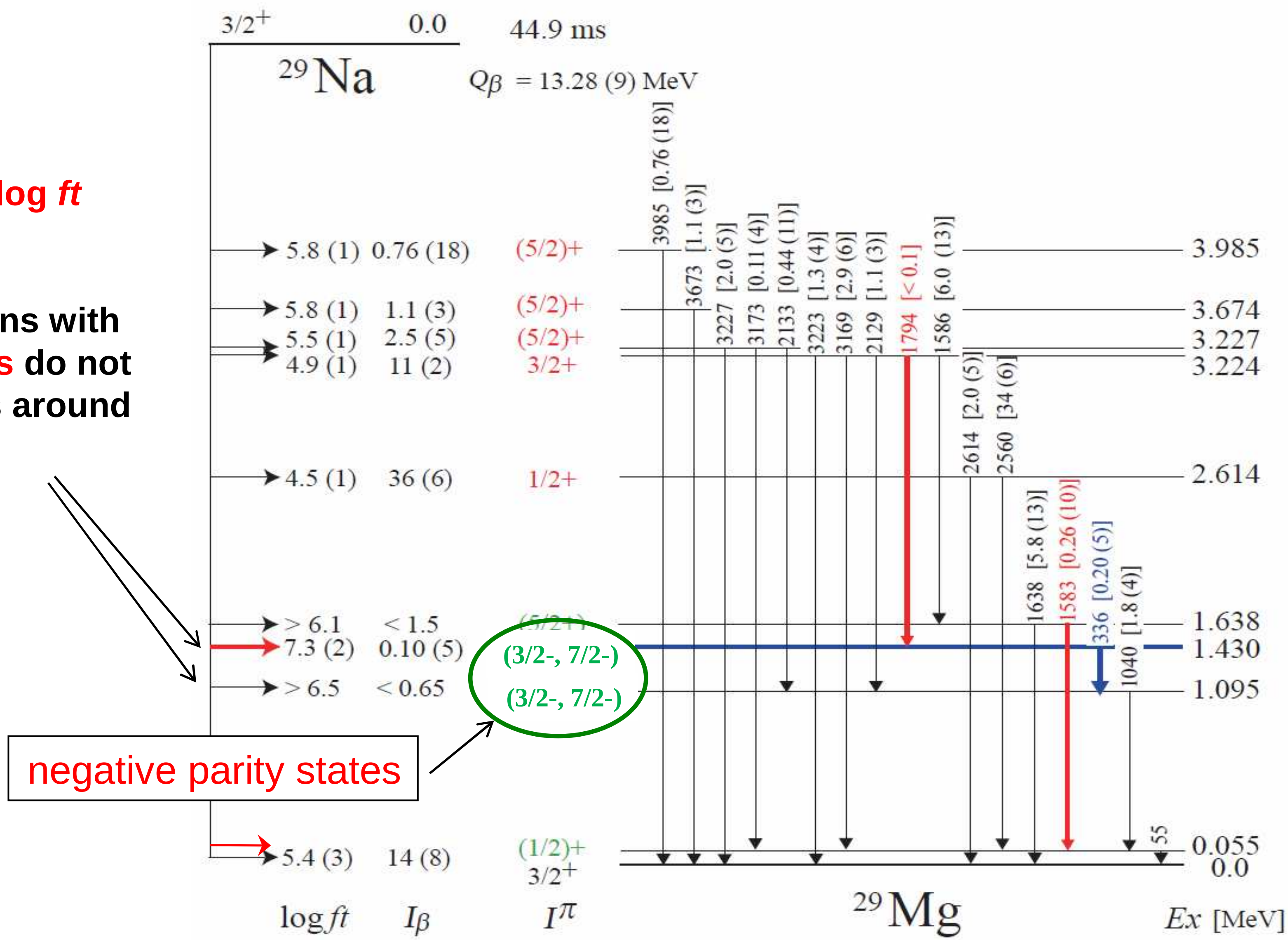
Green : assigned tentatively by γ ray transition probability



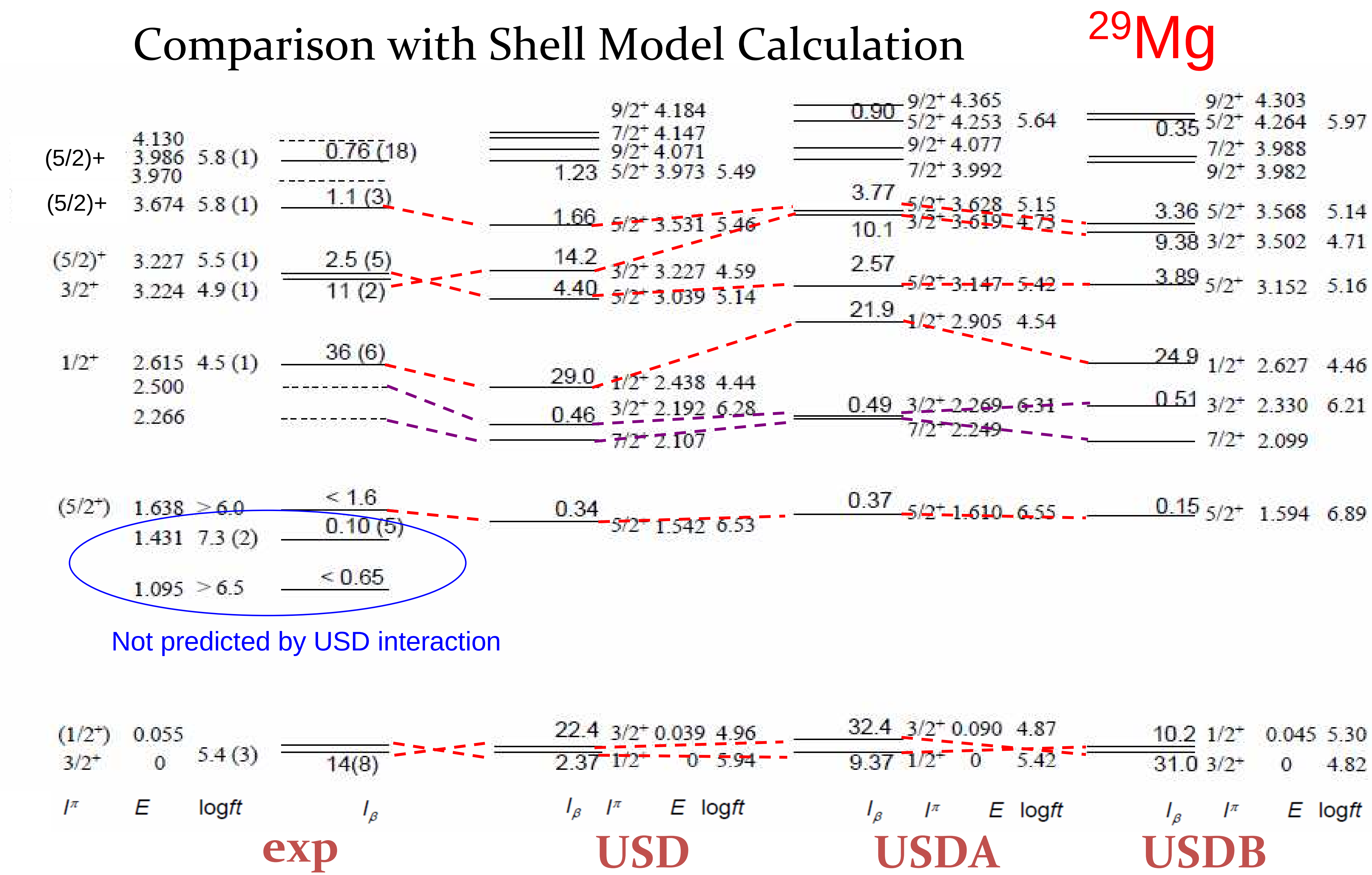
Revised Decay Scheme of ^{29}Na and Spin-Parity Assignments of ^{29}Mg Levels

These two levels are associated with large log *ft* values.

Shell model calculations with sd shell configurations do not predict no more levels around 1.0 - 1.5 MeV region.



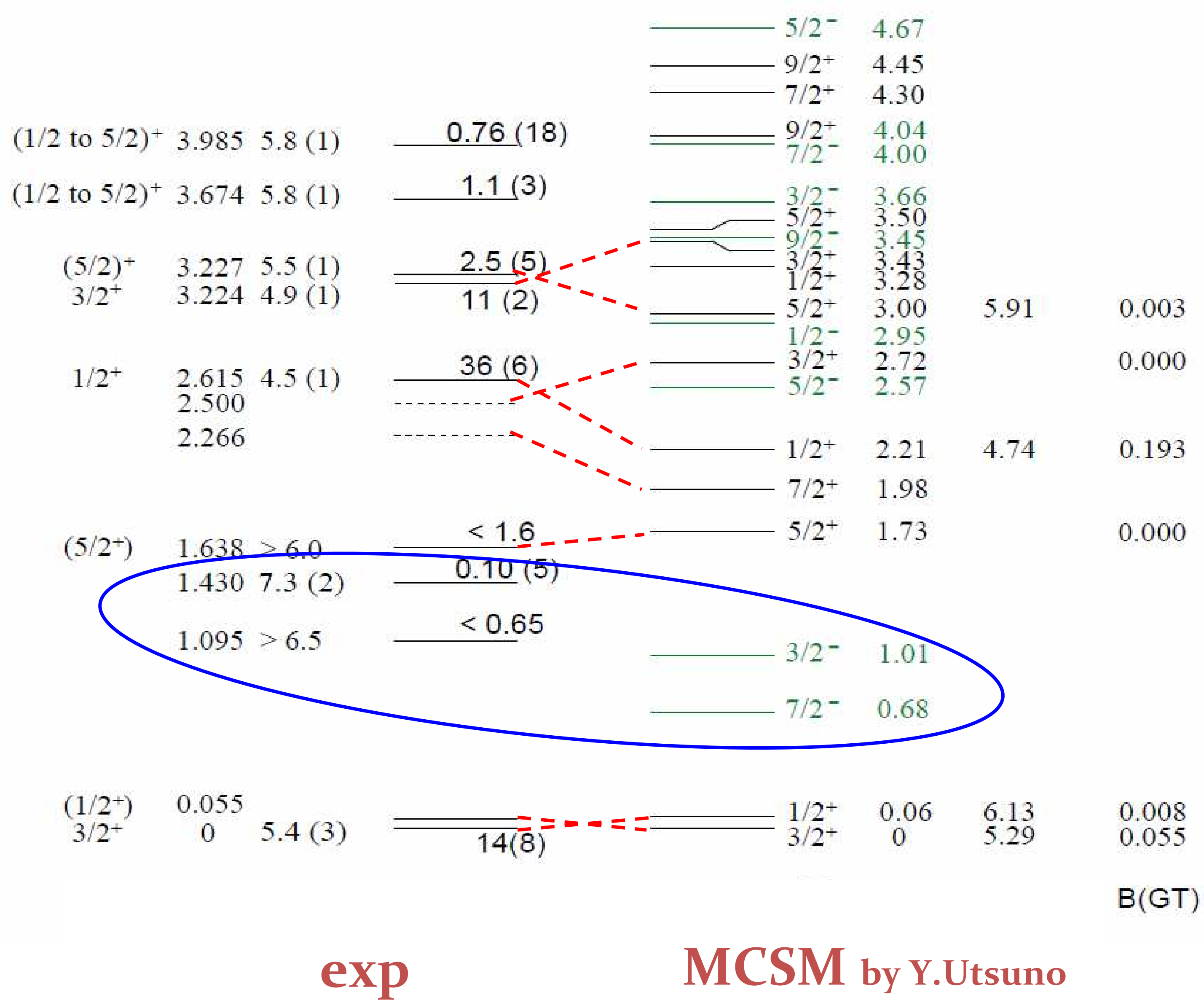
Comparison with Shell Model Calculation



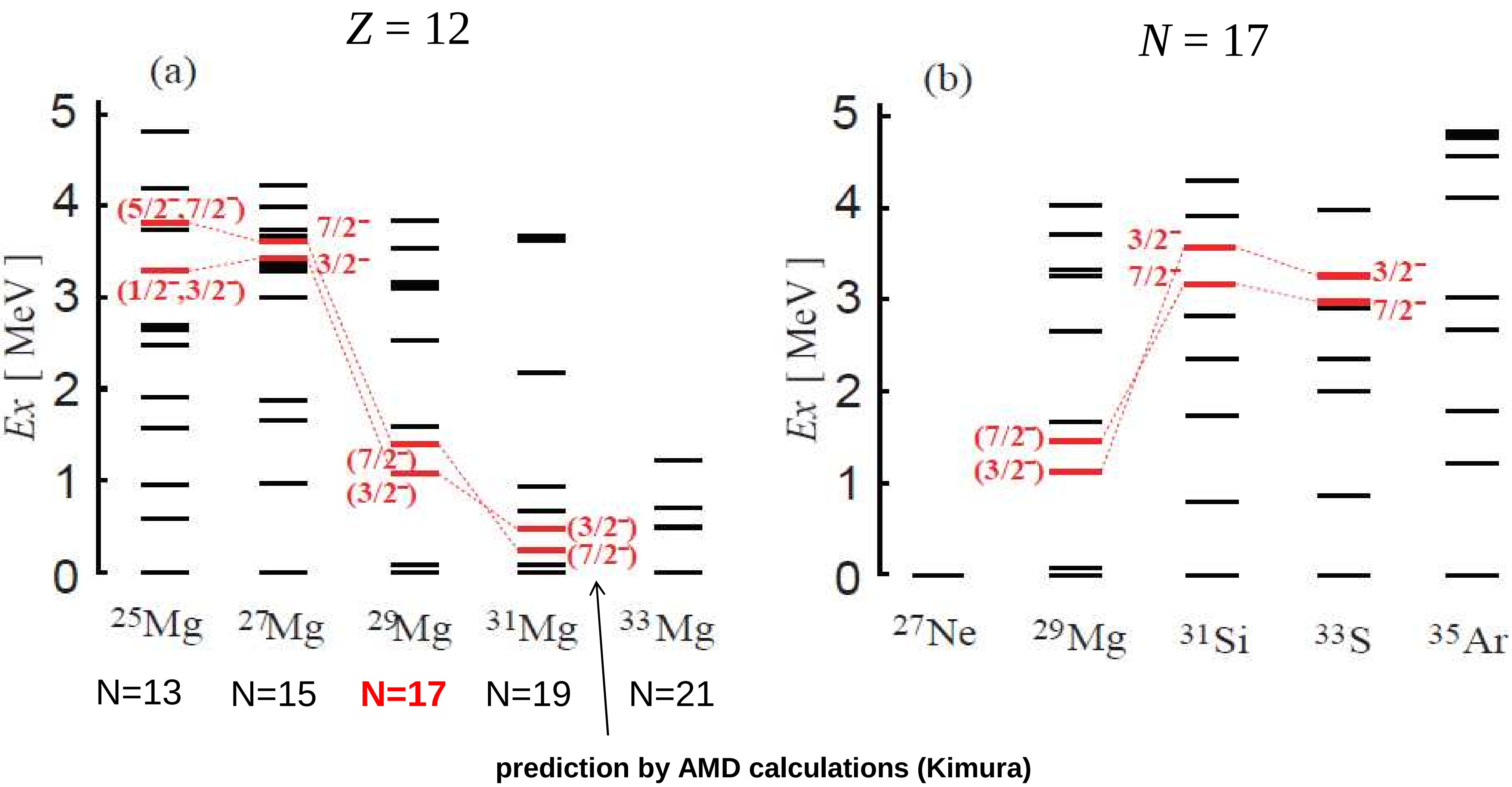
Code : NuShell

B.A. Brown et al., Phys. Rev. C74, 034315 (2006).

Comparison with Shell Model Calculation 2
(Monte Carlo Shell Model by Utsuno et al.)



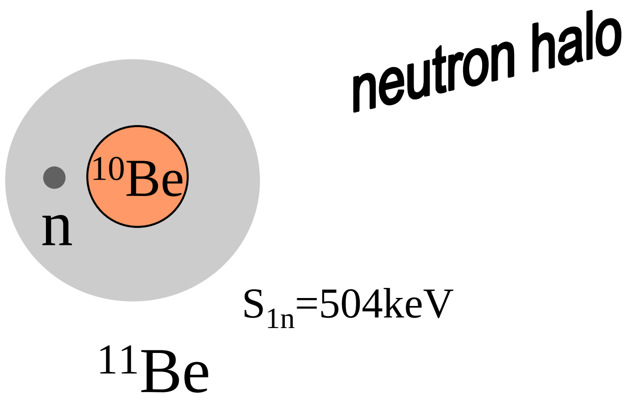
Systematics of negative parity levels (Exp.)

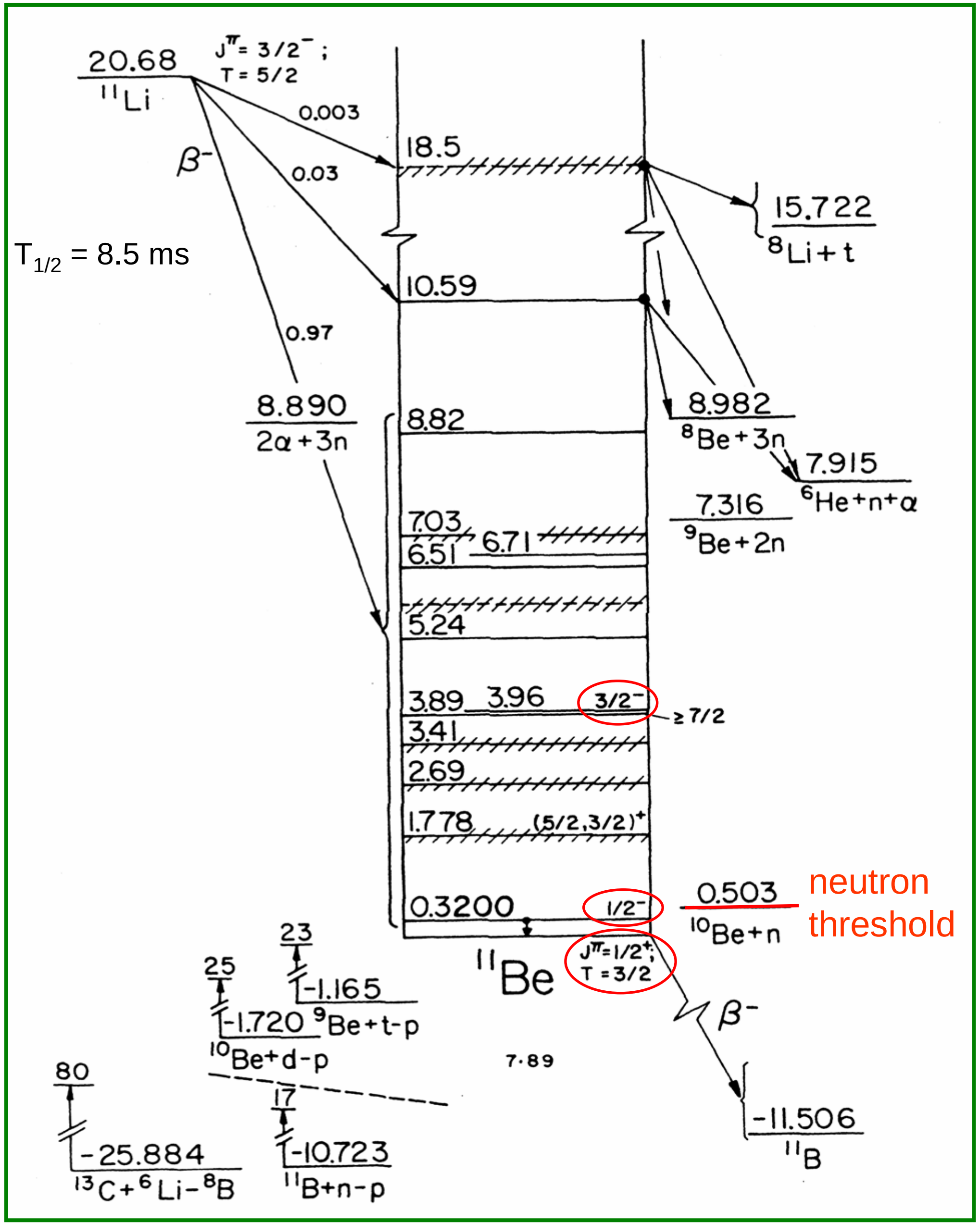


^{11}Li decay; establishing decay scheme and spin-parity assignments of ^{11}Be levels

200 particles per sec

Excited States of ^{11}Be





F. Ajzenberg-Selove, Nucl. Phys. A506 (1990) 1.

- only a few spin-parity assignments
- low level density in high energy region

Most of the excited states decay by neutron emission.

Experiment at TRIUMF (E903)

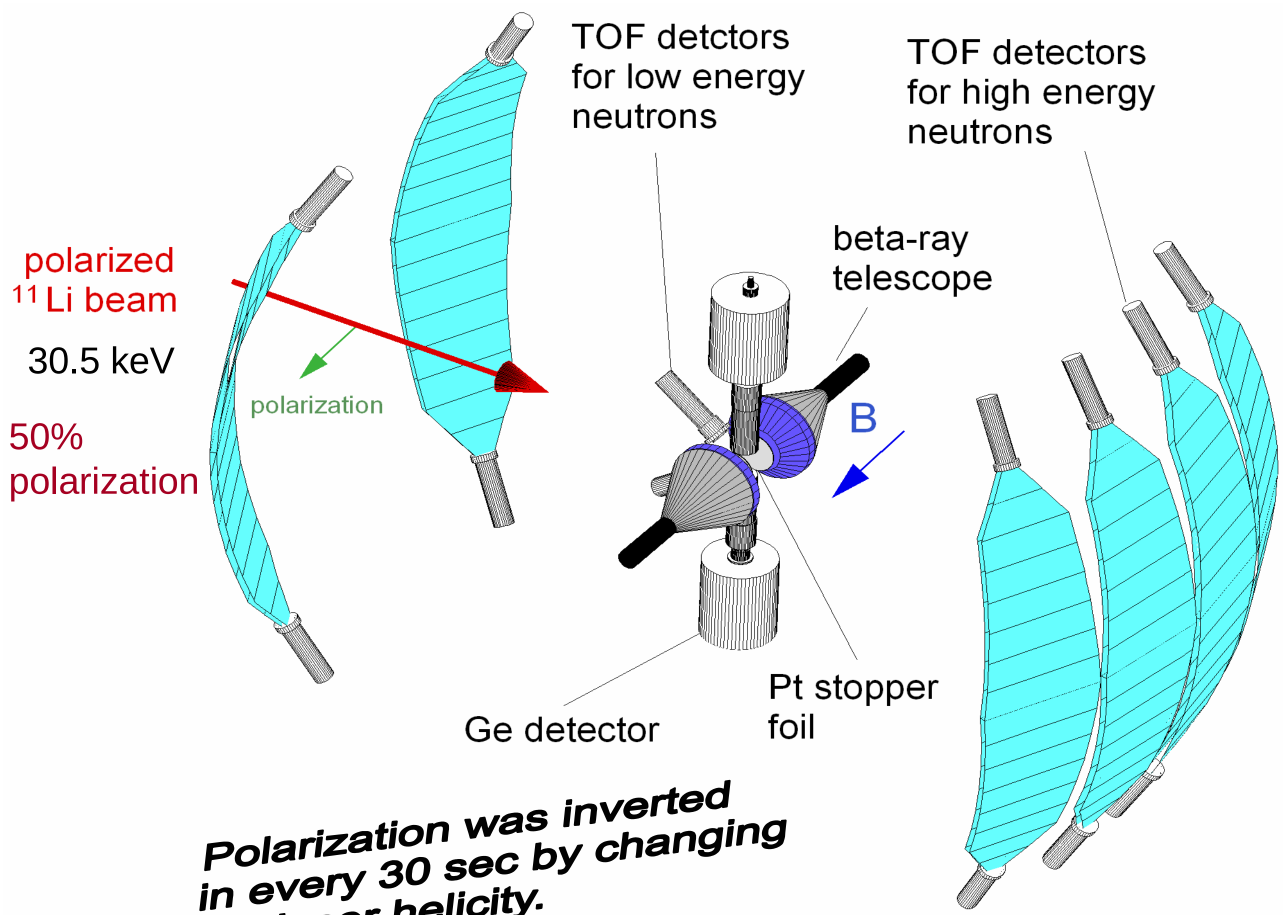
$\overrightarrow{^{11}\mathrm{Li}_{gs}} \Rightarrow {^{11}\mathrm{Be}^*} + \beta$

$\quad \hookrightarrow {^{10}\mathrm{Be}^*} + n$

$\quad\quad \hookrightarrow {^{10}\mathrm{Be}_{gs}} + \gamma$

β- n, β- γ, β- n-γ coincidence

β-decay asymmetry



Polarization was inverted in every 30 sec by changing the laser helicity.

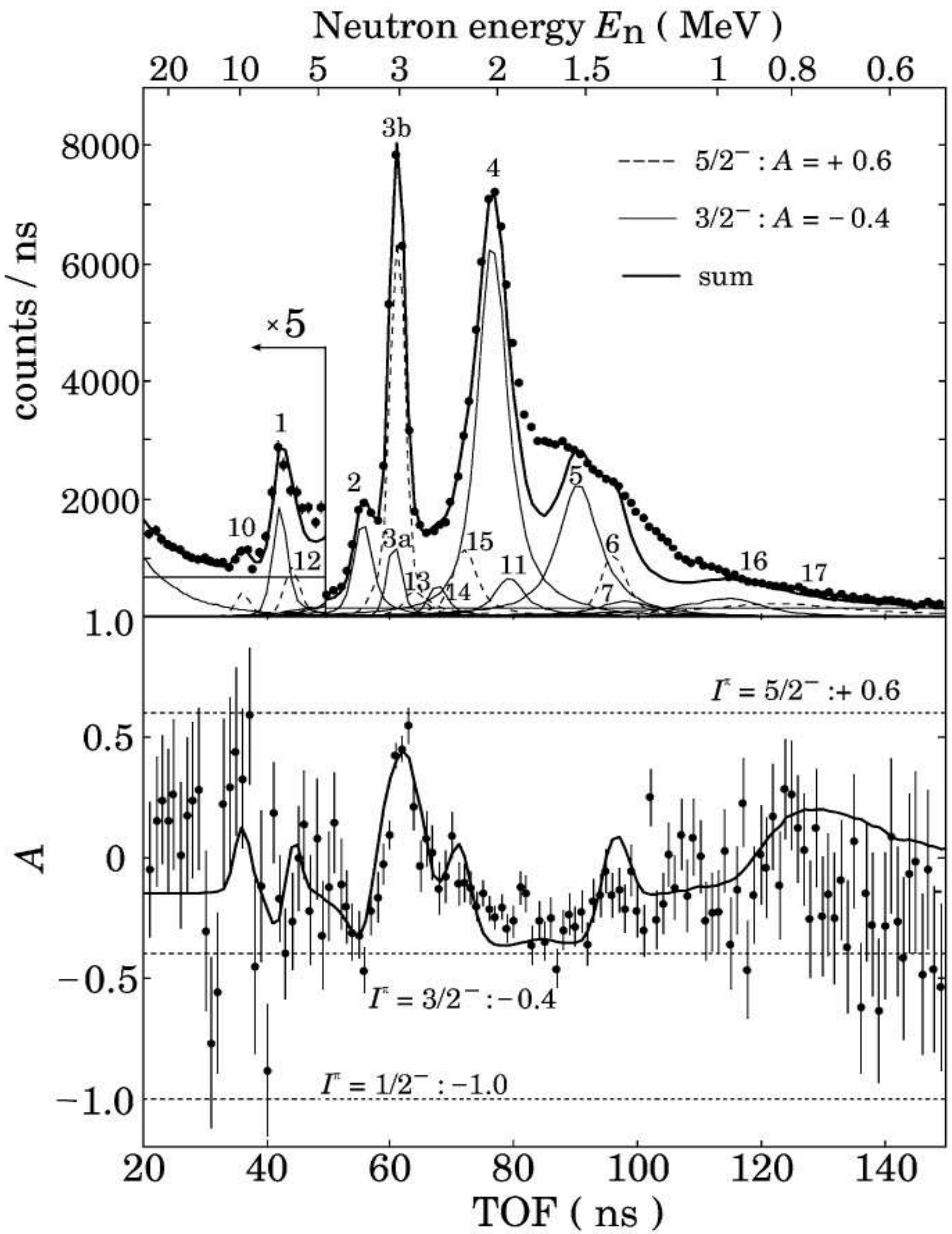
E_n = 1 keV – 9 MeV

β-ray telescope: $\Delta\Omega_\beta$ = 14.7% x 2,
ε_β = 90%

Ge detector: HPGe, 50 and 60 %,
$\Delta\Omega_\gamma \varepsilon_\gamma = 3.2\times10^{-3}$ @3 MeV

plastic scintillator: $\Delta\Omega_n$ = 1.8% x 6,
ε_n = 19%@2 MeV,
$E_n \geqq$ 500 keV
Flight Length: 1.5 m

Li-glass scintillator: $\Delta\Omega_n$ = 0.92% x 5,
ε_n =2.1%@15 keV,
ε_n = 1.3%@80 keV
$E_n \geqq$ 1 keV
Flight Length: 130 mm



neutron TOF spectrum
and coincident
β-decay asymmetry

$\overrightarrow{^{11}Li_{gs}}$ ➡ $^{11}Be^{*}+\beta$

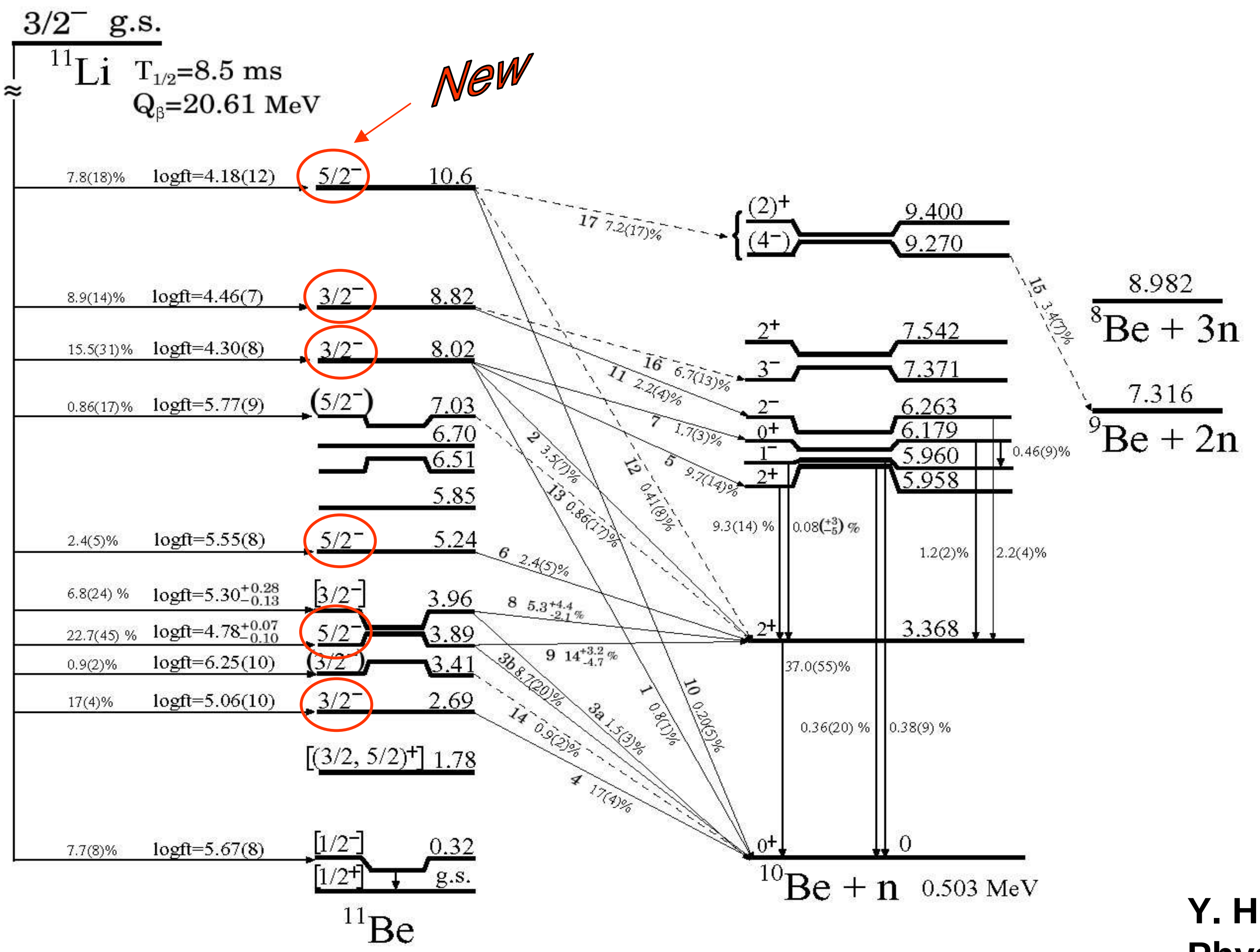
↳ $^{10}Be^{*} + n$

high energy neutrons

Asymmetry parameter is helpful to decompose the overlapping peaks.

Y. Hirayama *et al*.,
Phys. Lett. B611 (2005) 239

New Level and Decay Schemes of ^{11}Be



Y. Hirayama *et al.*,
Phys. Lett. B611 (2005) 239

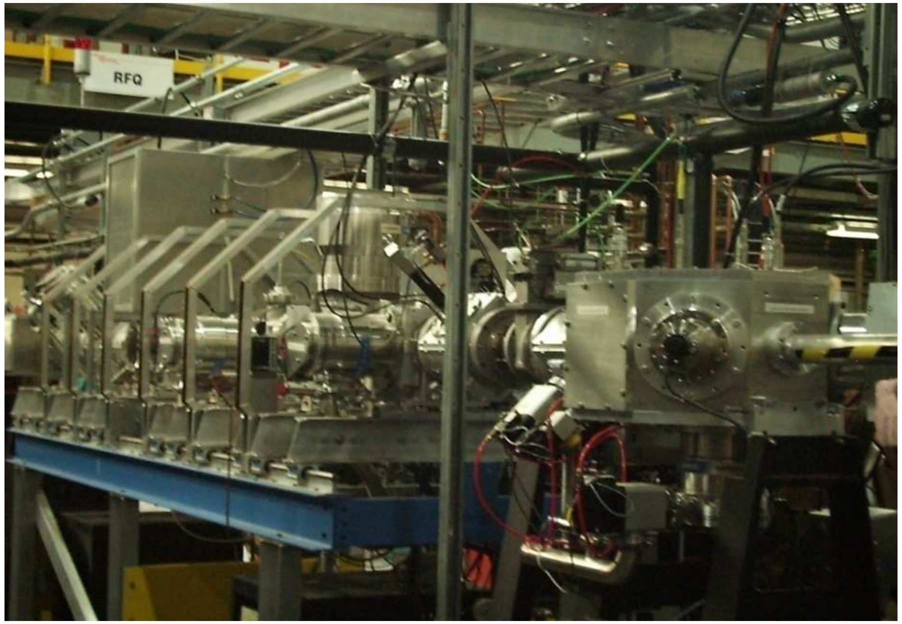
Summary

- Beta-decay asymmetry is very sensitive to spin value of the daughter state. The asymmetry is also helpful to clarify the decay scheme.

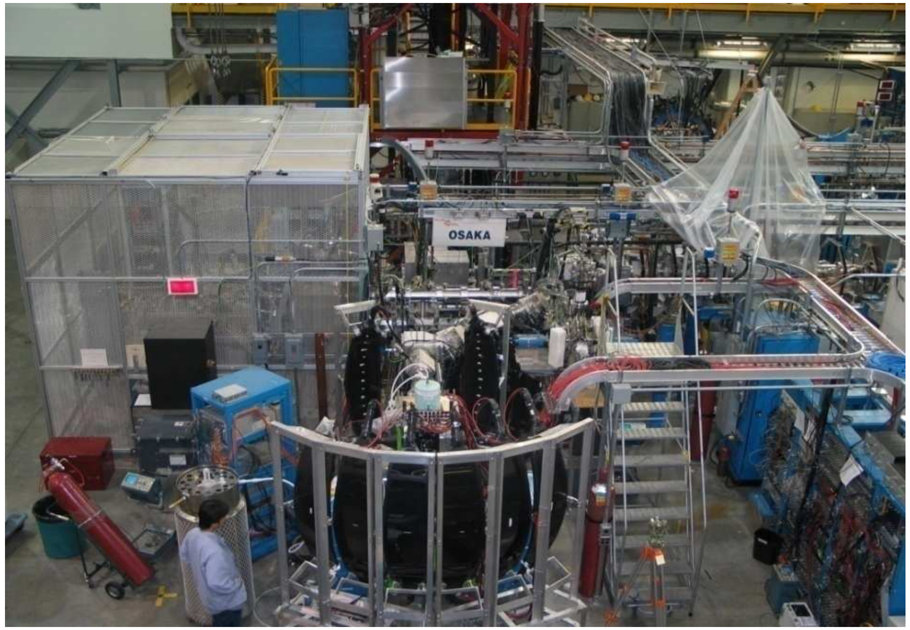
- The-beta-decay asymmetry can be a powerful tool in beta-delayed decay spectroscopy. Possibility to install a spin polarized at DSIER should be discussed.

- Higher polarization is essential to apply this method to fewer nucleus.

- New methods to polarize nuclear species other than alkaline atom nucleus are strongly requested.



polarizer



Osaka beam line:
$^{11}Li \rightarrow {}^{11}Be^* \rightarrow {}^{10}Be^* + n$

2002 - 2004

Osaka beam line:
$^{28,29,30,31,32}Na \rightarrow {}^{28,29,30,31,32}Mg^* + \gamma$

Nov. 2007 -

TRIUMF Experiment S1114

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Dec. 2007
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