Precise Nuclear Moments of Extremely Proton-Rich Nuclei ^{23}Al

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Collaborators

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RIKEN Nishina Center (Japan) : H. Ueno, A. Yoshimi, Y. Ichikawa, H. Kawamura
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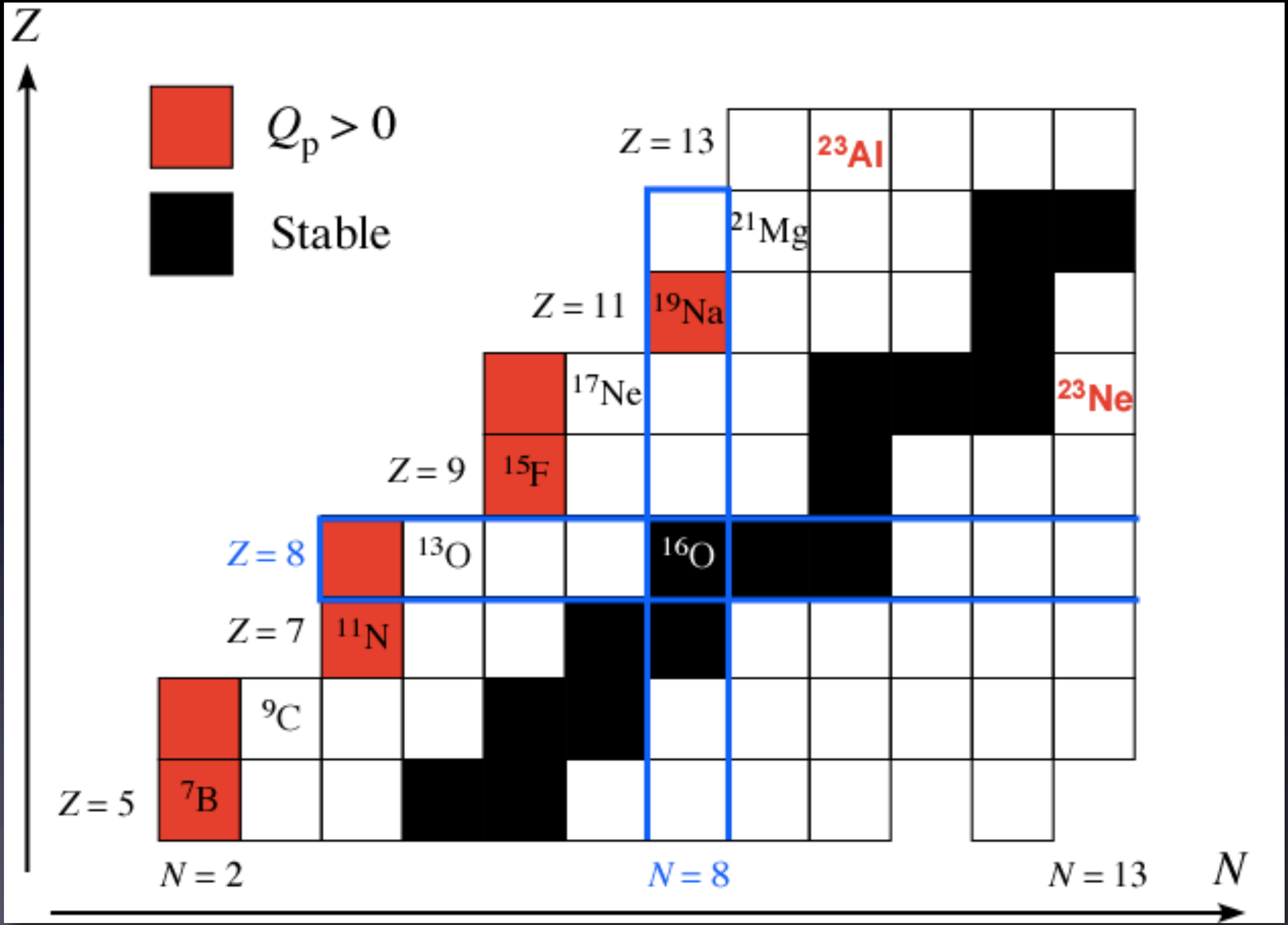
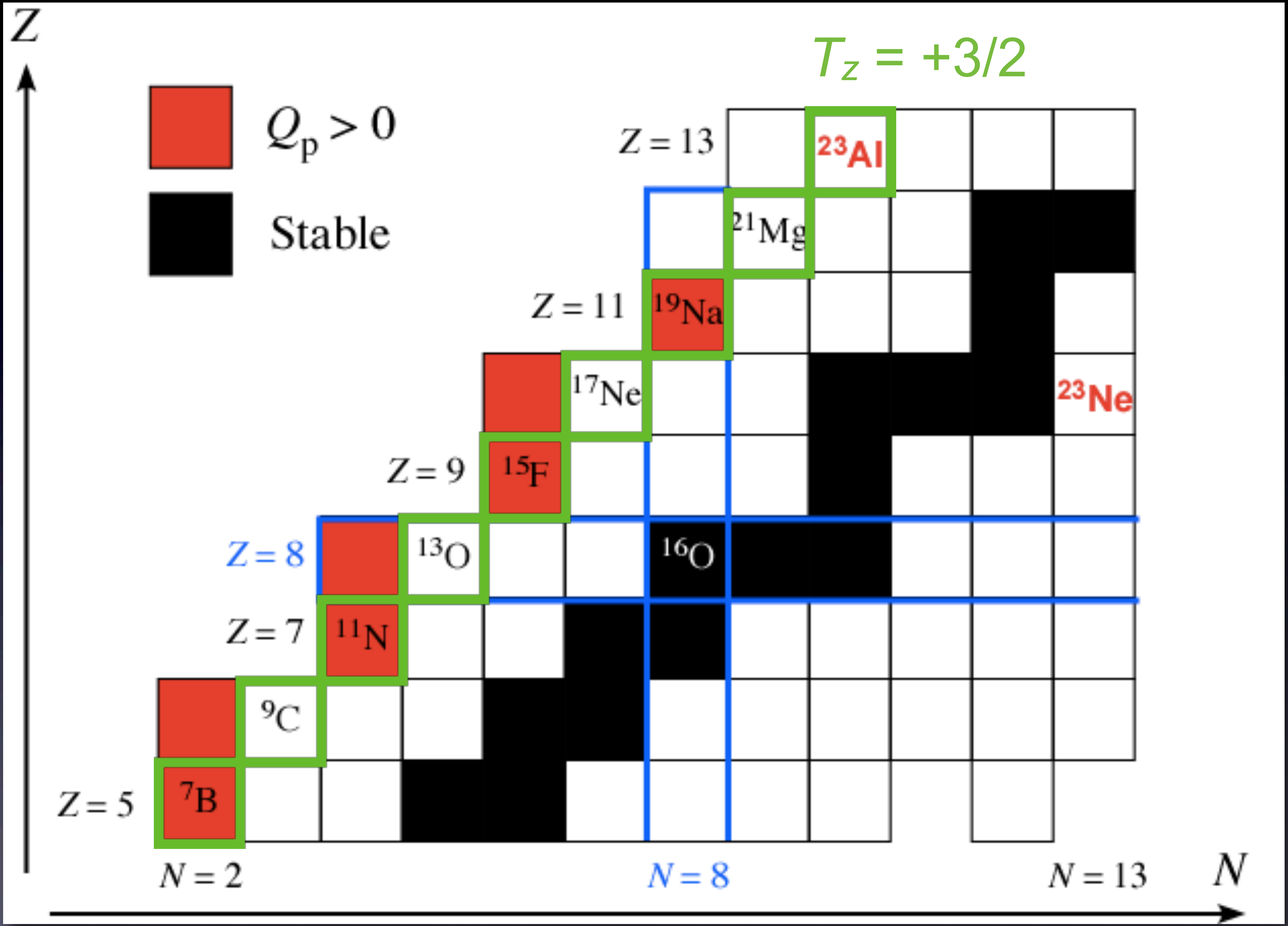
Tokyo Institute of Technology (Japan) : A. Asahi, M. Uchida, K. Suzuki, T. Inoue, Y. Hasama, H. Iijima
Tokyo University of Science (Japan) : T. Sumikama
Fukui University of Technology (Japan) : T. Minamisono


Z
$Q_p > 0$
Stable
Z = 13
^{23}Al
^{21}Mg
Z = 11
^{19}Na
^{17}Ne
^{23}Ne
Z = 9
^{15}F
Z = 8
^{13}O
^{16}O
Z = 7
^{11}N
^{9}C
Z = 5
^{7}B
N = 2
N = 8
N = 13
N


$T_z = +3/2$
Z
$Q_p > 0$
Stable
Z = 13
^{23}Al
^{21}Mg
Z = 11
^{19}Na
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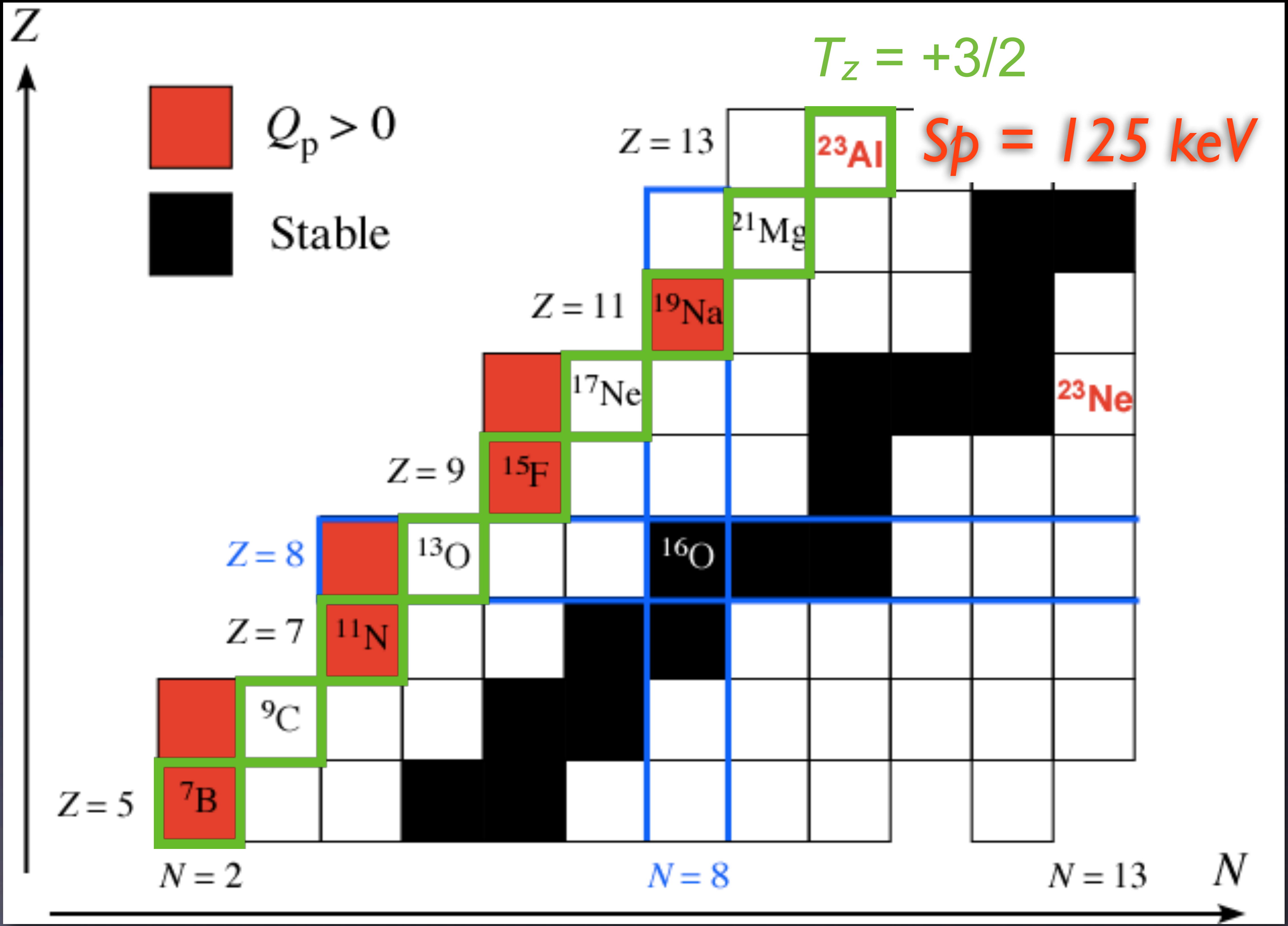
N = 8
N = 13
N


T_z = +3/2
Sp = 125 keV
Z
$Q_p > 0$
Stable
Z = 13
^{23}Al
^{21}Mg
Z = 11
^{19}Na
^{17}Ne
^{23}Ne
Z = 9
^{15}F
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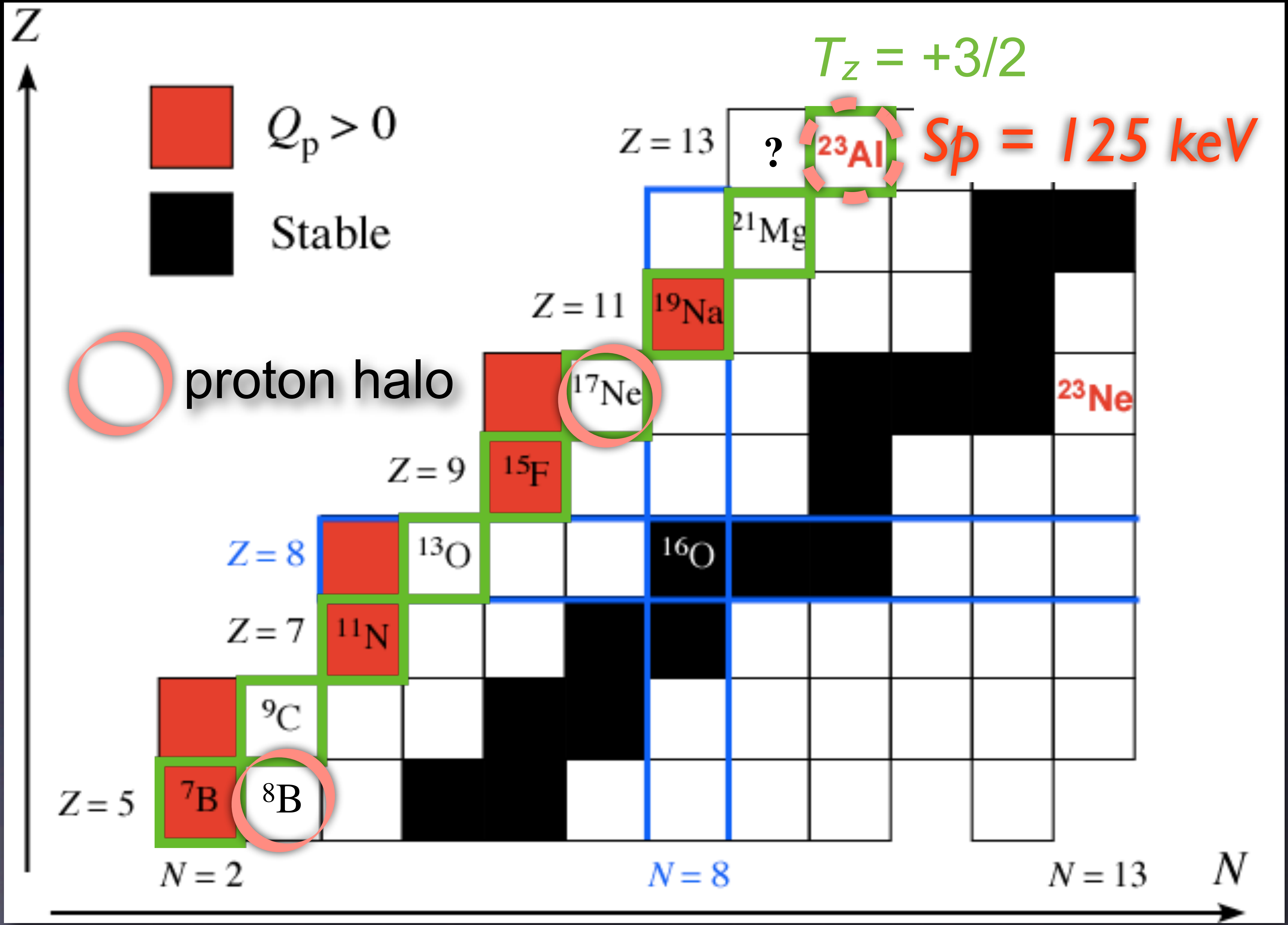
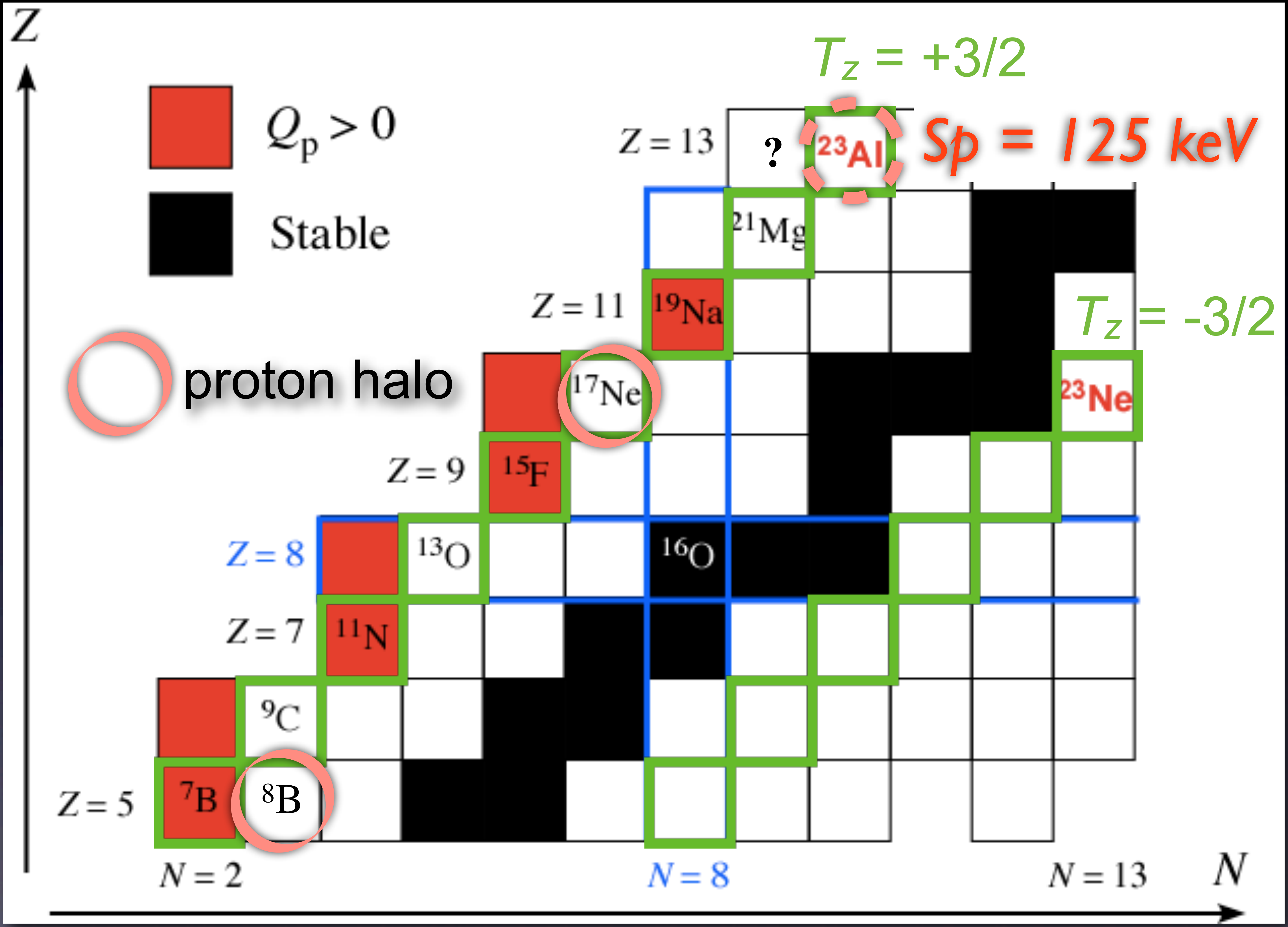
N = 8
N = 13
N

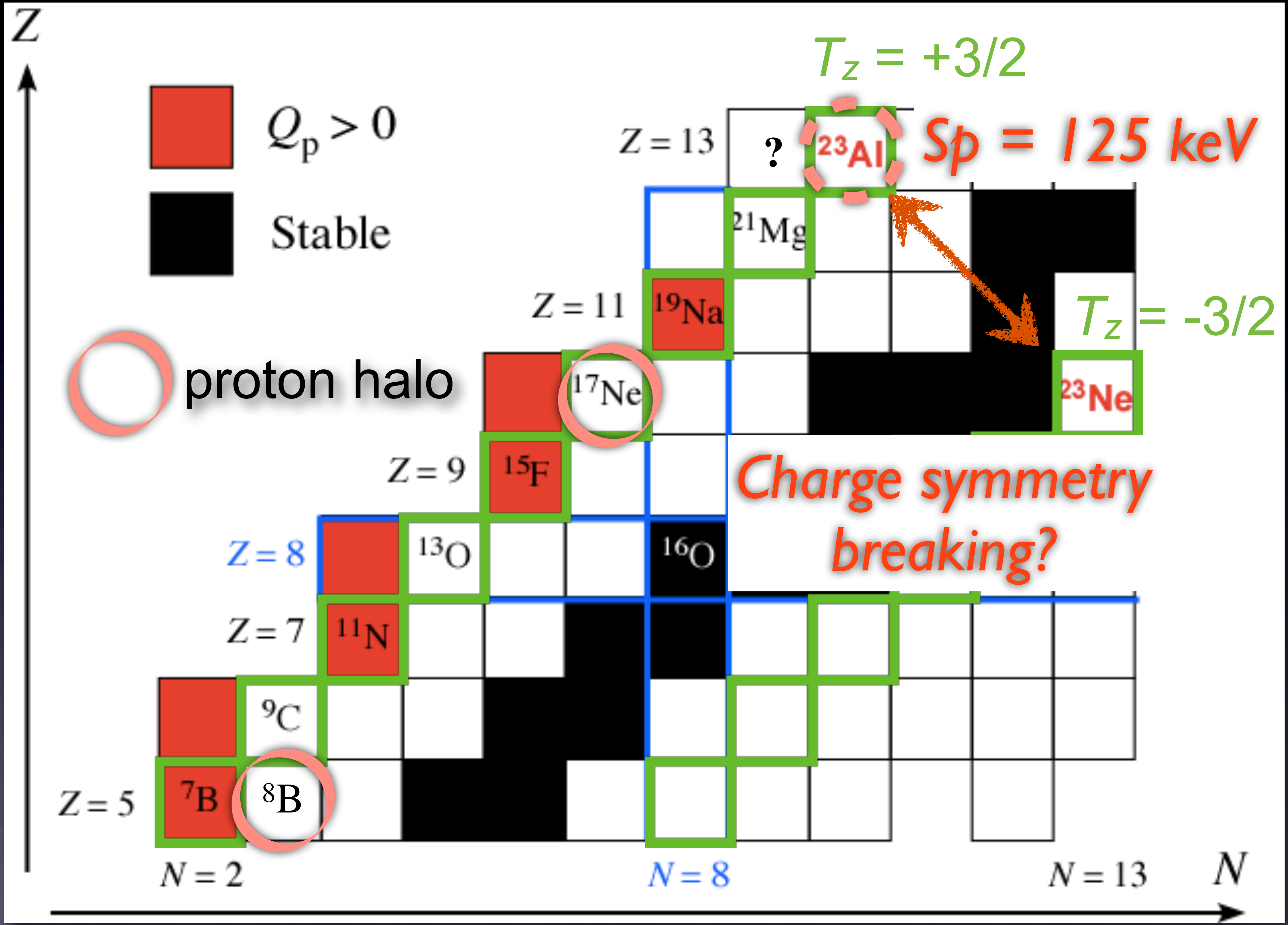


$T_z = +3/2$

S_p = 125 keV

proton halo


Z
Q_p > 0
Stable
proton halo
Z = 13
?
23Al
Sp = 125 keV
Tz = +3/2
21Mg
Z = 11
19Na
Tz = -3/2
17Ne
23Ne
Z = 9
15F
Z = 8
13O
16O
Z = 7
11N
9C
Z = 5
7B
8B
N = 2
N = 8
N = 13
N



$T_z = +3/2$

S_p = 125 keV

$T_z = -3/2$

proton halo

Charge symmetry breaking?

Studies of ^{23}Al ($T_{1/2}$ = 470 ms)

- Extremely small proton-separation energy

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- β decay and μ-moment

β decay : K. Peräjärvi et.al, Phys. Lett. B65, 1, (2000)
***μ*-moment : A. Ozawa et.al, Phys.Rev. C74, 021301(R) (2006)**

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→ $I^{\pi} = 5/2^{+}$

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→ $I^{\pi} = 5/2^{+}$

- Mirror nucleus ^{23}Ne (I^{π}=5/2^{+})

μ-moment : R. Matsumiya et al, OULNS Ann. Rep. 04, p.51 (2006)
Next to stability line : NO exotic structure

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→ Charge-symmetry braking ?

Q moment of ^{23}Al

Q-moment : $Q = \sqrt{16\pi/5} <r^2 Y_2>$

→ Charge deformation (shape)

direct information of ***Shape of Nucleus***

Anomalous Q should be seen

... if ^{23}Al has an exotic structure

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Q-moment : $Q = \sqrt{16\pi/5} \langle r^2 Y_2 \rangle$

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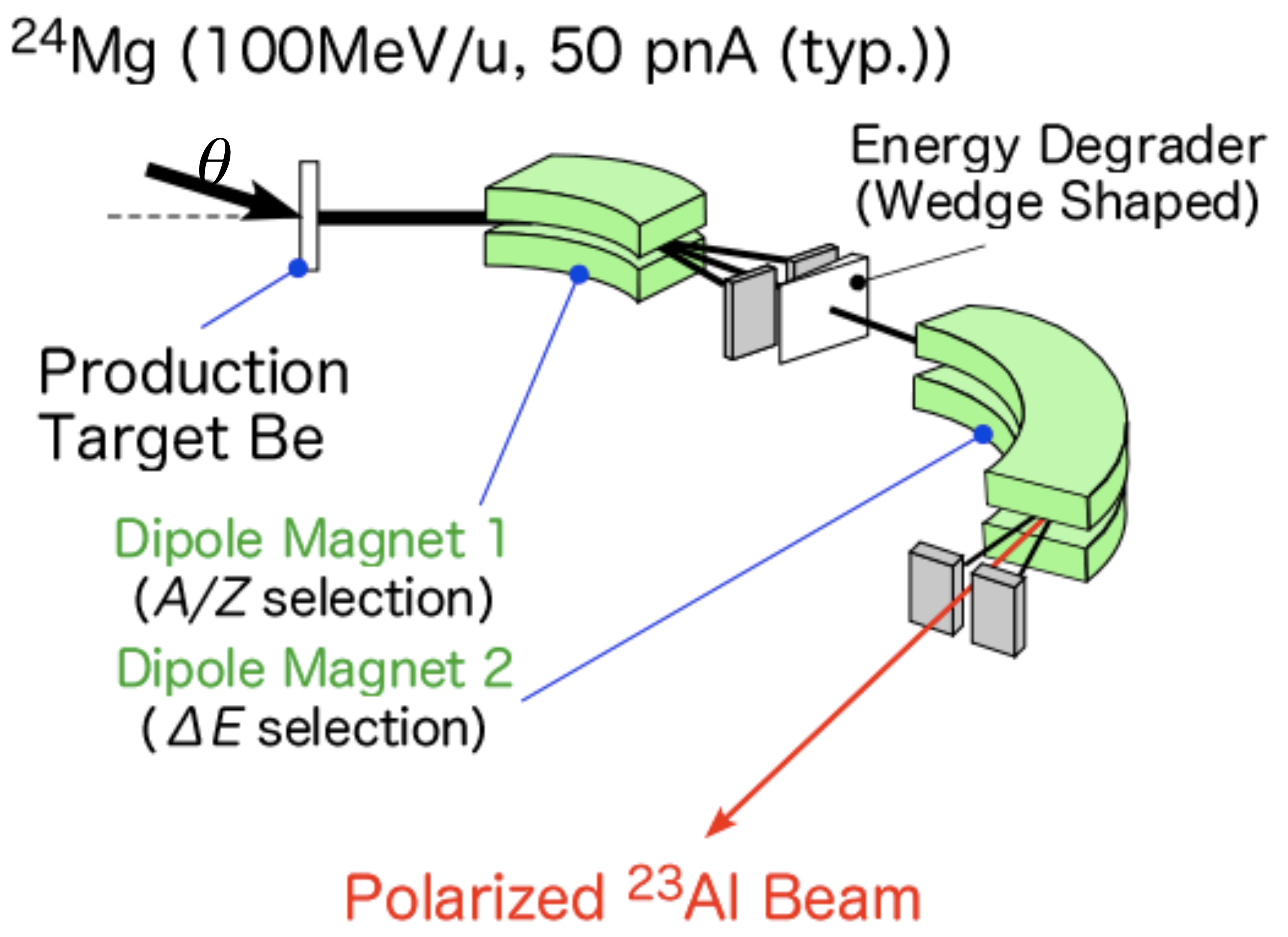
... if ^{23}Al has an exotic structure

β-NQR measurement on ^{23}Al in α-Al_2O_3
at RIBF of RIKEN Nishina Center

Production of Polarized ^{23}Al

Fragment Separator "RIPS"
at RIKEN



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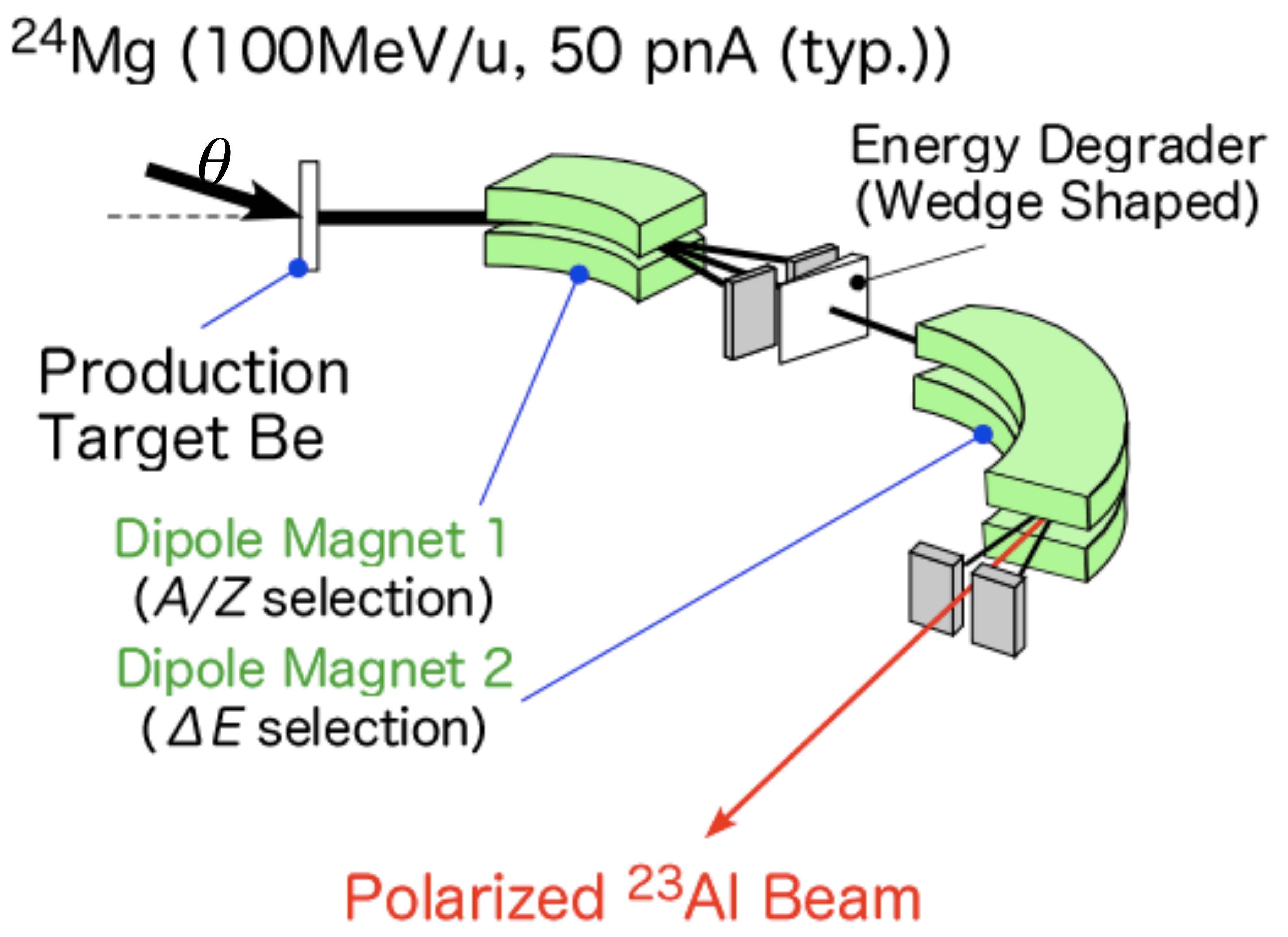

To polarize ^{23}Al ...

Production of Polarized ^{23}Al

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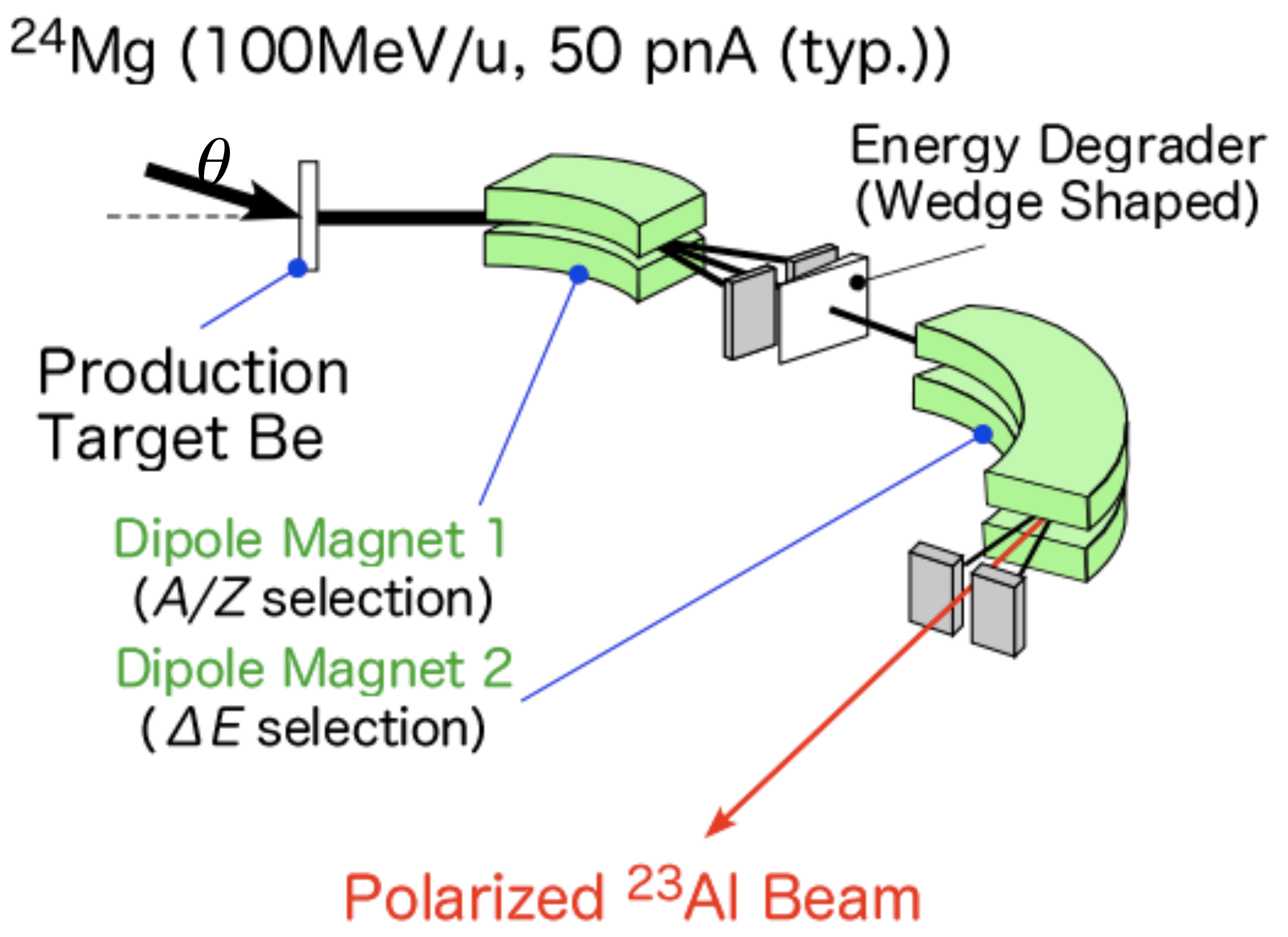

To polarize ^{23}Al ...

$\theta = (3.0 \pm 2.6)^\circ$

Production of Polarized ^{23}Al

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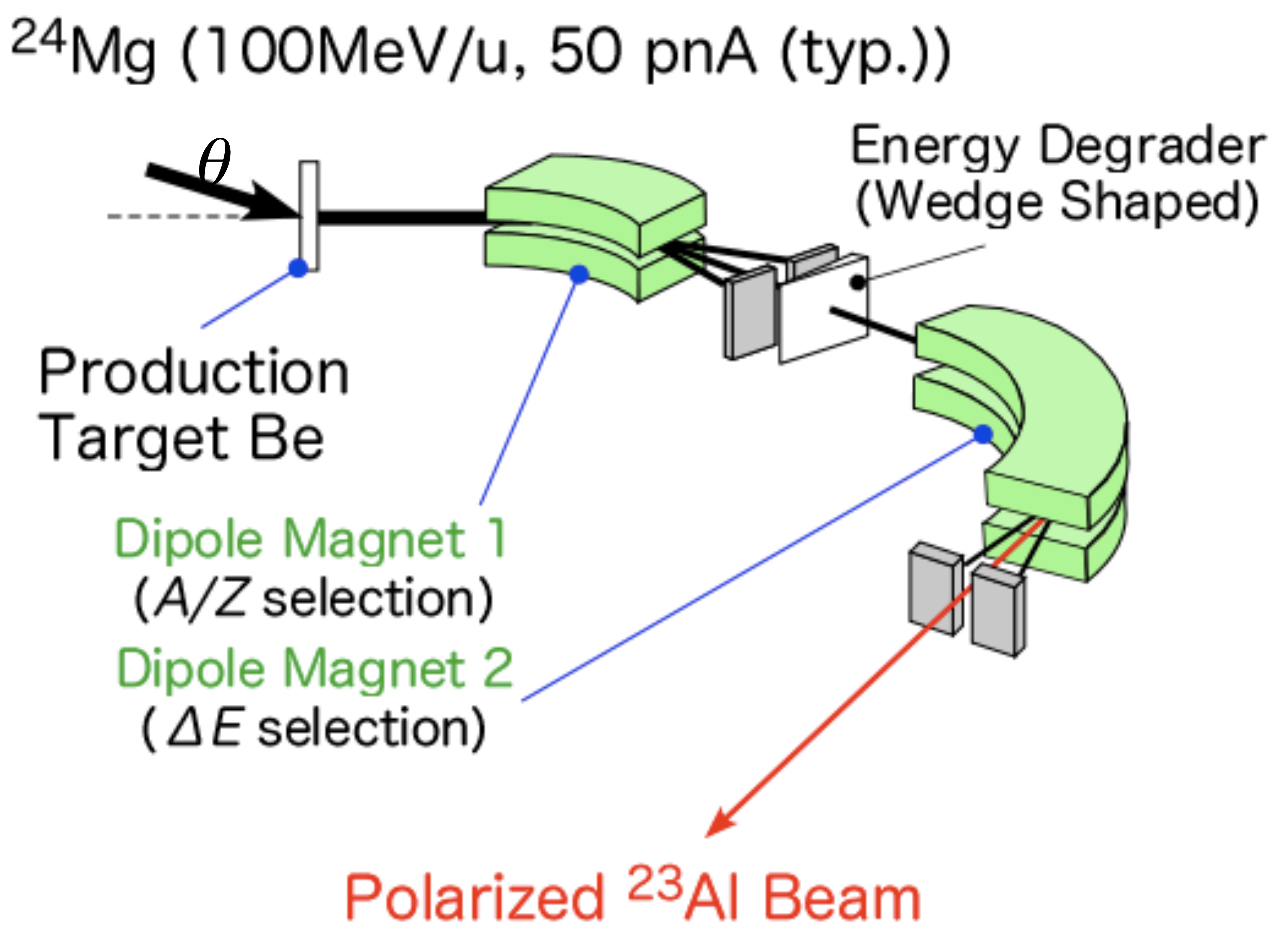

To polarize ^{23}Al ...

$\theta = (3.0 \pm 2.6)^\circ$

$\Delta p/p_0 =$
$-(2.05 \pm 1.75)\%$

(p_0 ← beam velocity)

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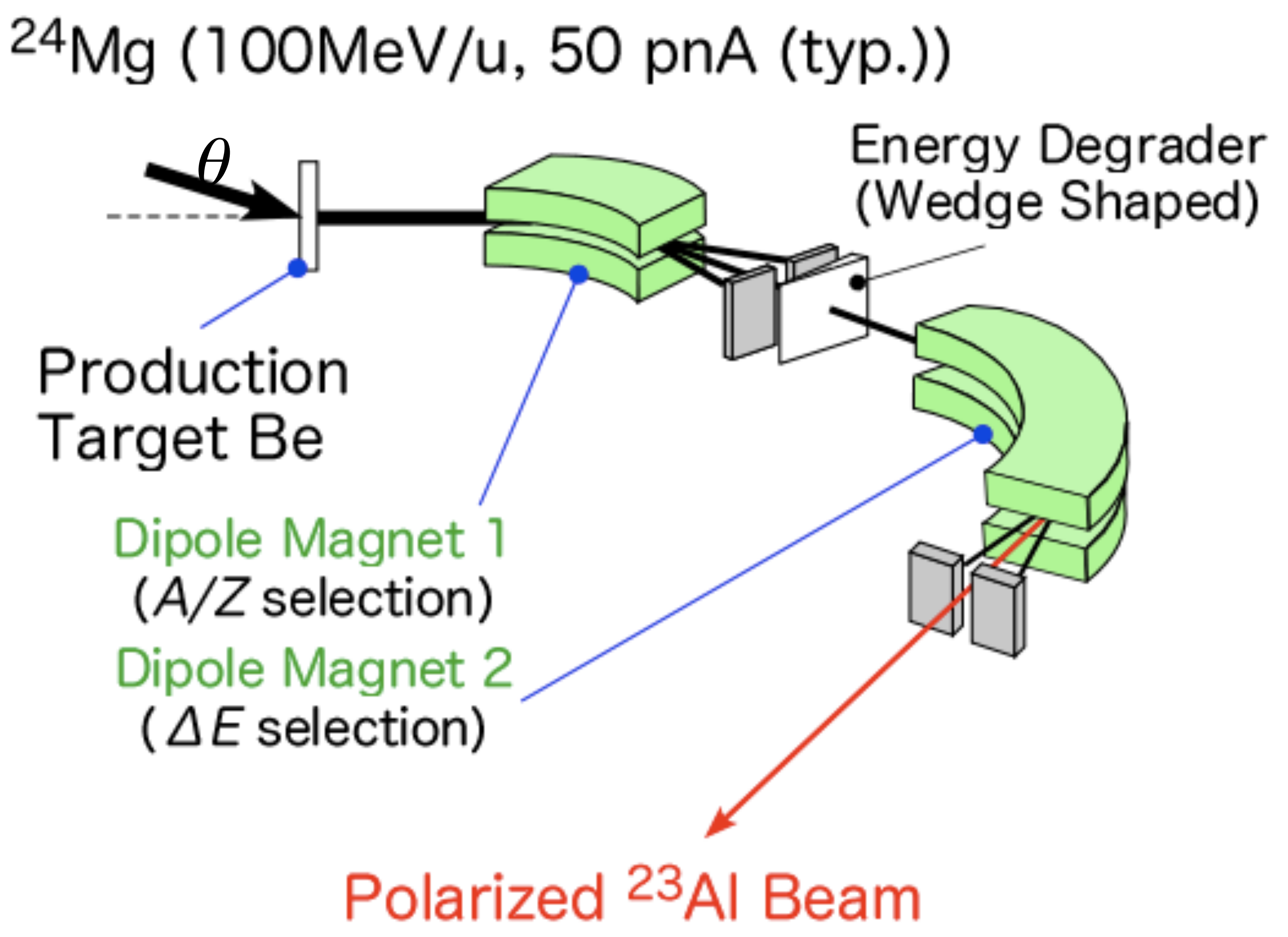

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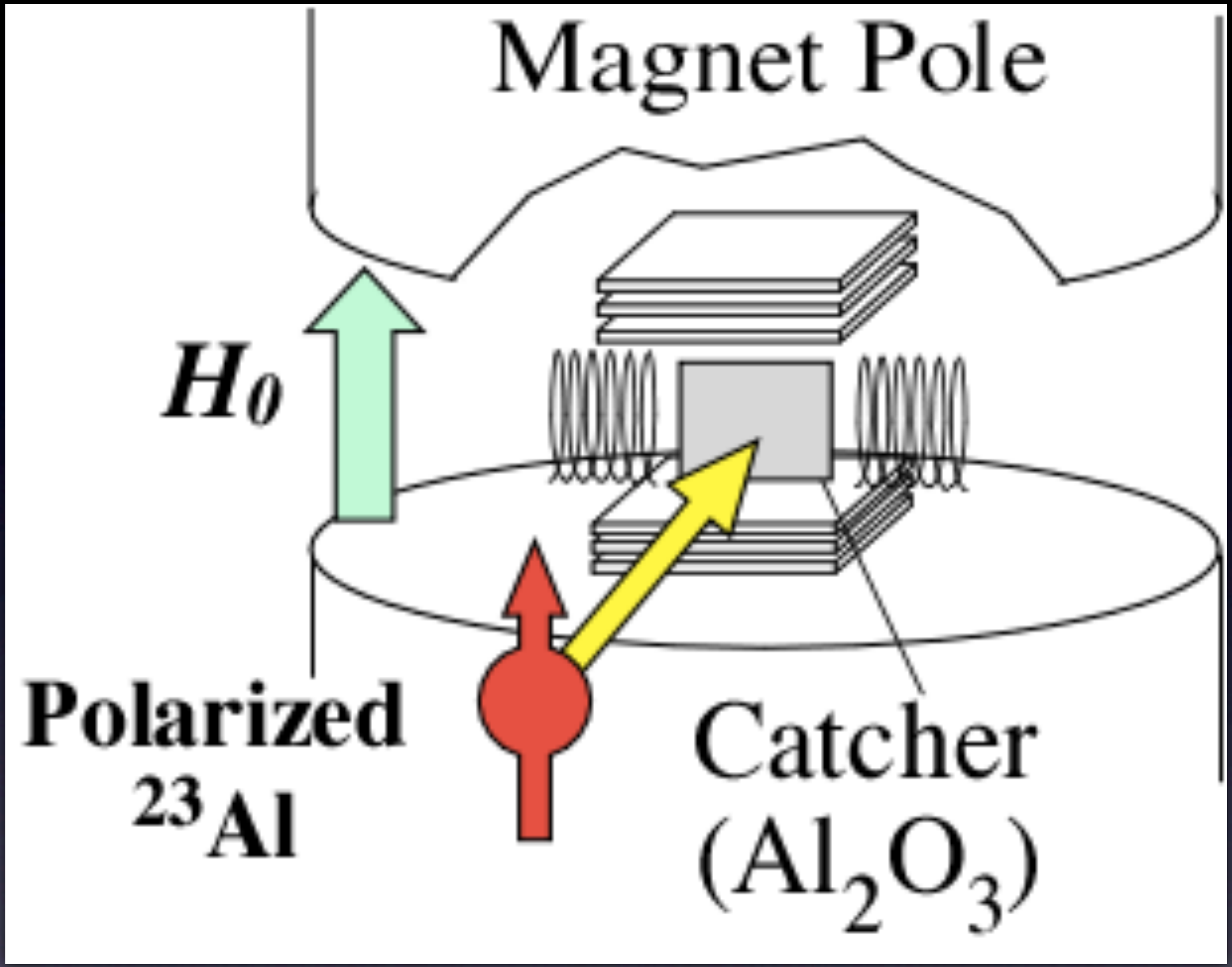
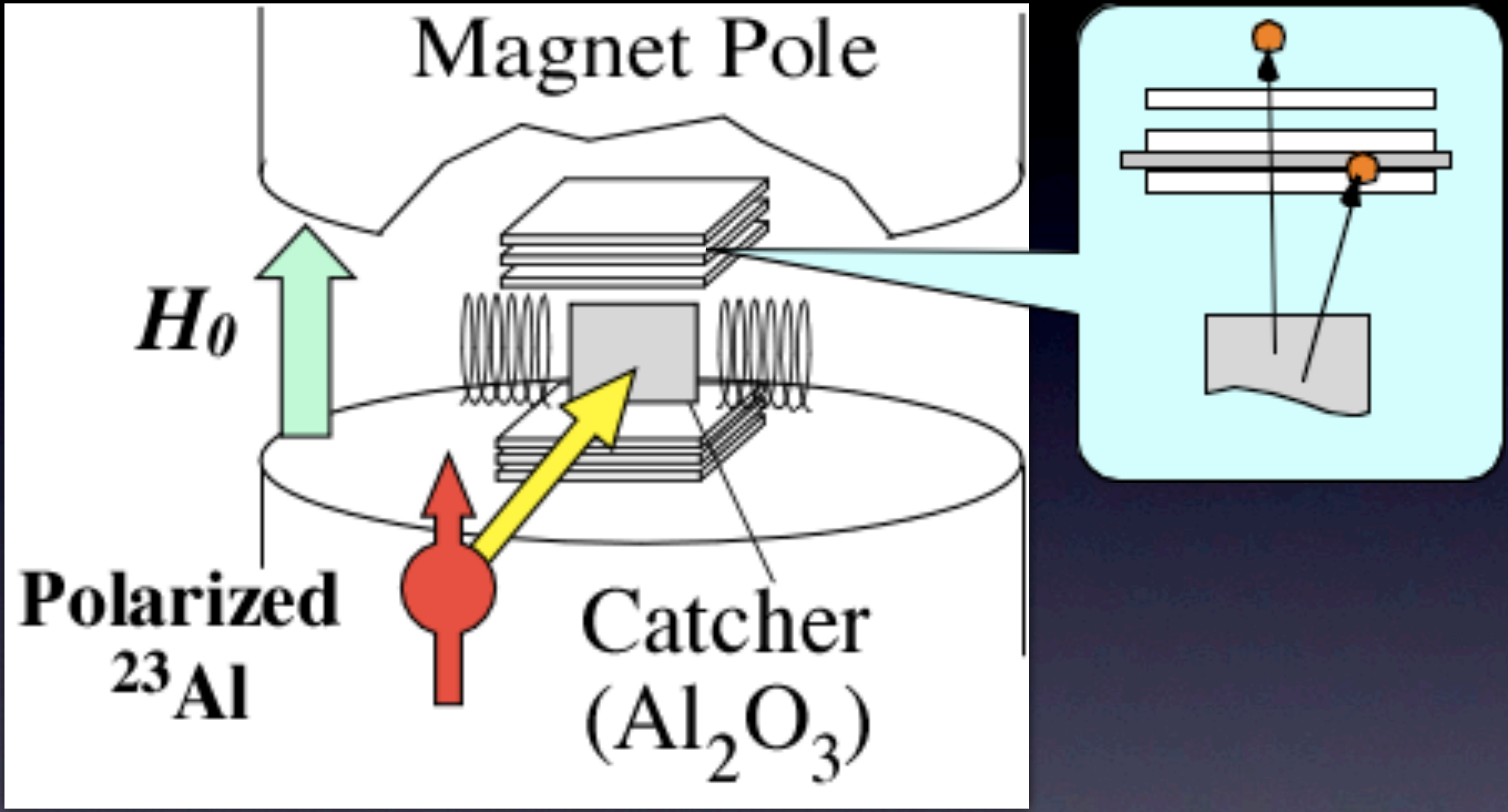
Polarization ~ 1%

β-NMR/NQR Setups



H_0 = 0.4575(4)T
H_1 ~ 0.8 mT

β-NMR/NQR Setups

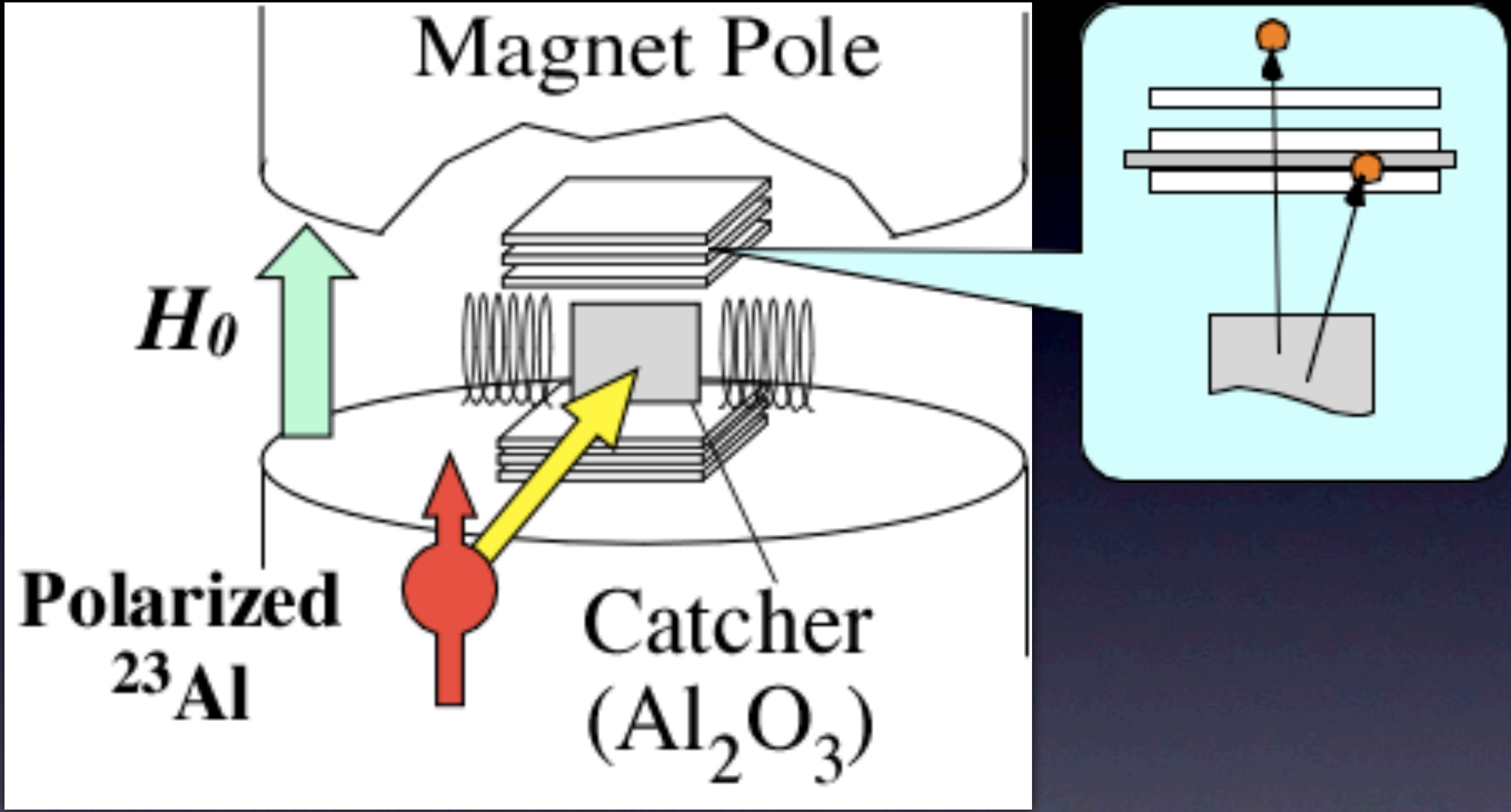


Al(2mmt)

H_0 = 0.4575(4)T
H_1 ~ 0.8 mT

β-NMR/NQR Setups

β^+ from ^{23}Al
(E_{max} =12 MeV)



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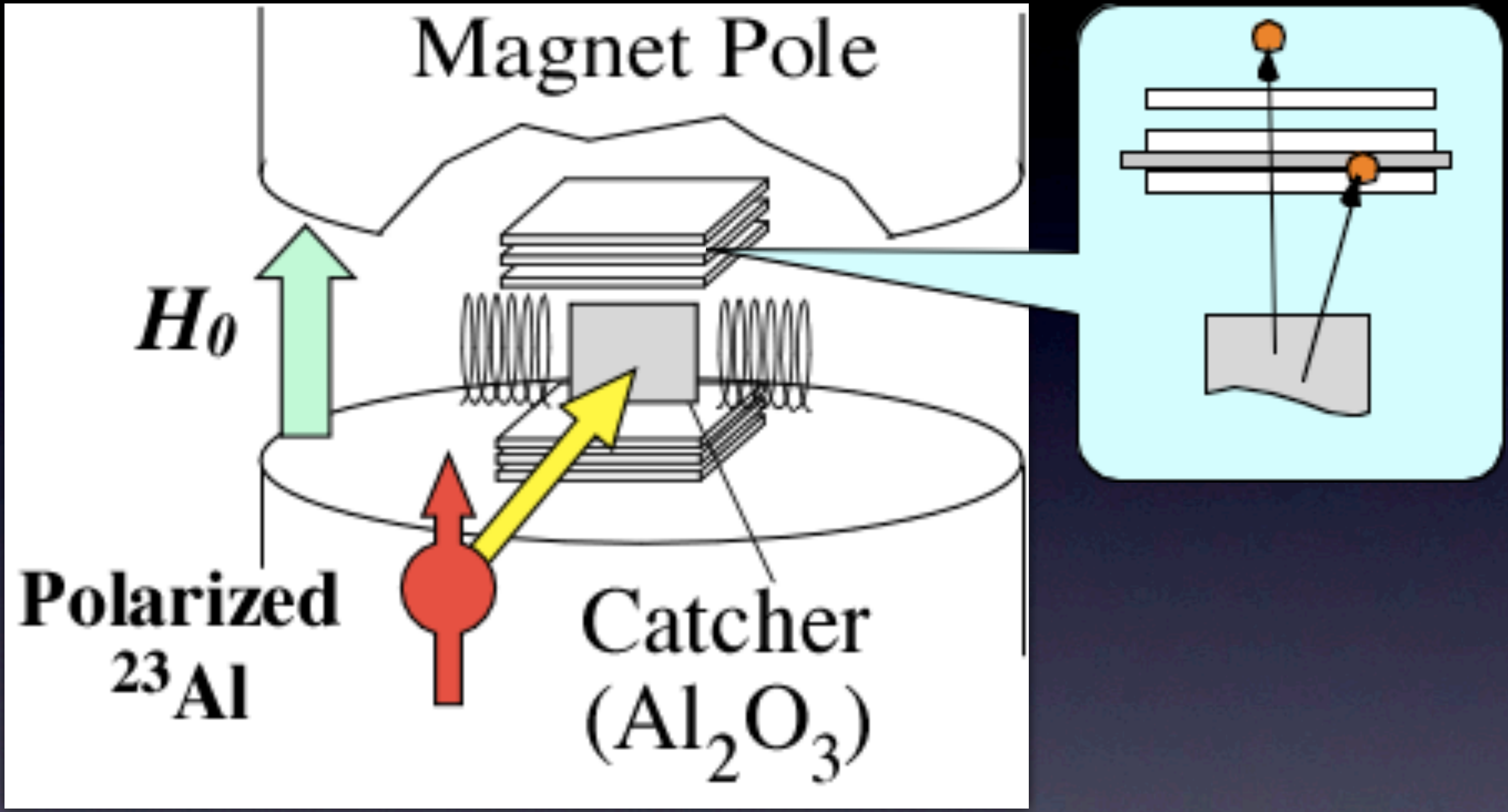


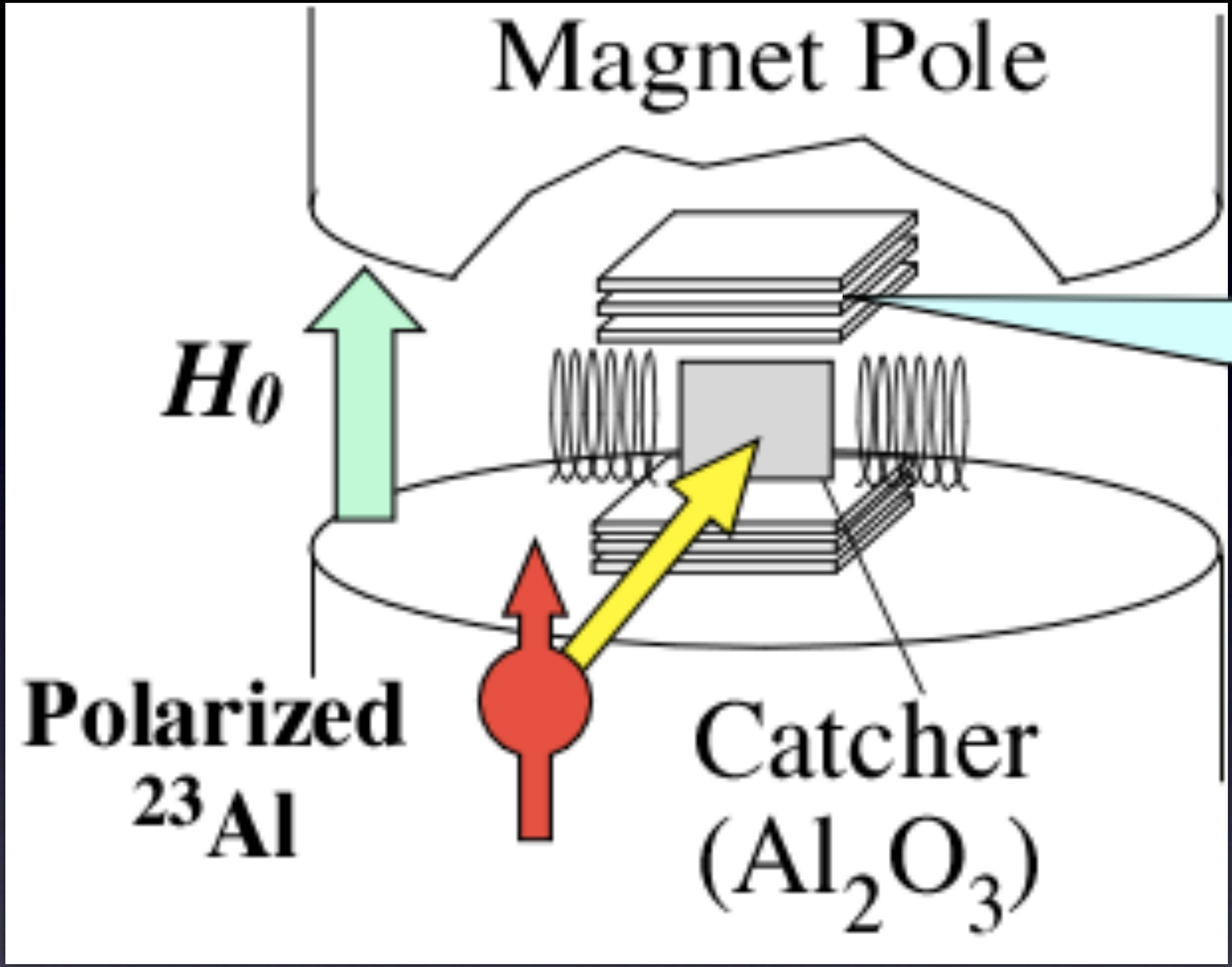
β^+ from ^{23}Al
(E_{max} =12 MeV)

Al(2mmt)

β^+ from
^{22}Mg, ^{21}Na
(E_{max}~4 MeV)

$H_0 = 0.4575(4)$T
$H_1 \sim 0.8$ mT

β-NMR/NQR Setups



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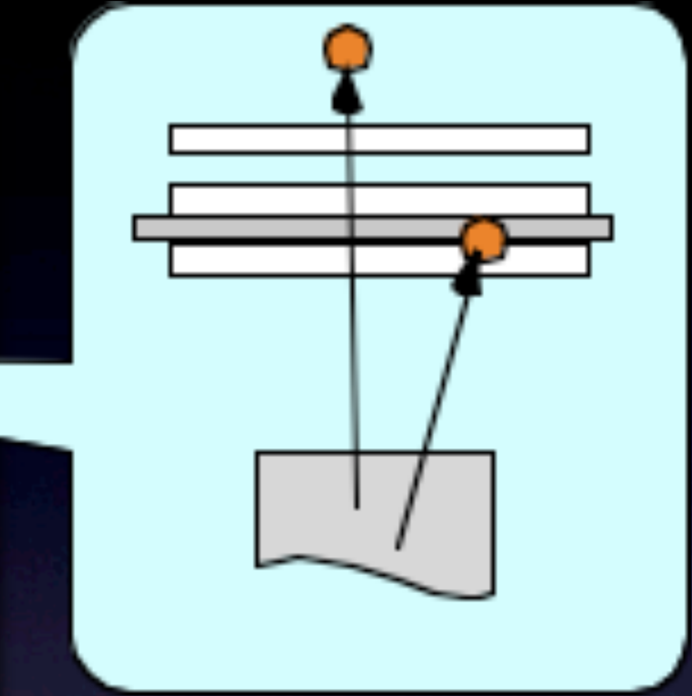
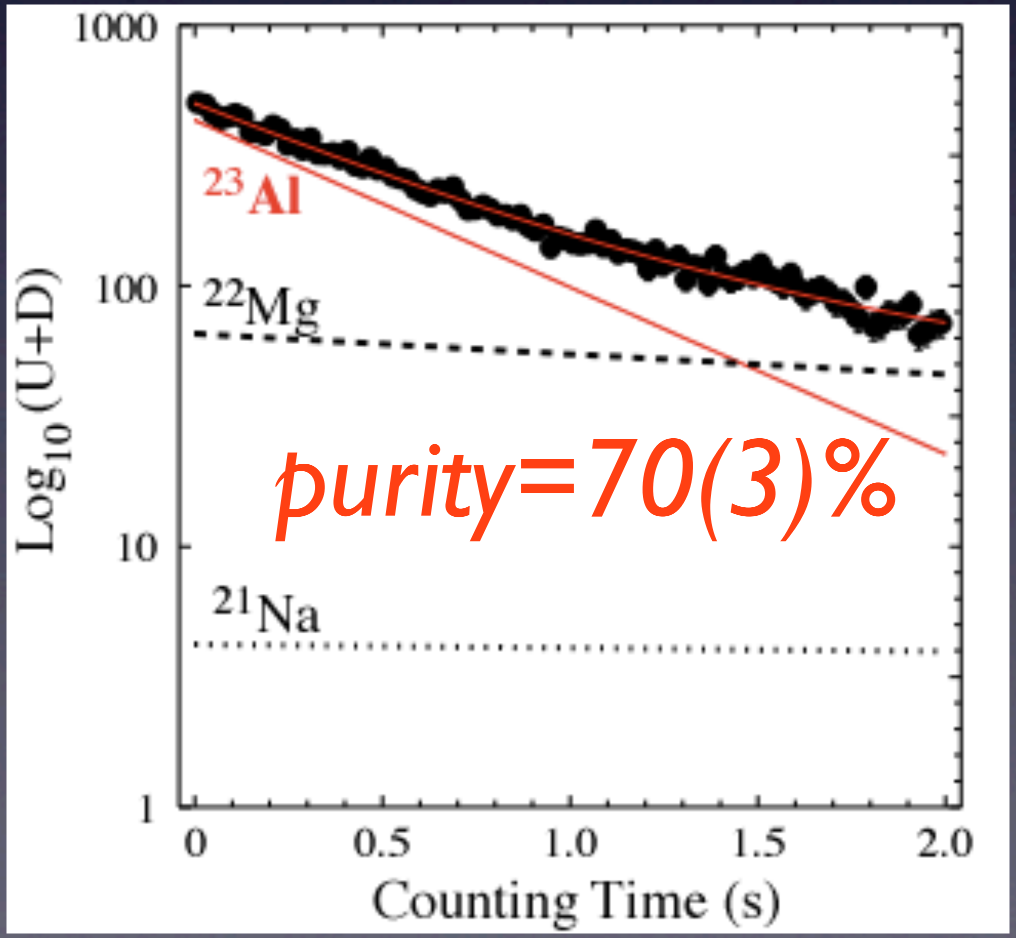


Al(2mmt)

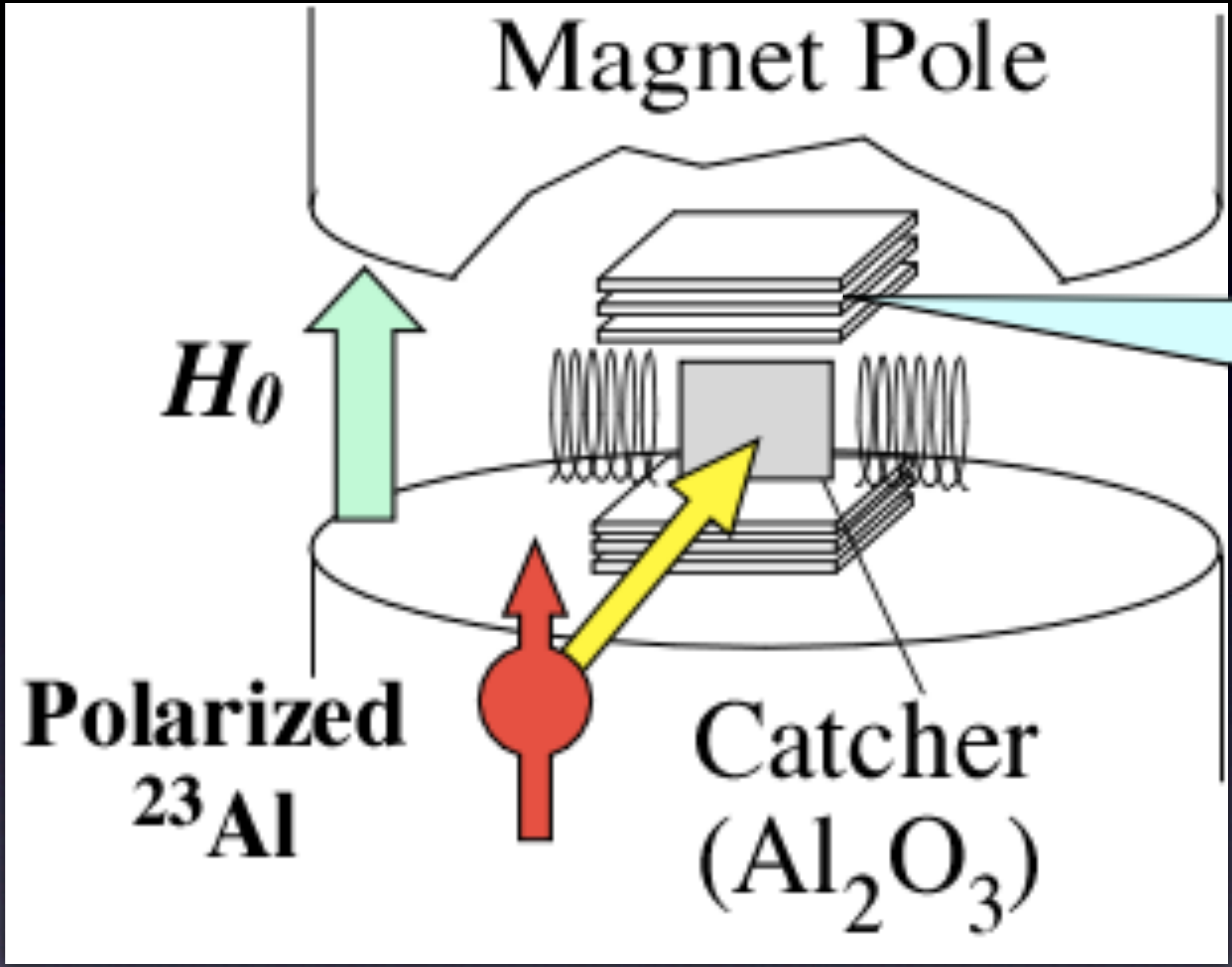
β^+ from ^{22}Mg, ^{21}Na
(E_{max}~4 MeV)

H_0 = 0.4575(4)T
H_1 ~ 0.8 mT

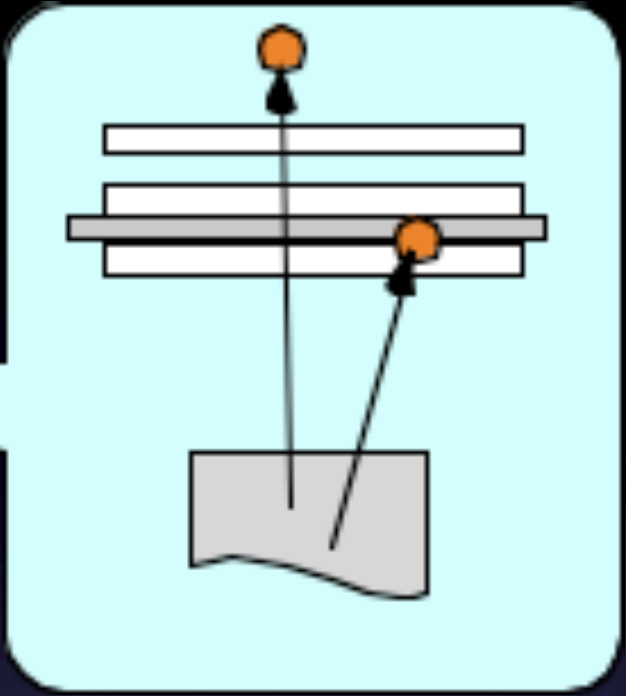


purity=70(3)%

β-NMR/NQR Setups



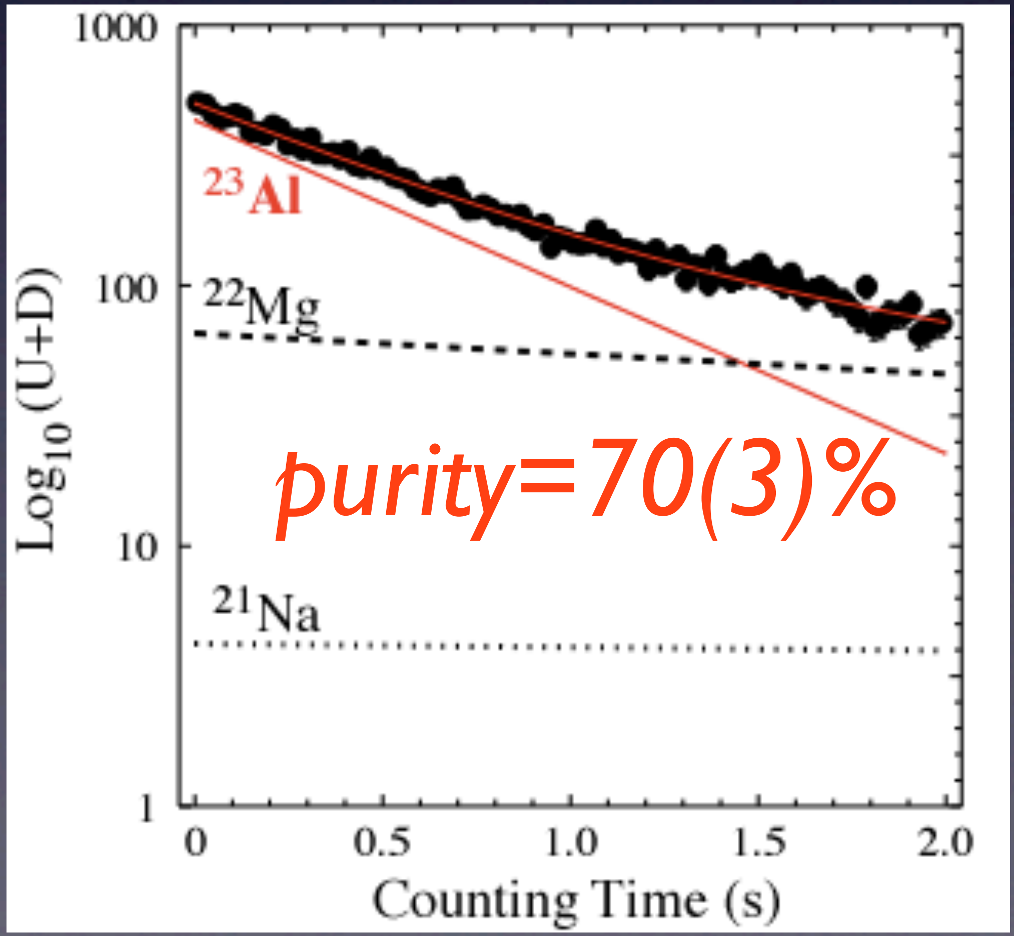
β^+ from ^{23}Al
(E_{max} =12 MeV)



Al(2mmt)

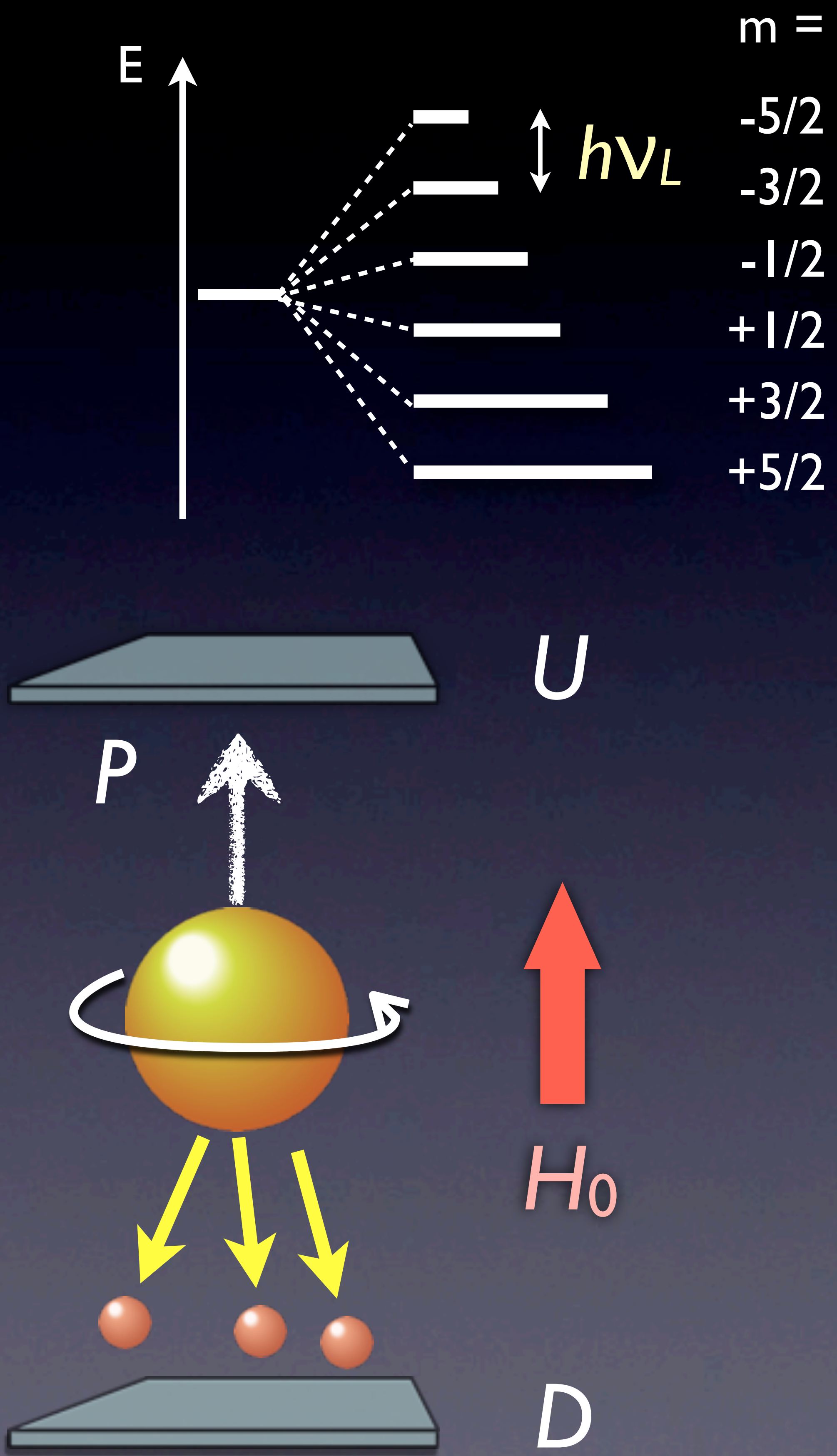
β^+ from
^{22}Mg, ^{21}Na
(E_{max}~4 MeV)

H_0 = 0.4575(4)T
H_1 ~ 0.8 mT
Y_β ~ 100 cps



purity=70(3)%

β-NMR Technique



E

m =

-5/2

-3/2

-1/2

+1/2

+3/2

+5/2

$h\nu_L$

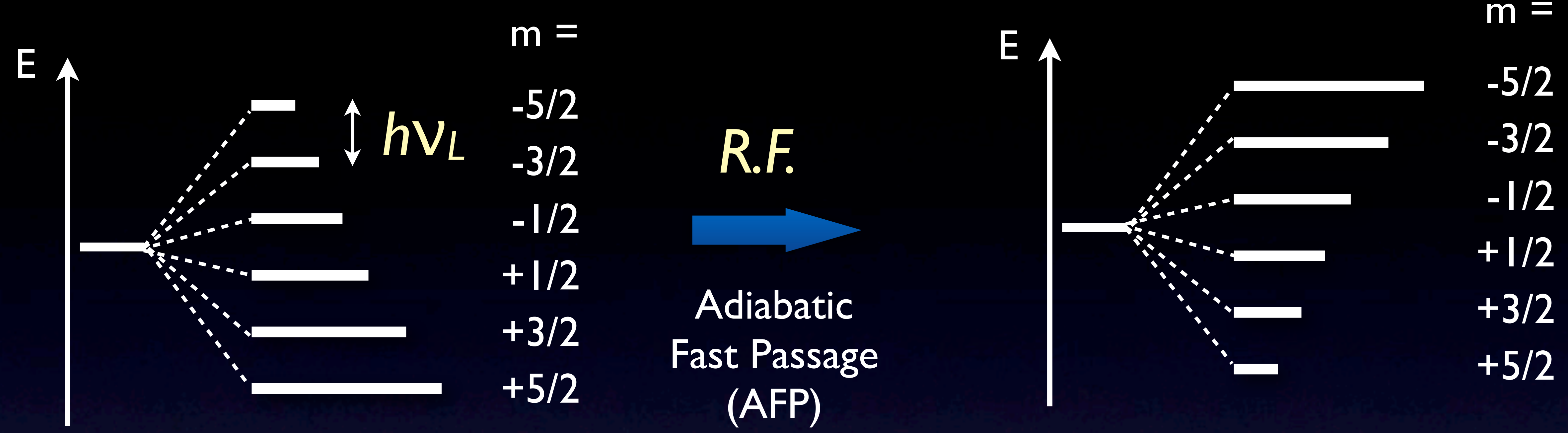
U

P

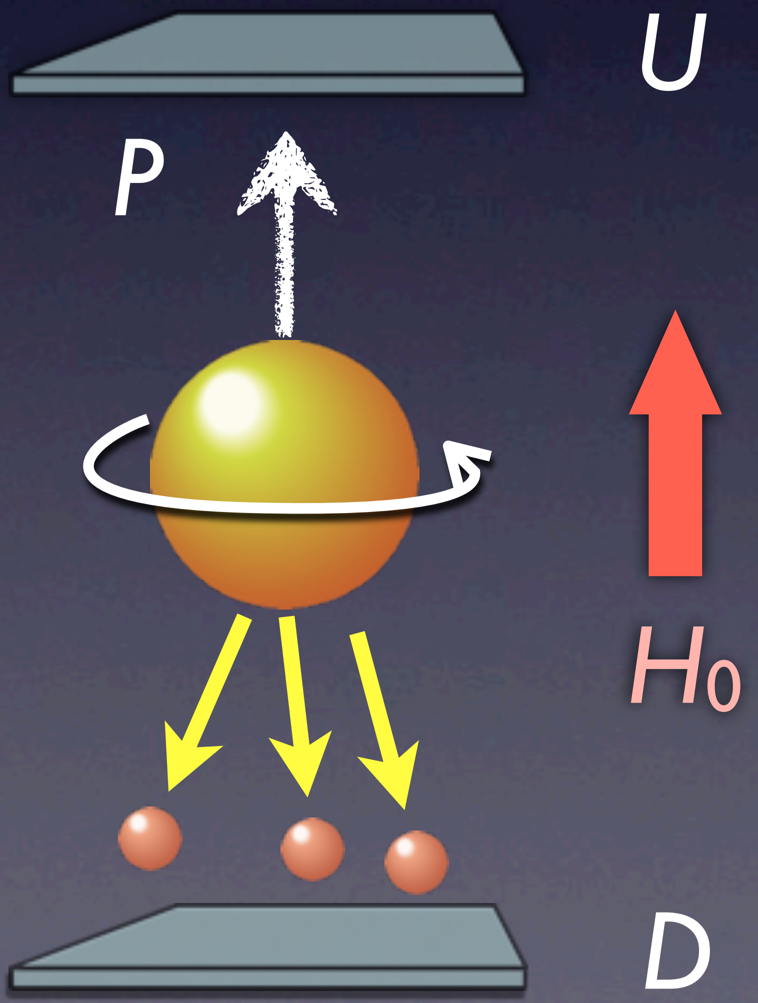
H_0

D

β-NMR Technique



Adiabatic
Fast Passage
(AFP)



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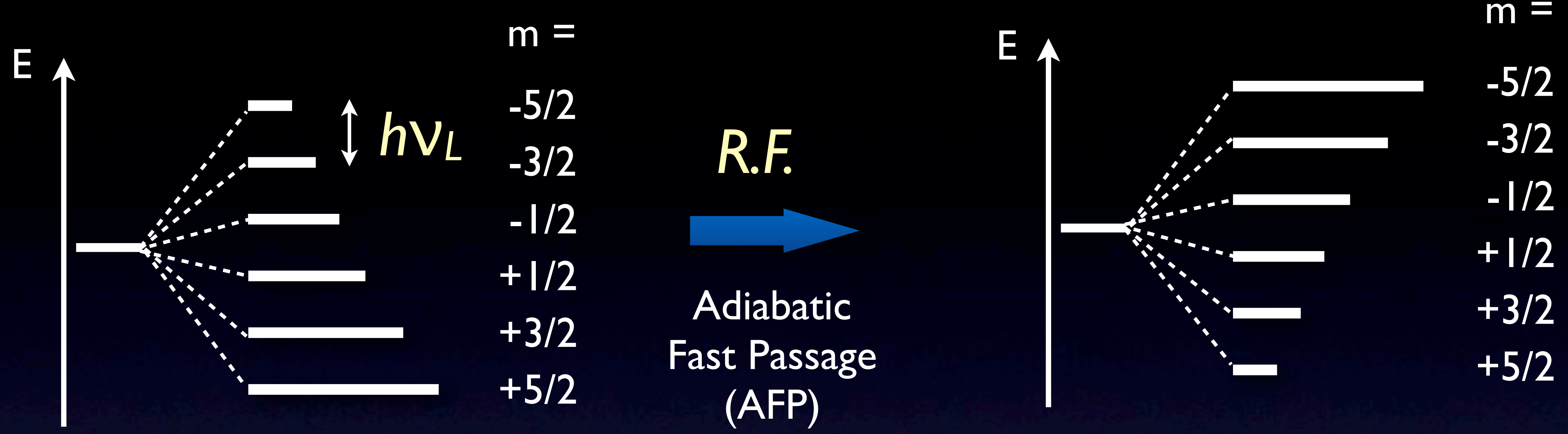

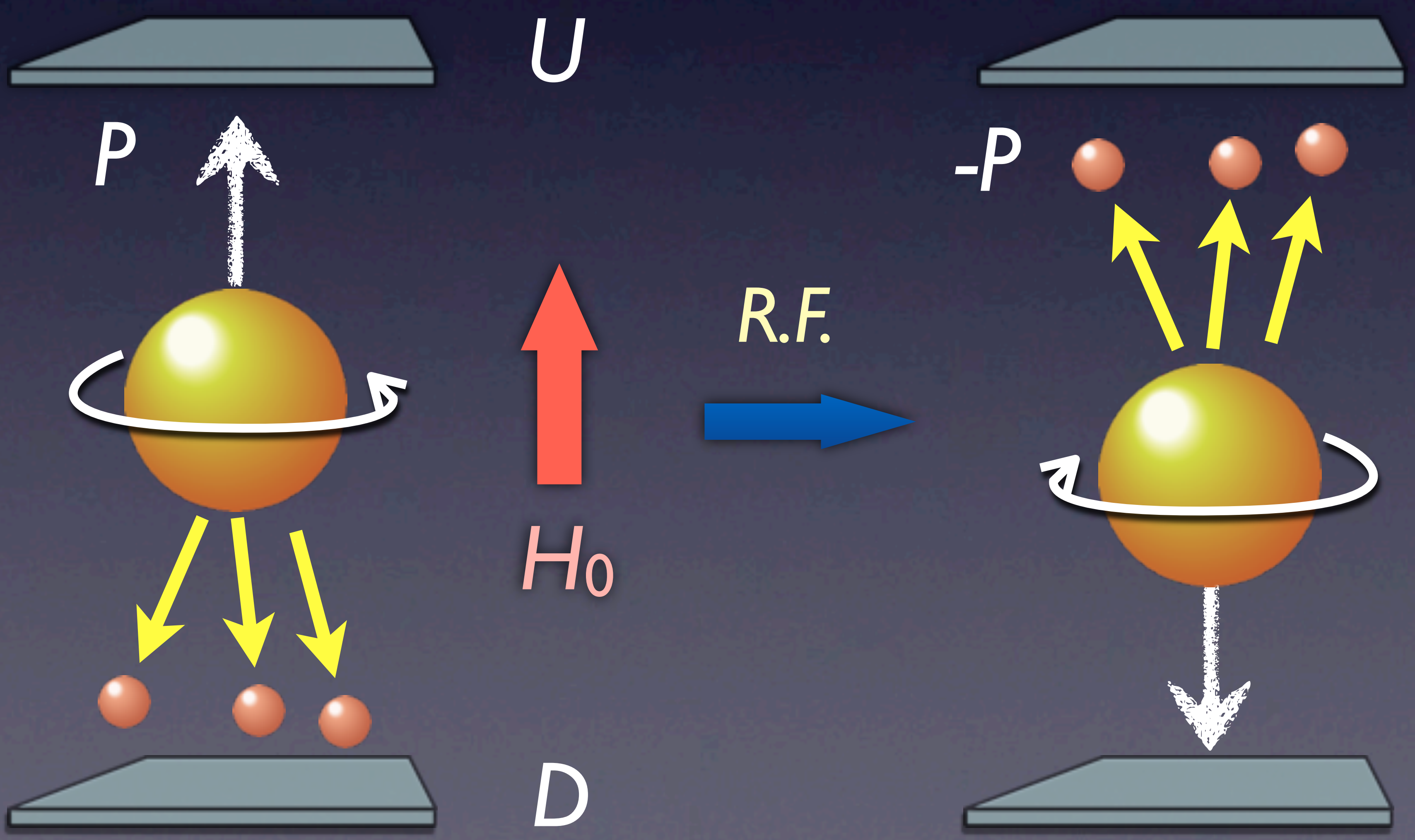

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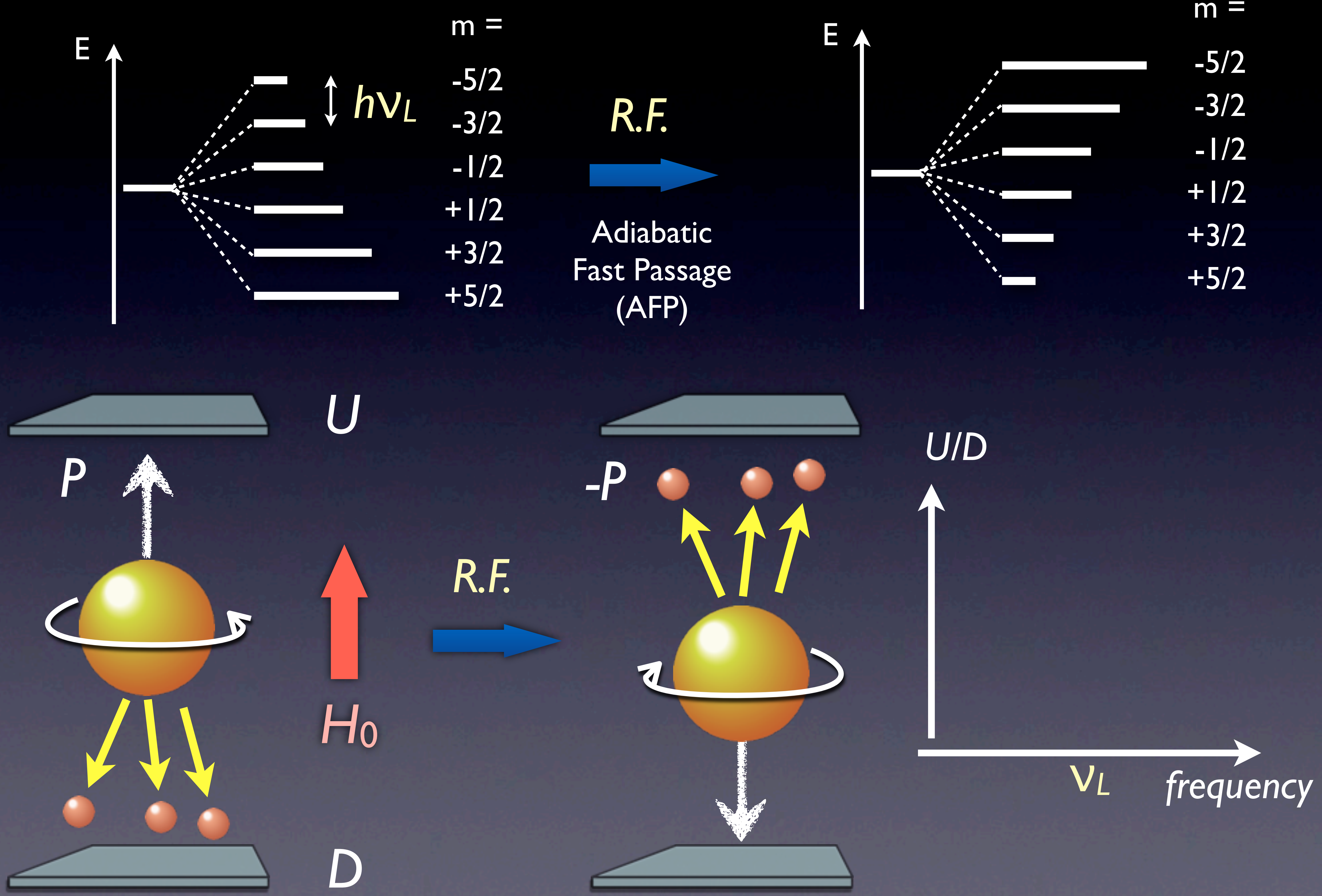

Adiabatic
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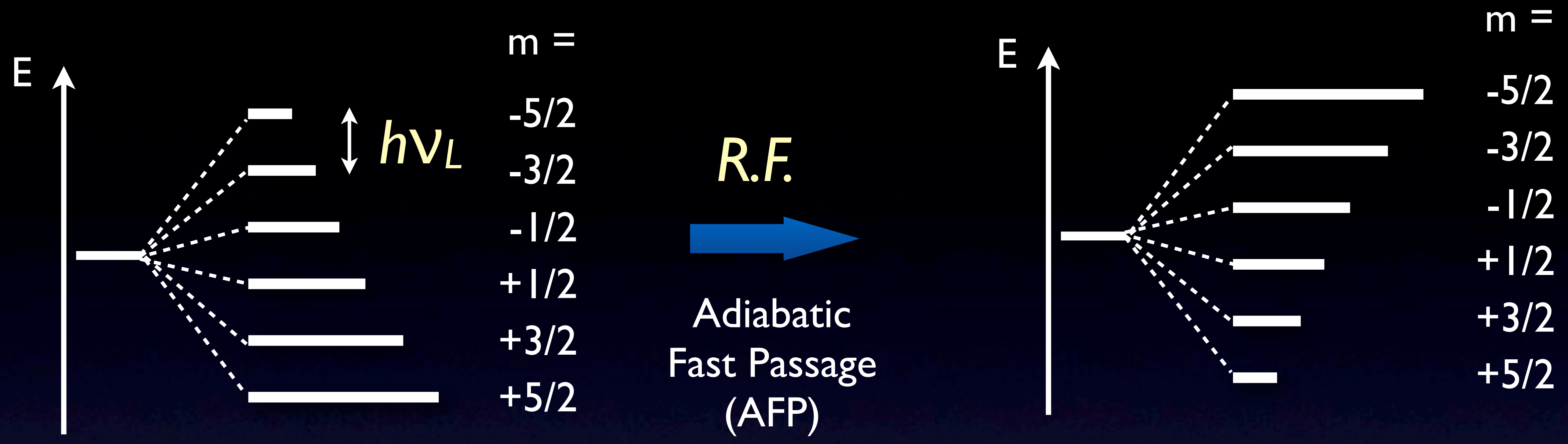
β-NMR Technique



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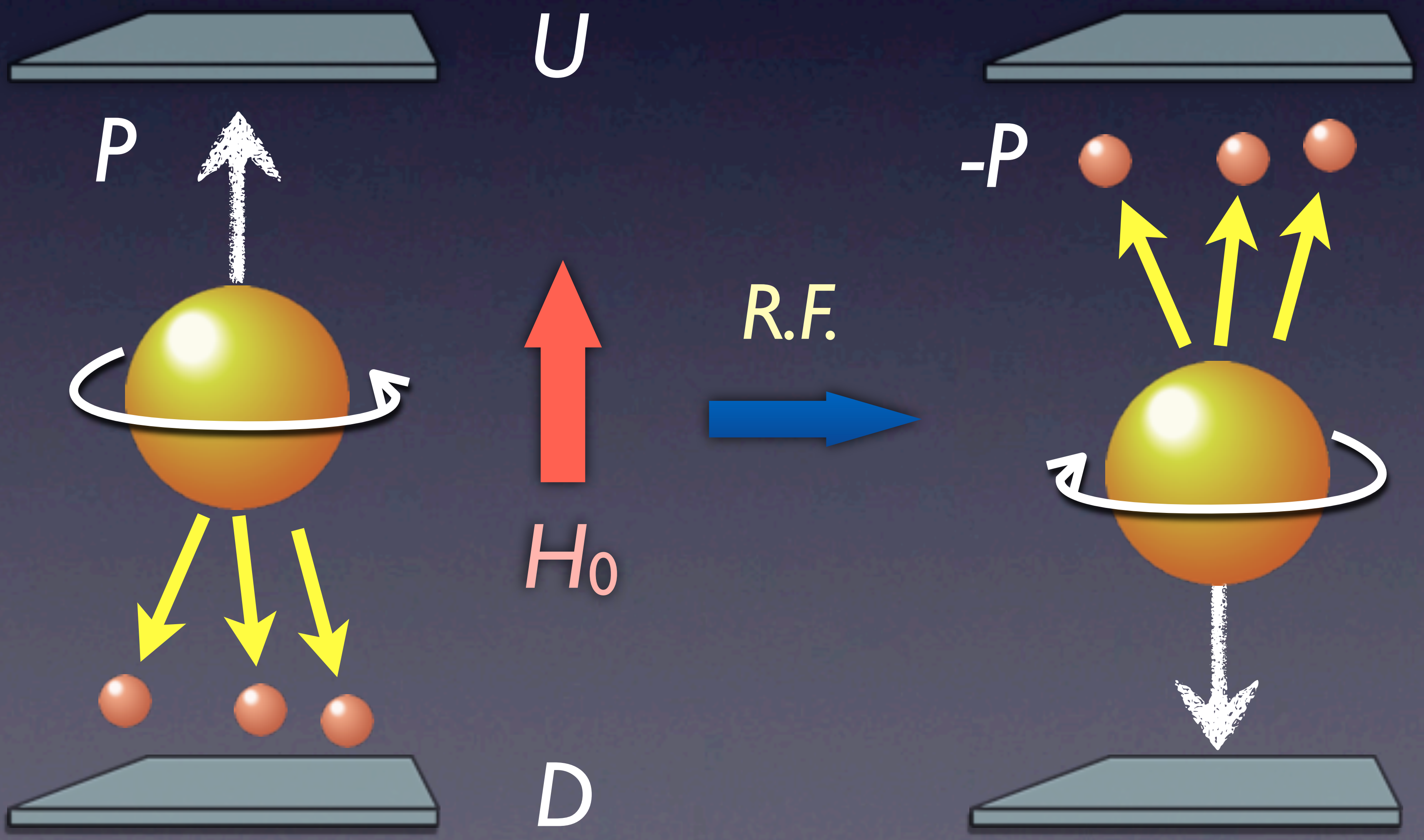

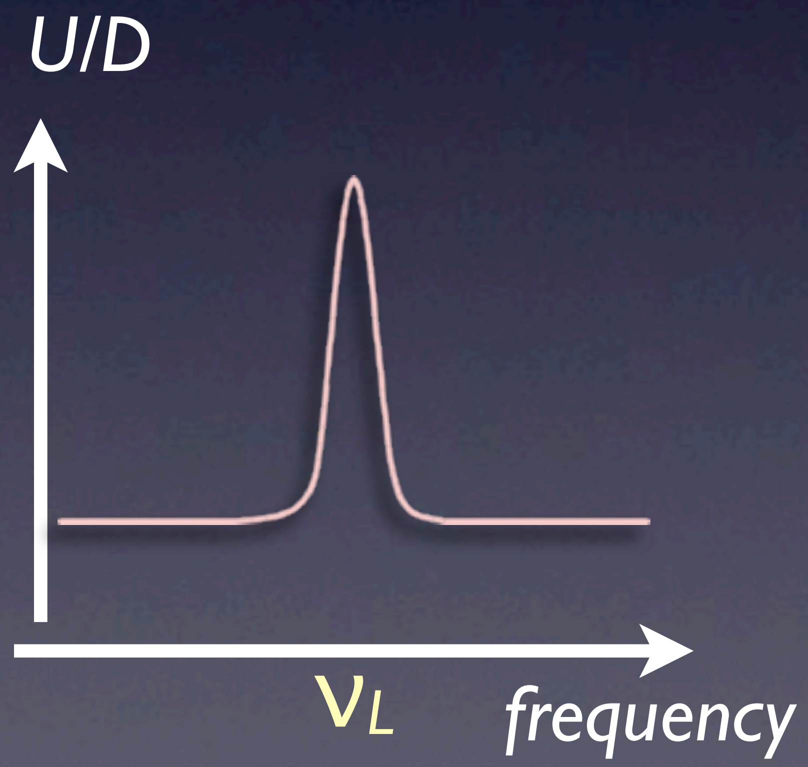

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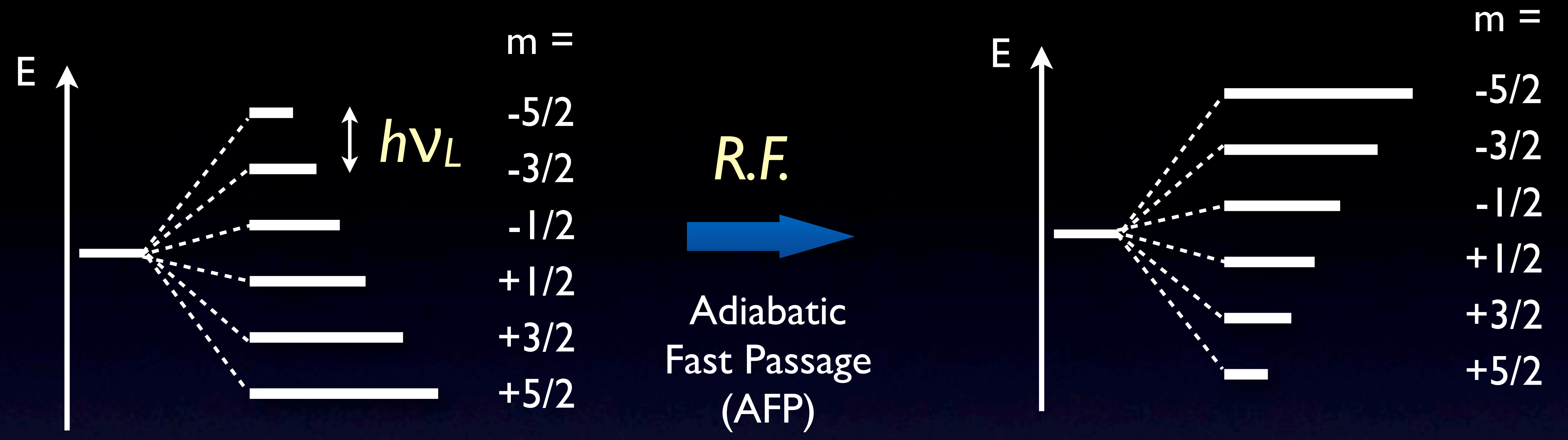
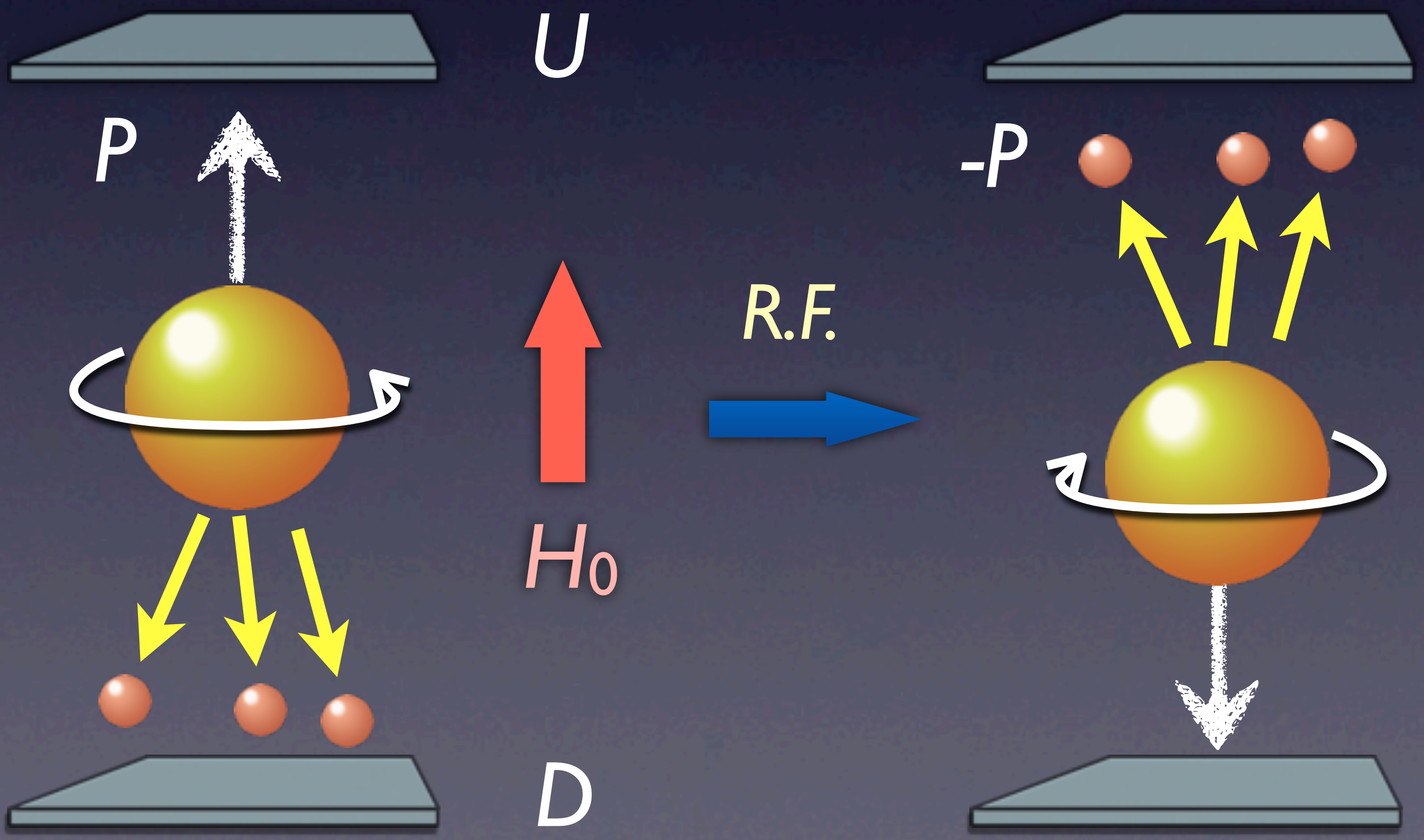
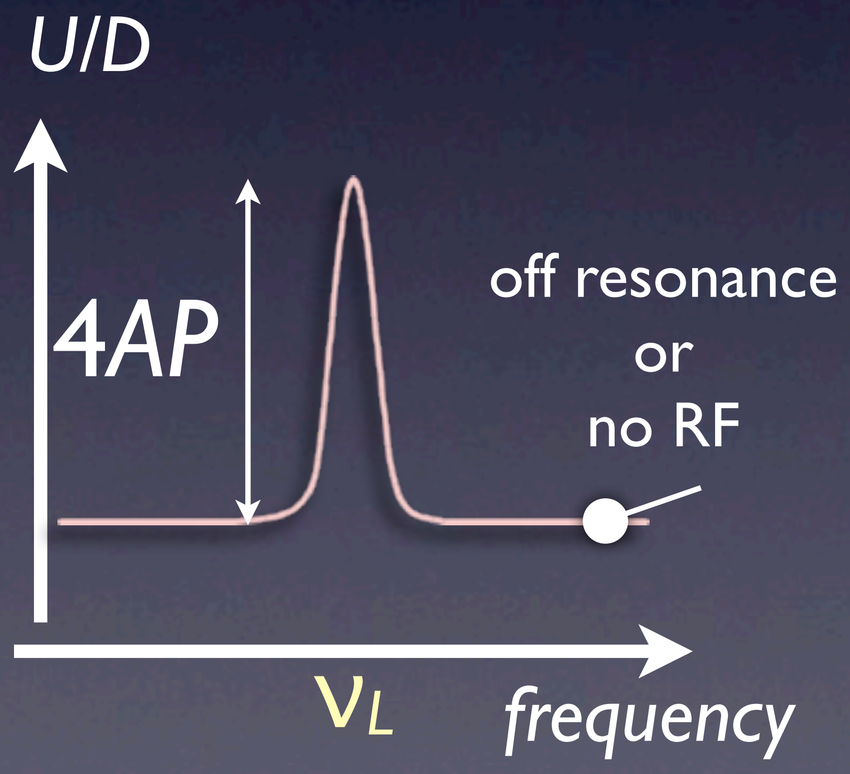
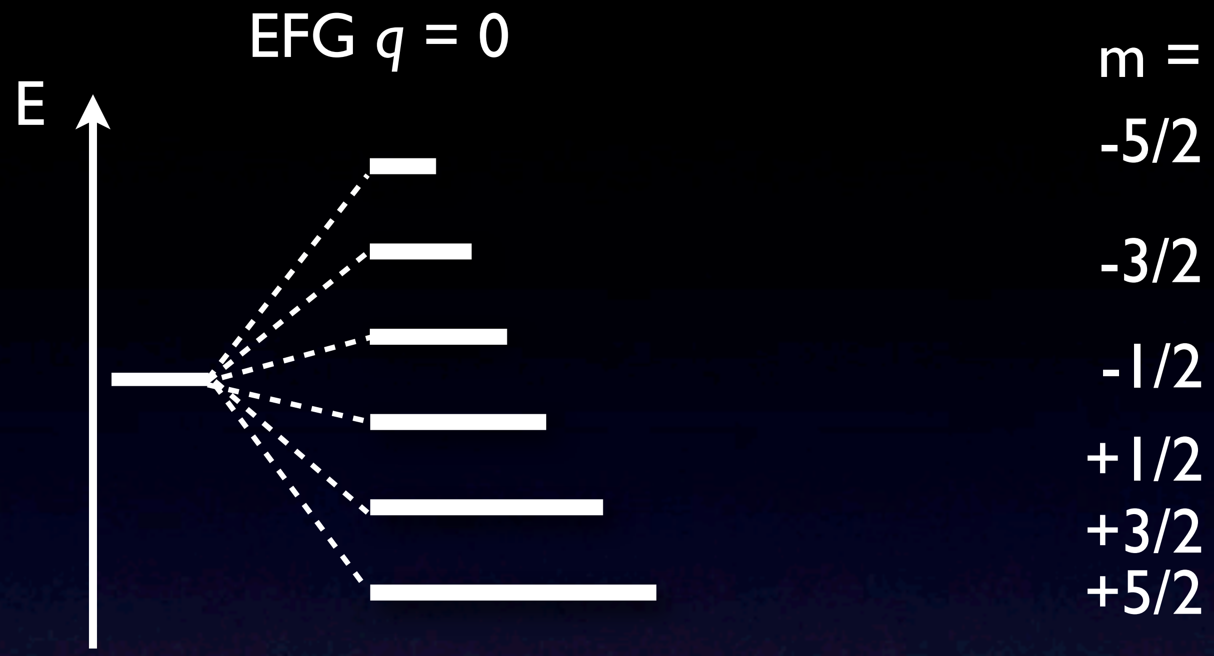






β-NQR Technique : Utilizing EFG *q*



EFG $q = 0$

E

m =

-5/2

-3/2

-1/2

+1/2

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+5/2

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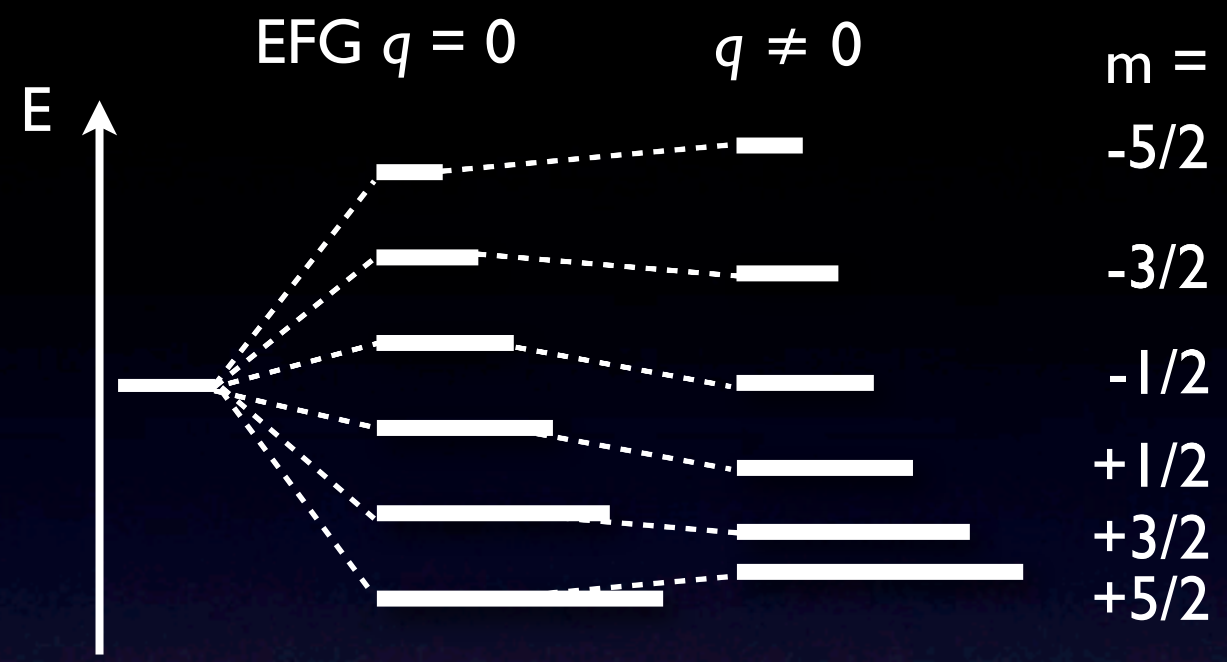

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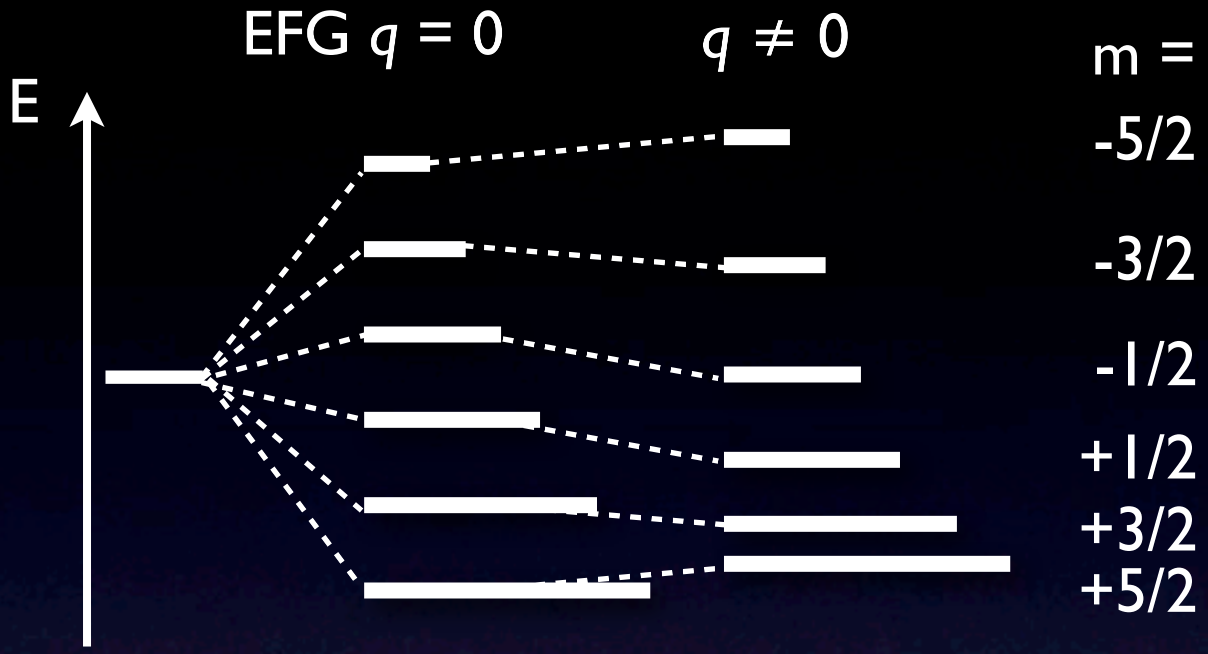

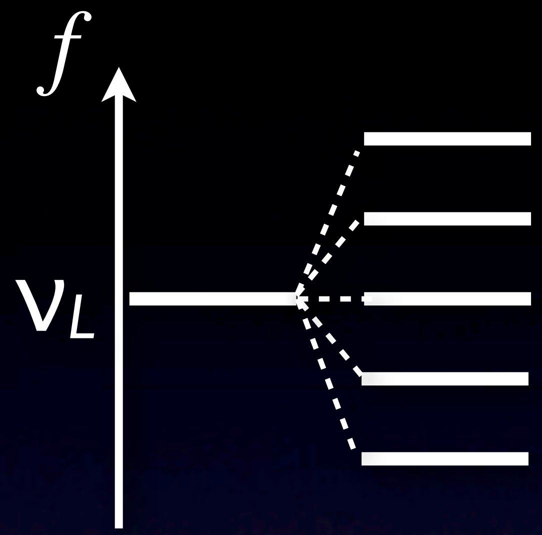

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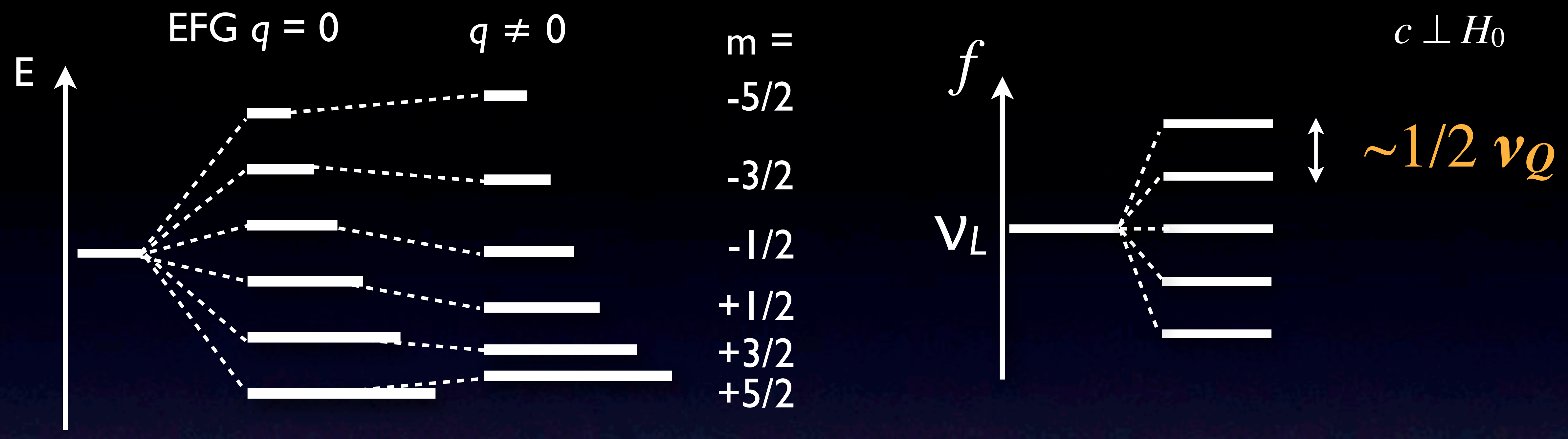

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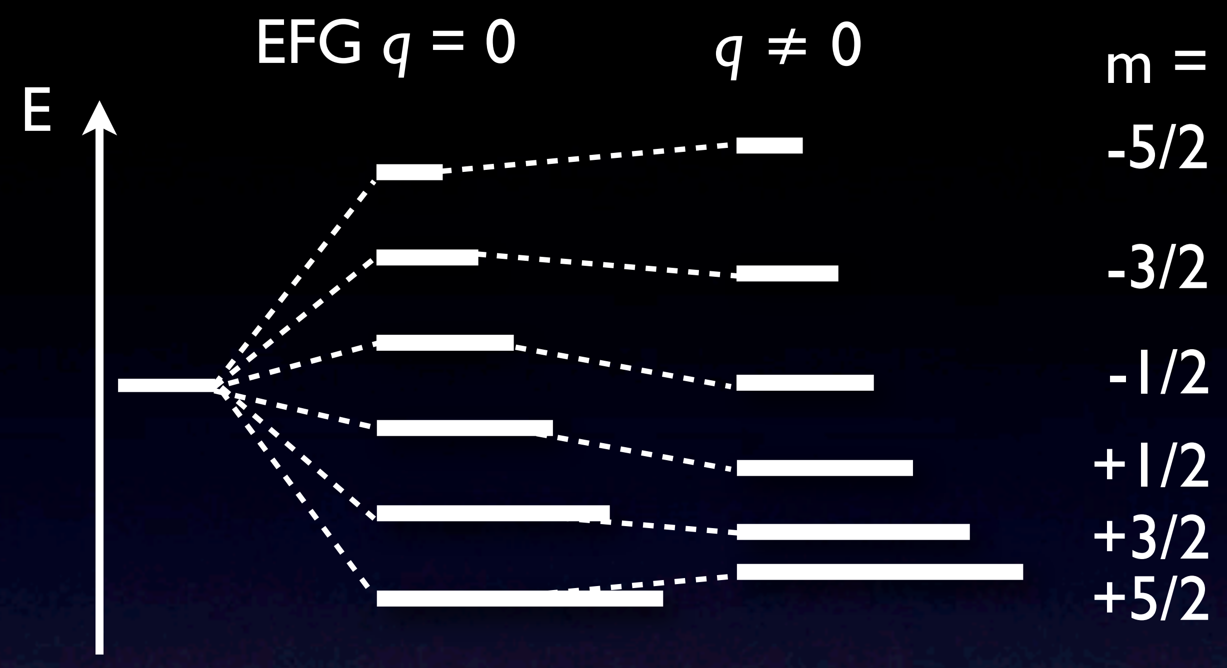
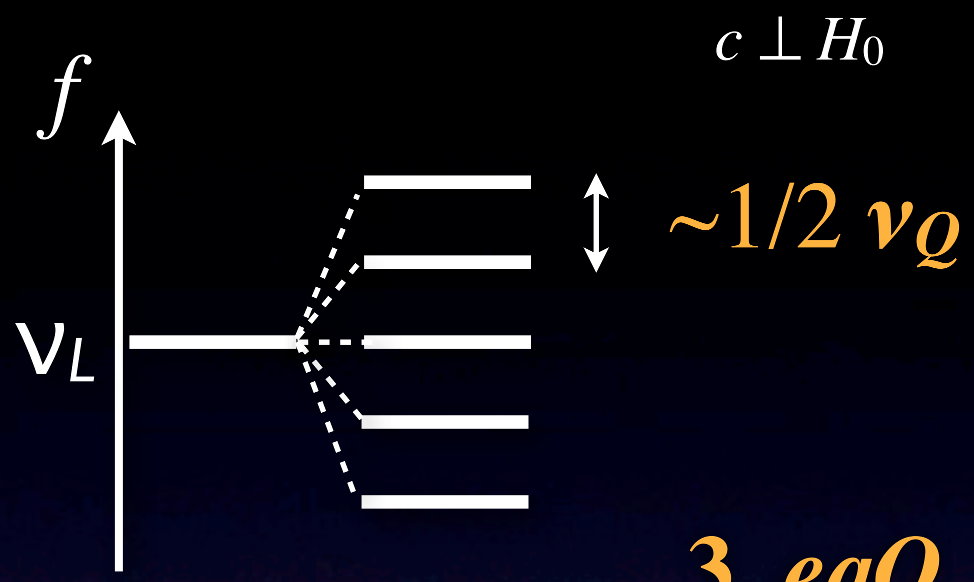
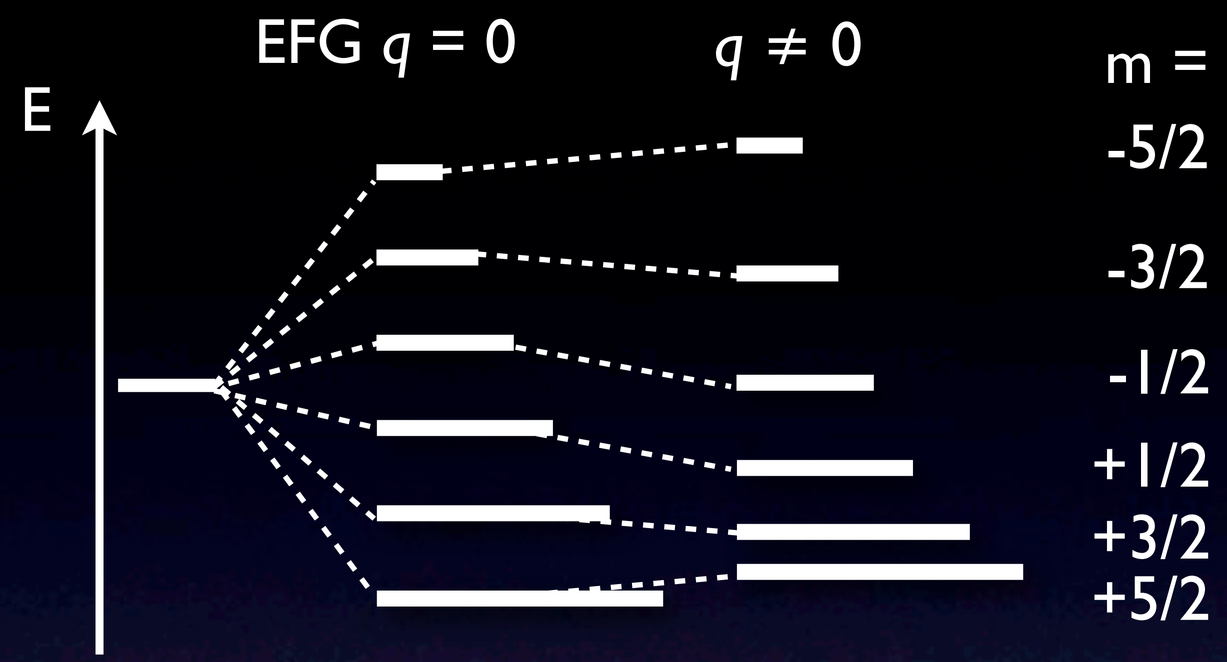
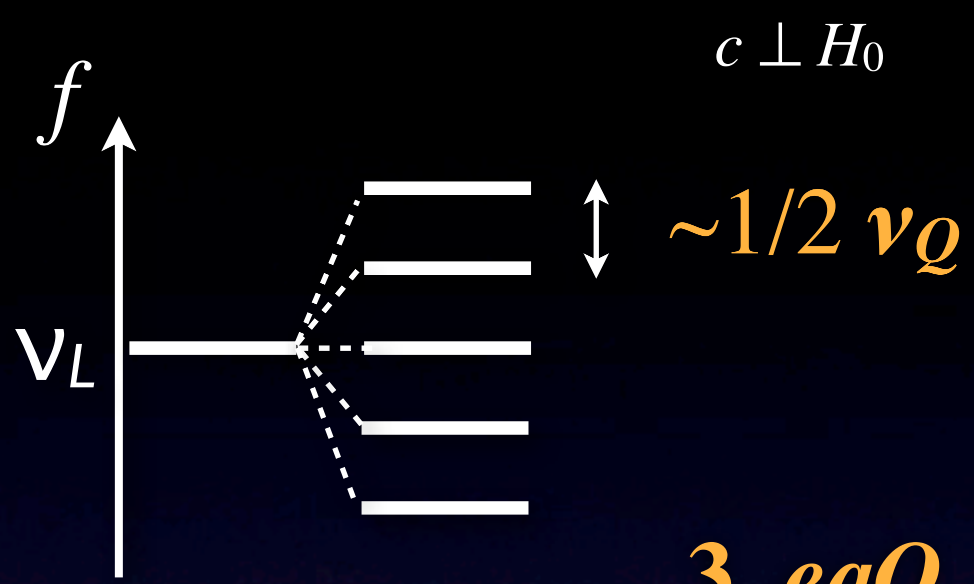




$$\nu_Q = \frac{3}{20}\frac{eqQ}{h}$$

β-NQR Technique : Utilizing EFG q





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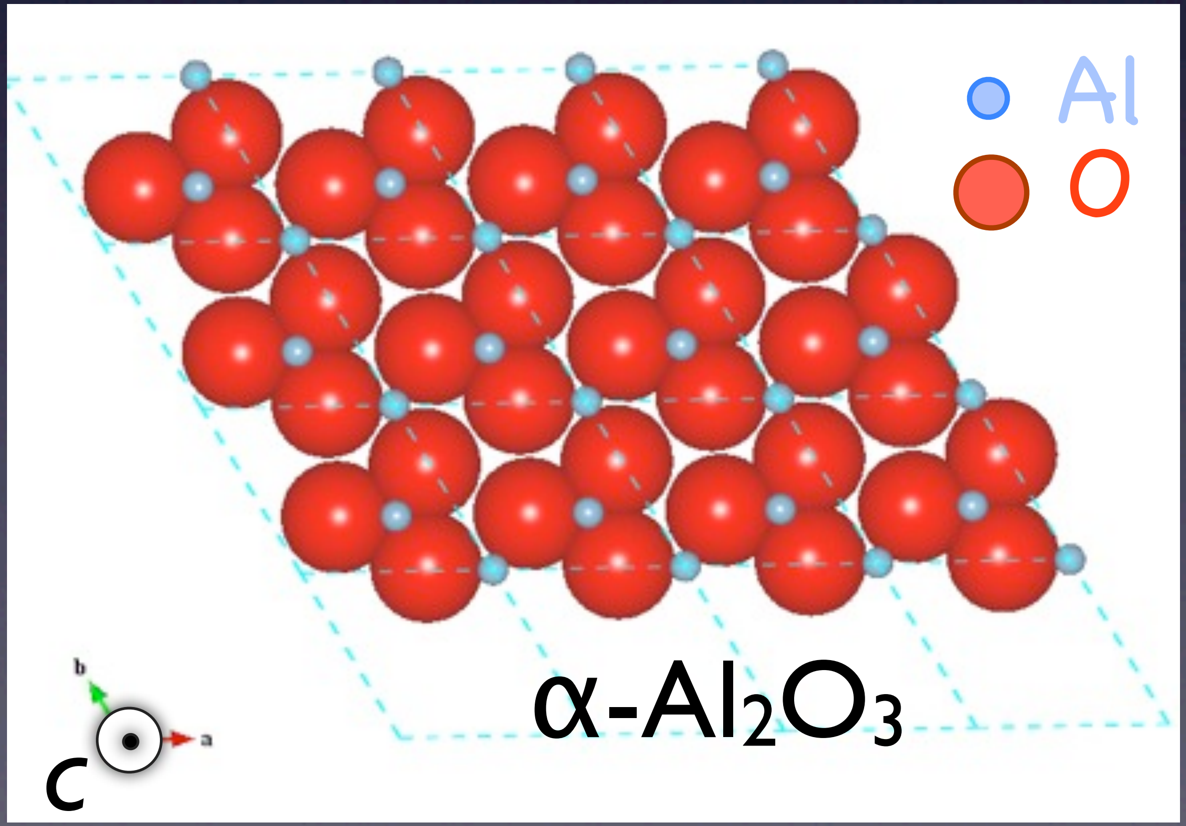

Al substitutional site

$|eqQ(^{27}\text{Al})/h| = 2389(2)$ kHz

$\eta \sim 0$

S.J. Gravina et al, J. Mag. Reson. 89, p515 (1990)

$|Q(^{27}\text{Al})| = 146.6\ (10)$ mb

V. Kellö et al, Chem. Phys. Lett. 304, p414 (1999)

Results : Obtained β-NQR of ^{23}Al in Al_2O_3

Asymmetry Change

$$= \frac{\mathrm{U/D}(\nu_Q)}{\mathrm{U/D}_{\text{no R.F.}}} - 1$$

$$\nu_Q = \frac{3}{20}\frac{eqQ}{h}$$

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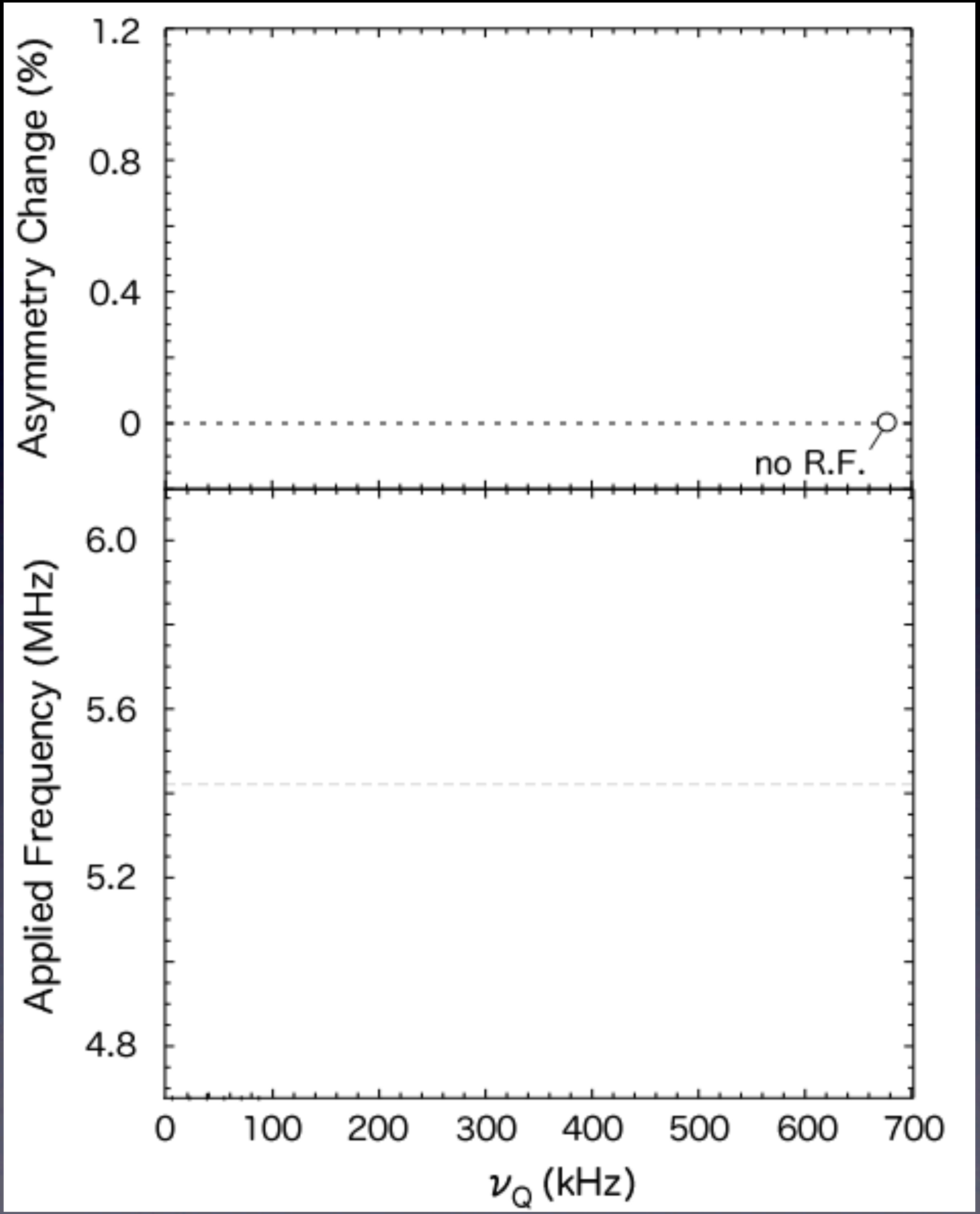

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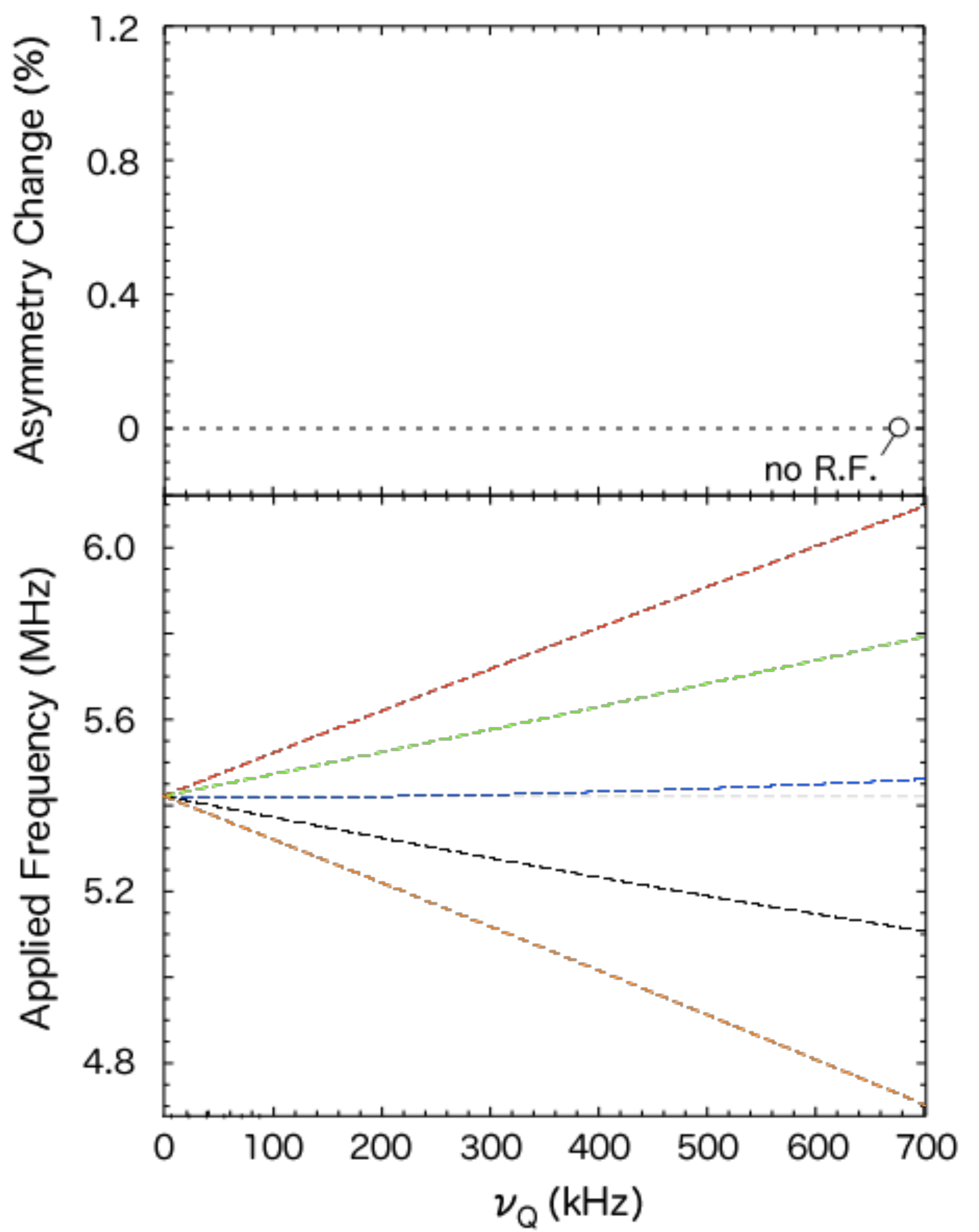

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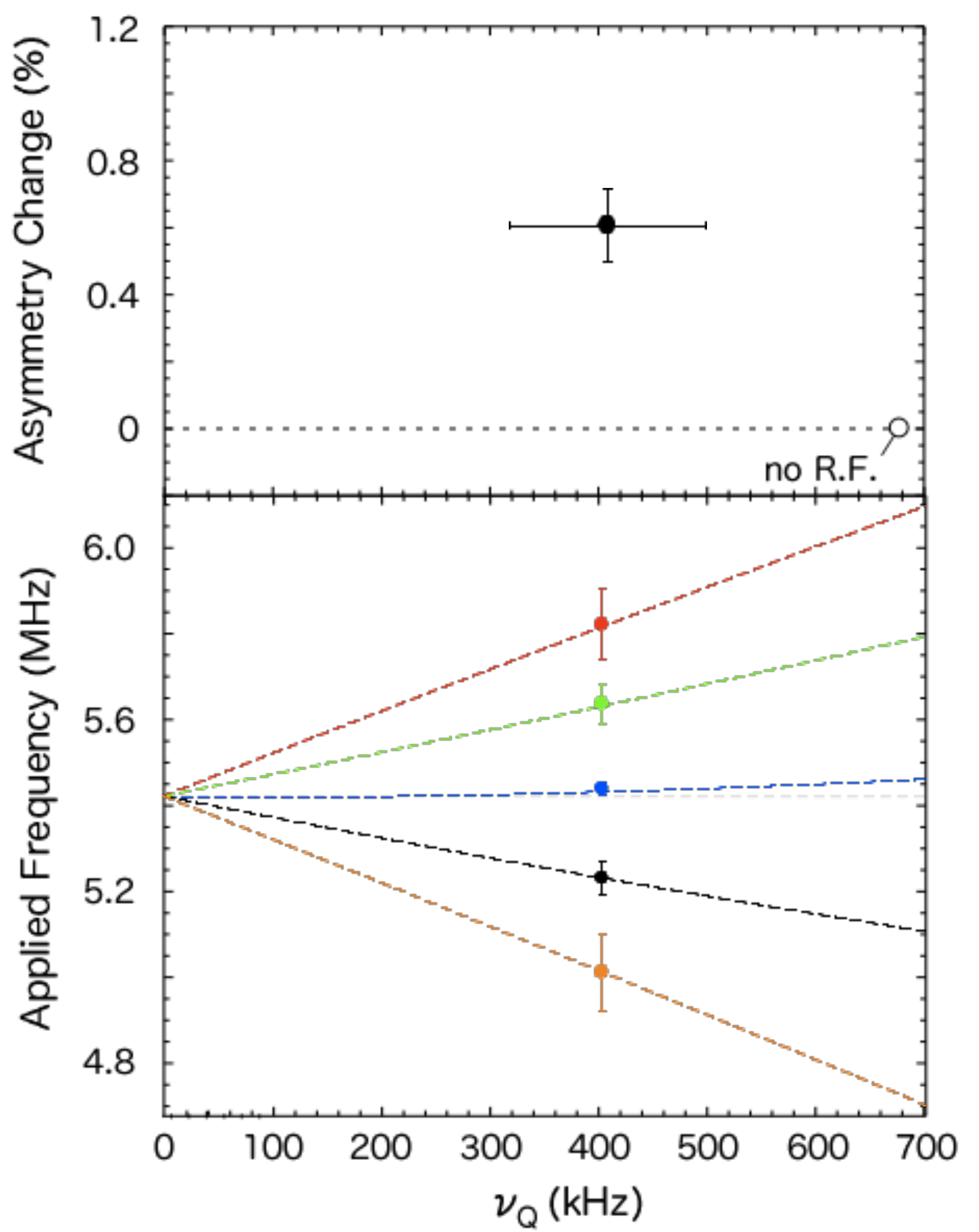
$$\nu_Q = \frac{3}{20}\frac{eqQ}{h}$$



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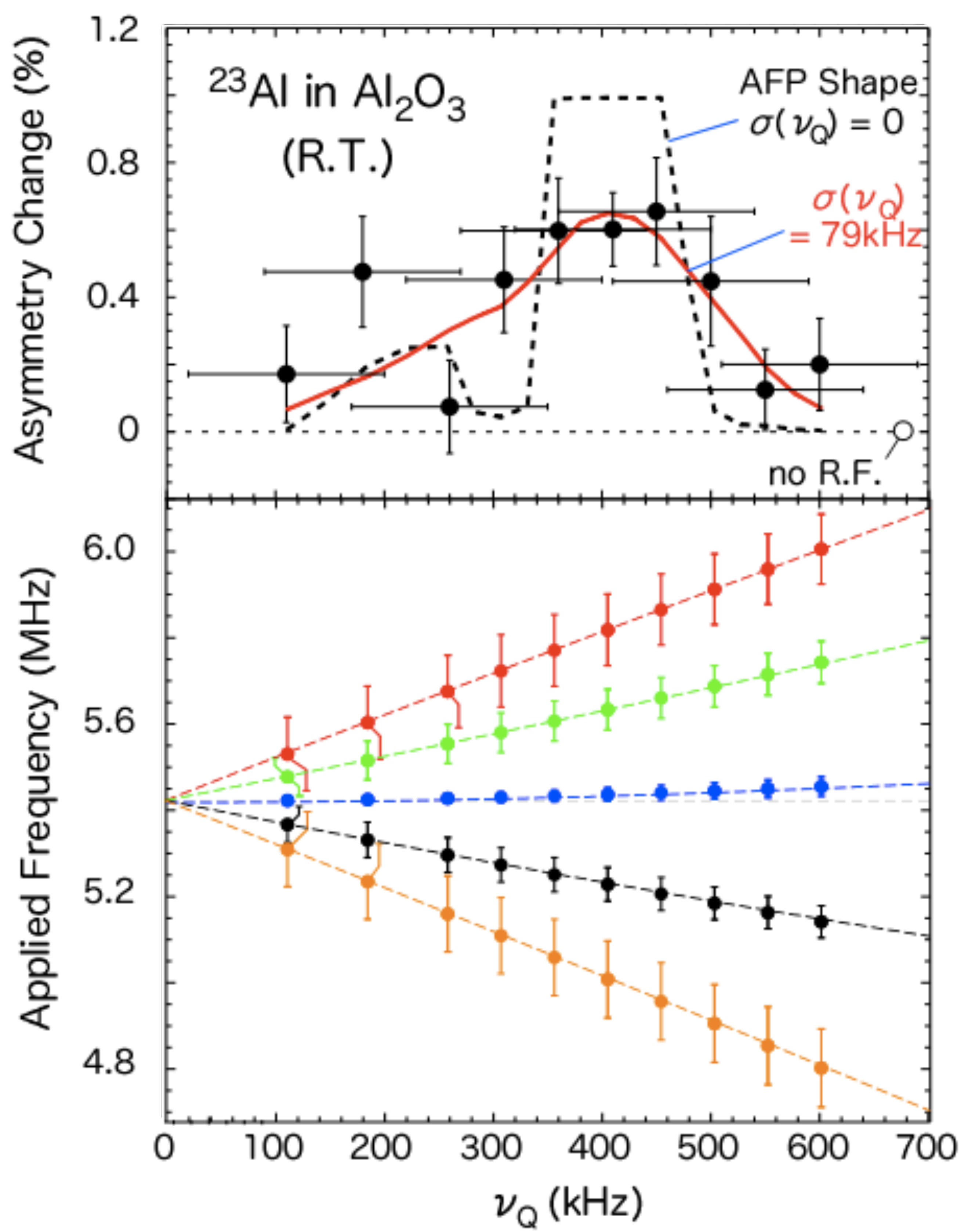

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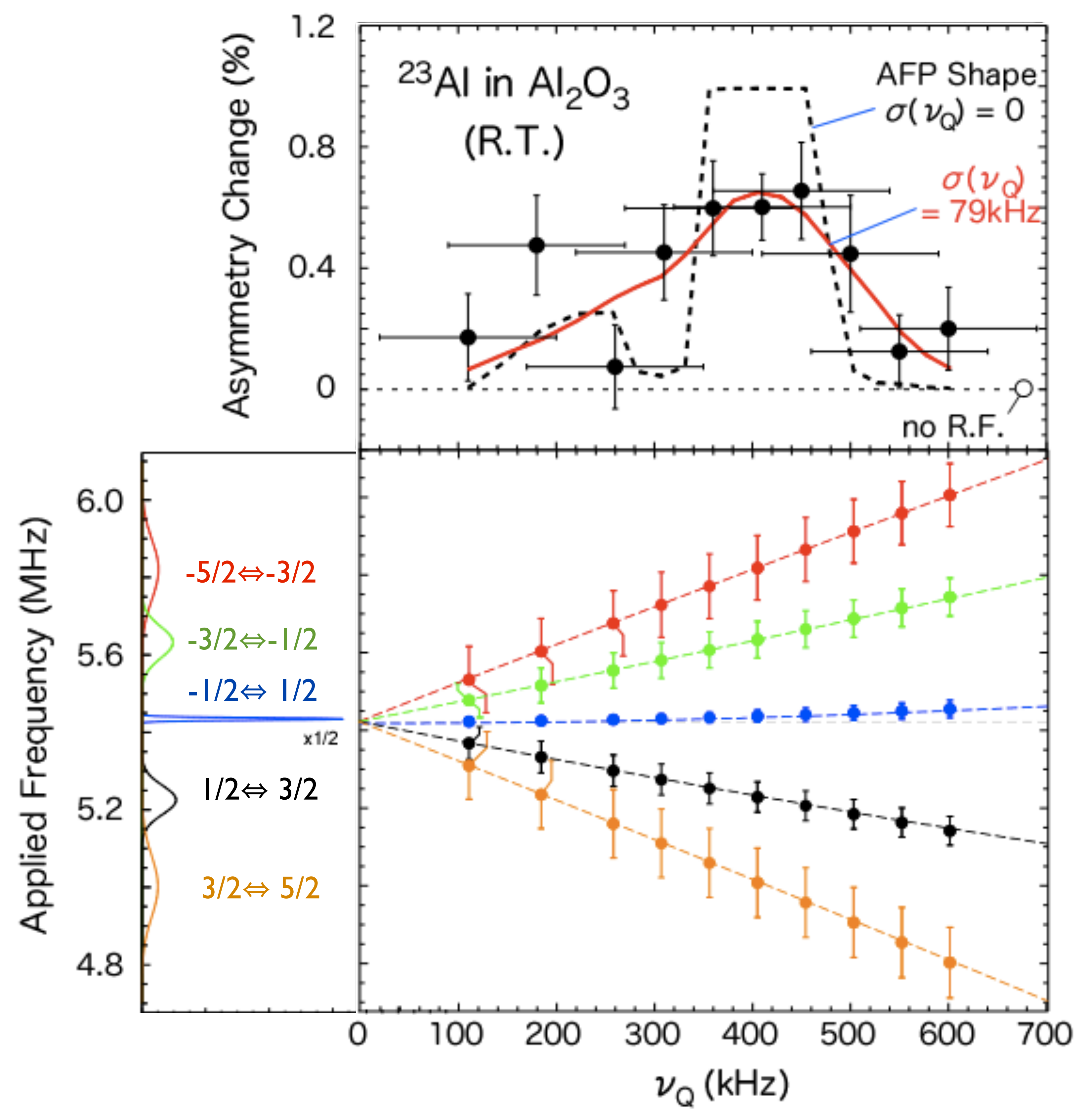

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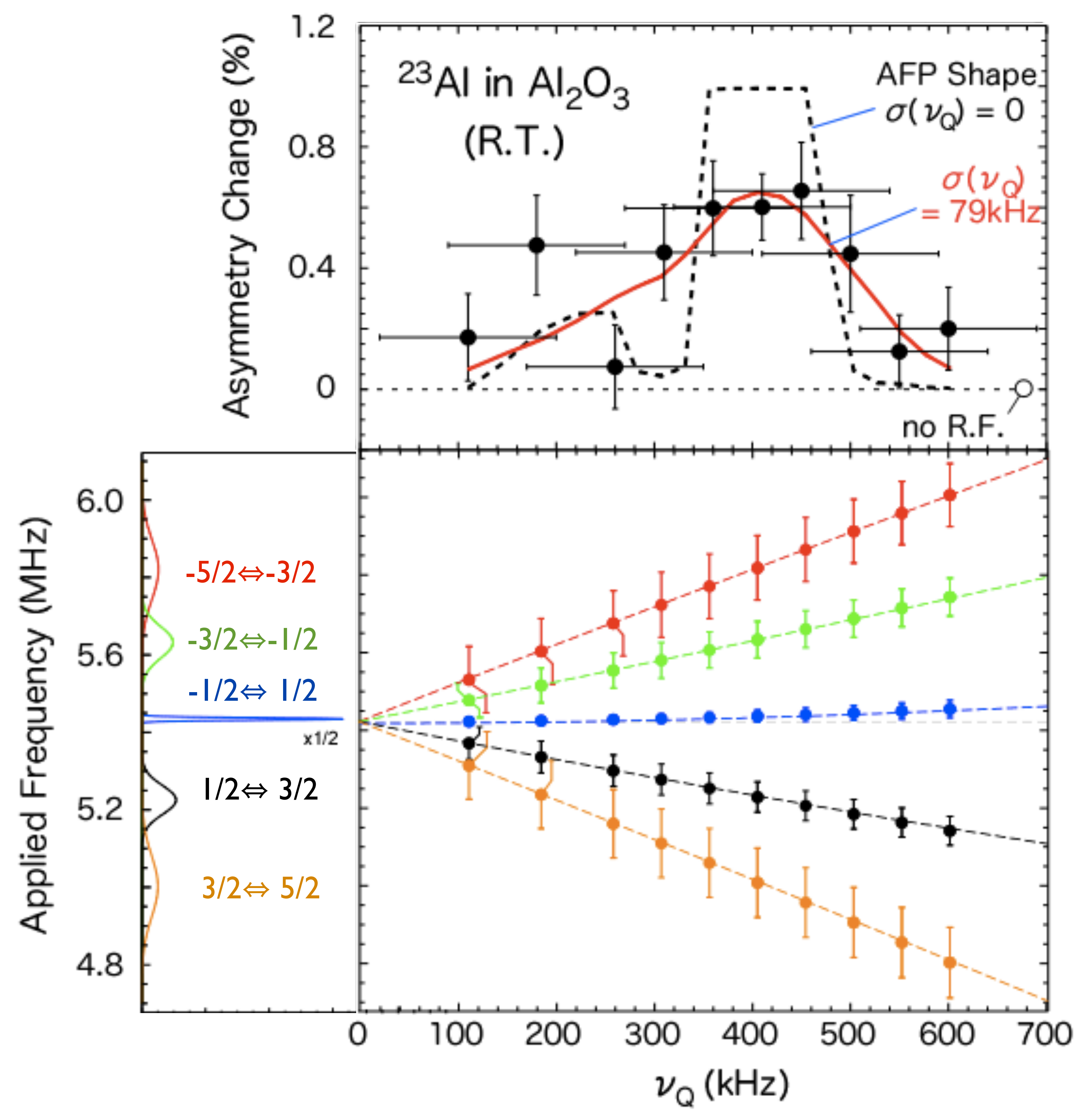

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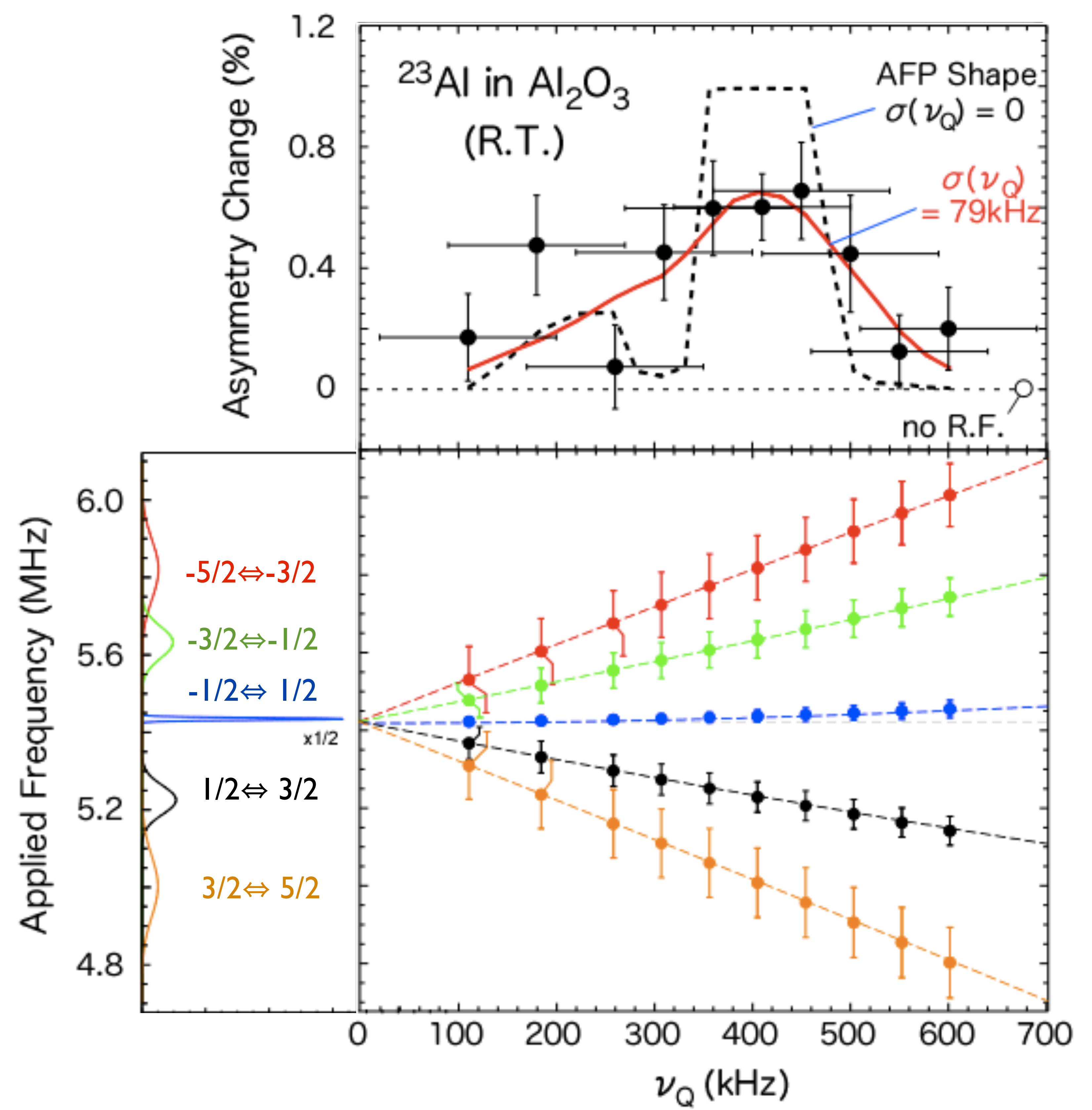

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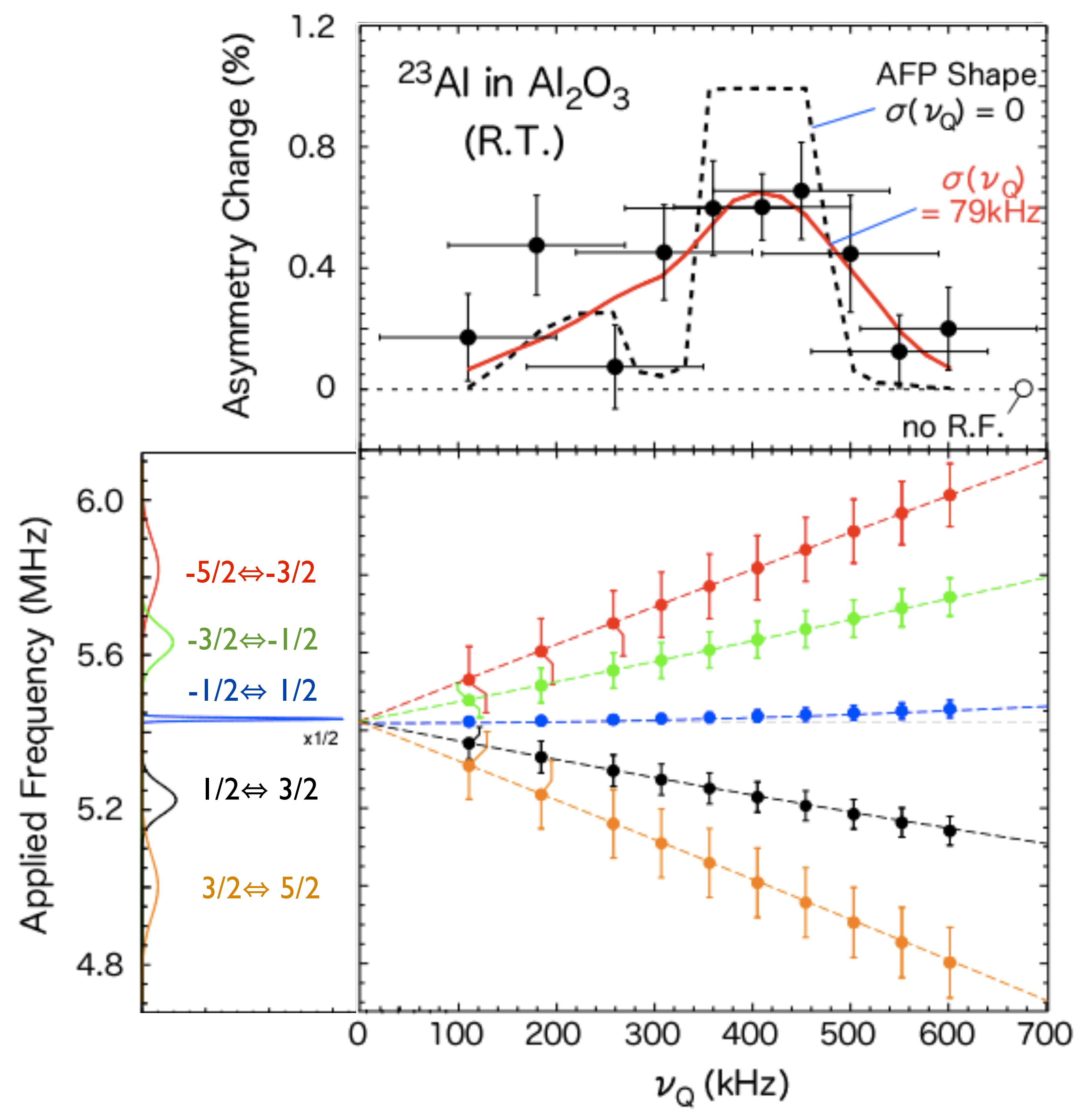

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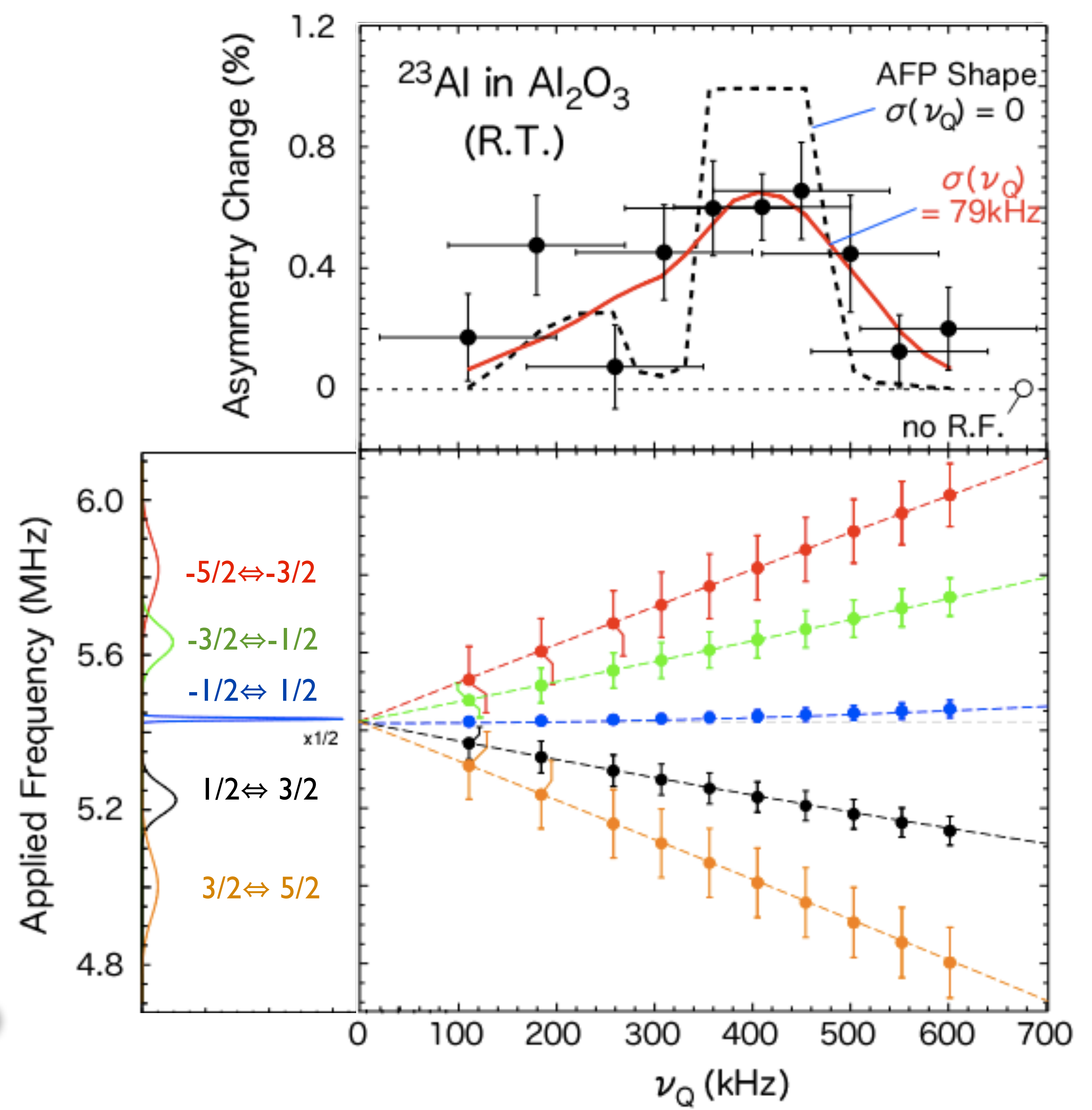
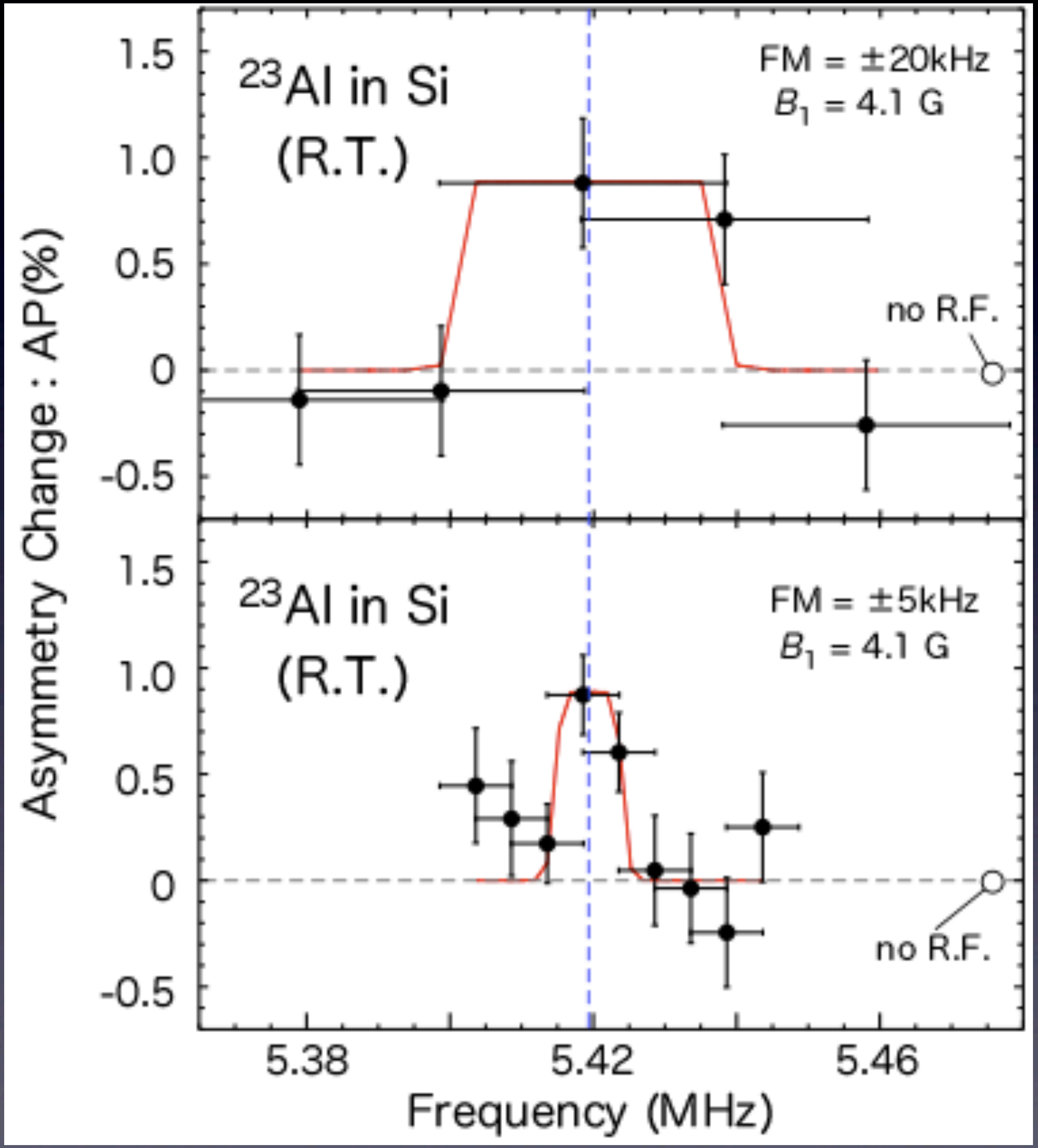


Re-measurement β-NMR of ^{23}Al in Si

(before NQR measurement)



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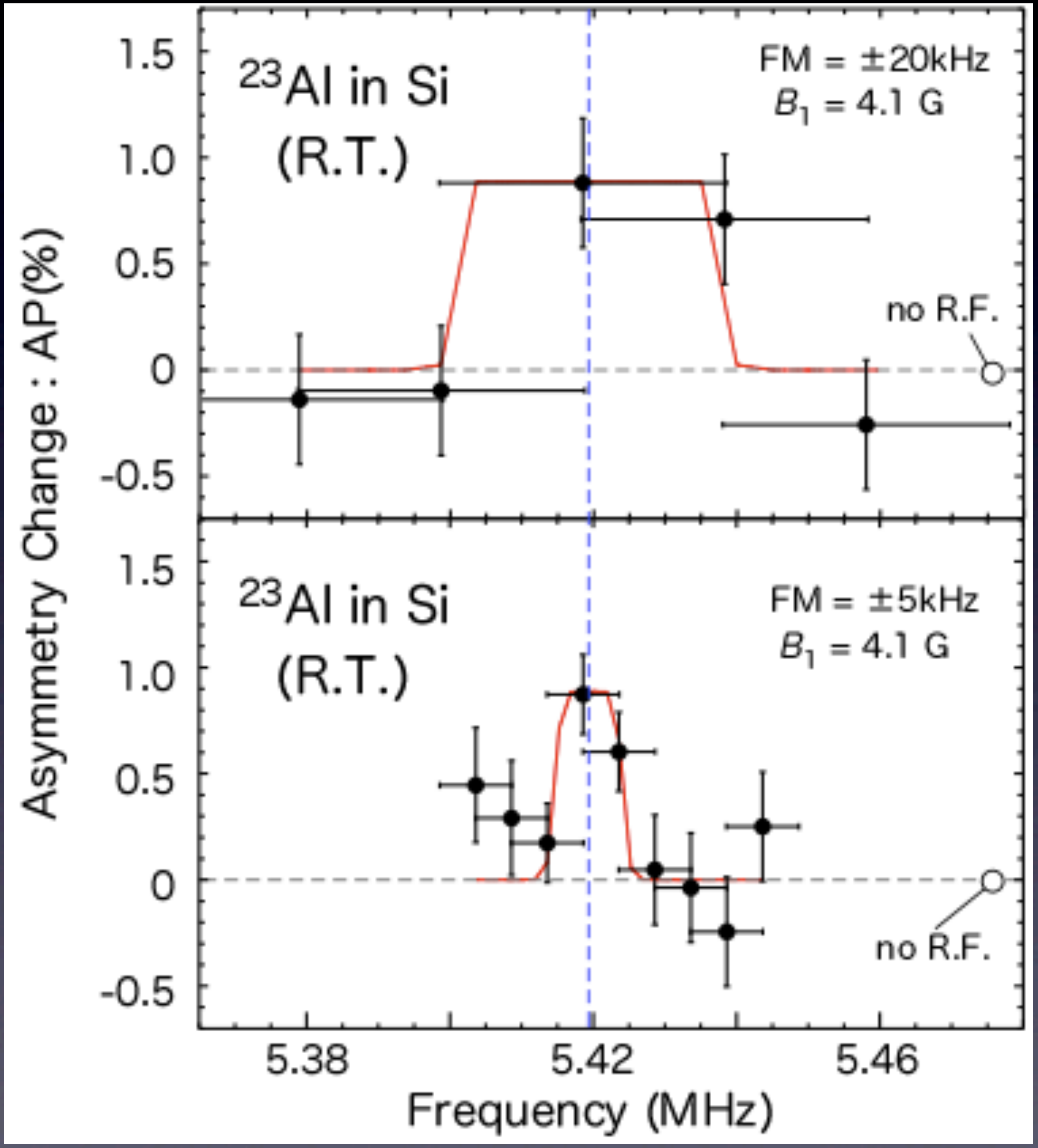

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as a reference … ^{25}Al in Si

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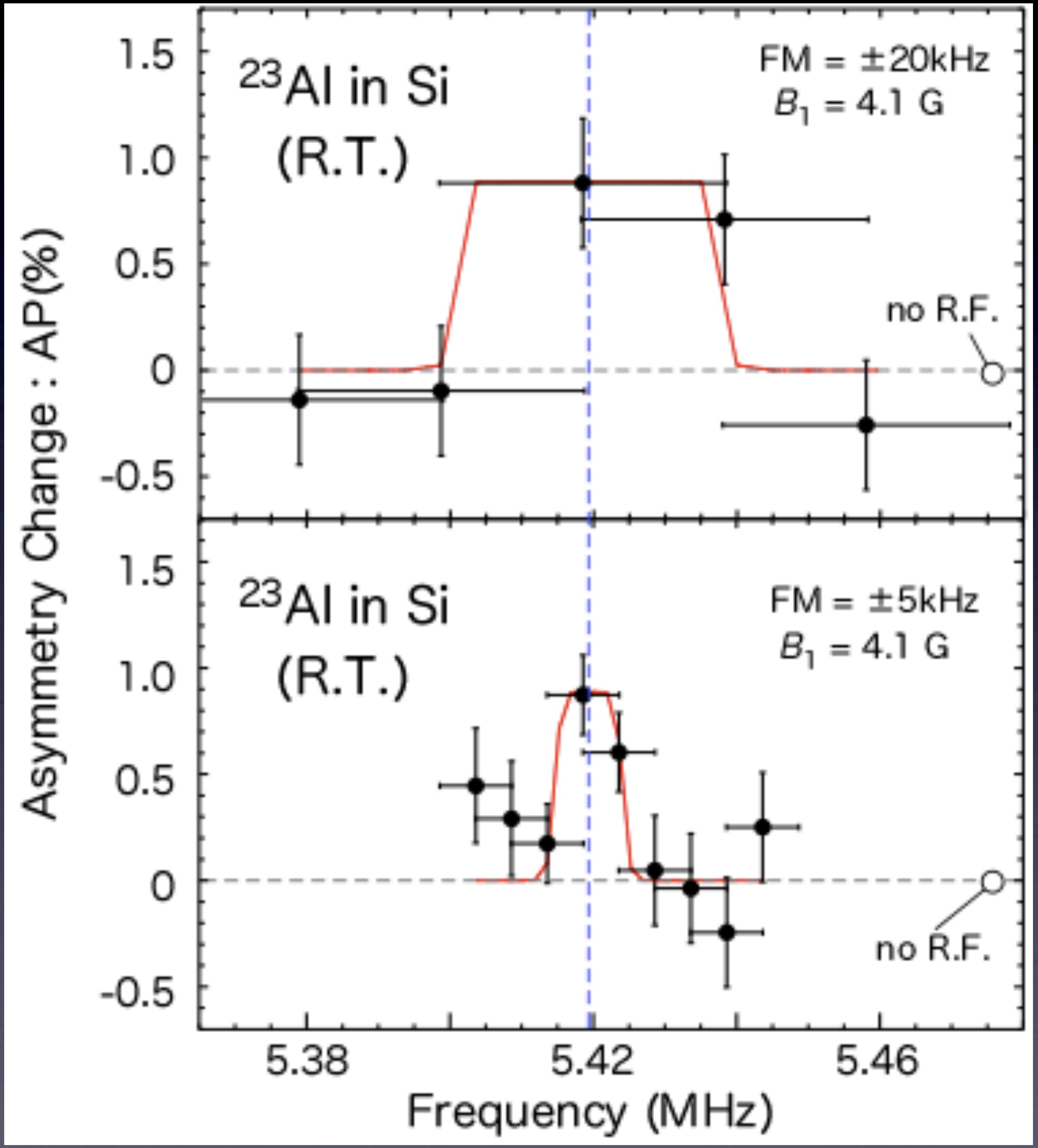

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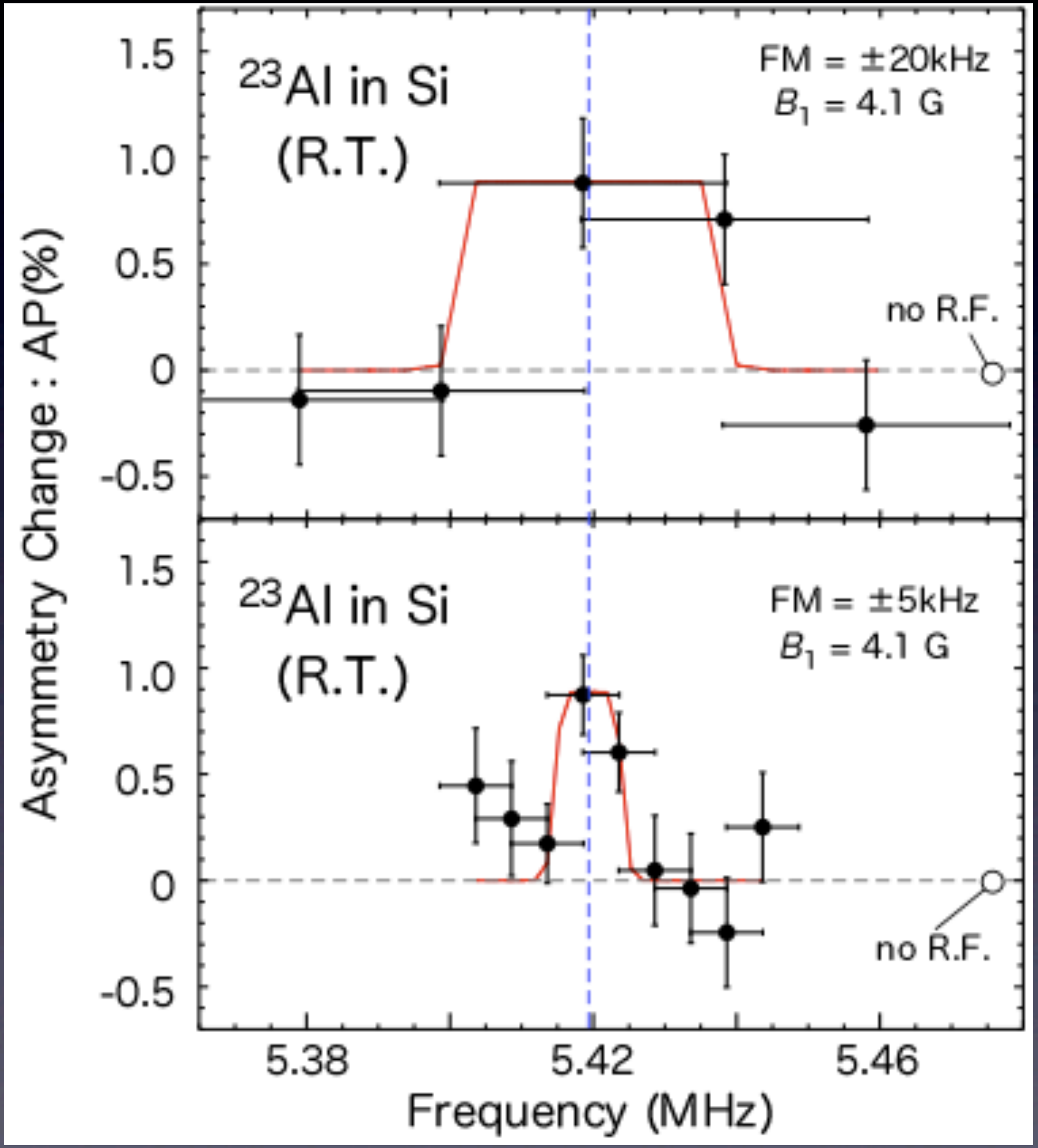

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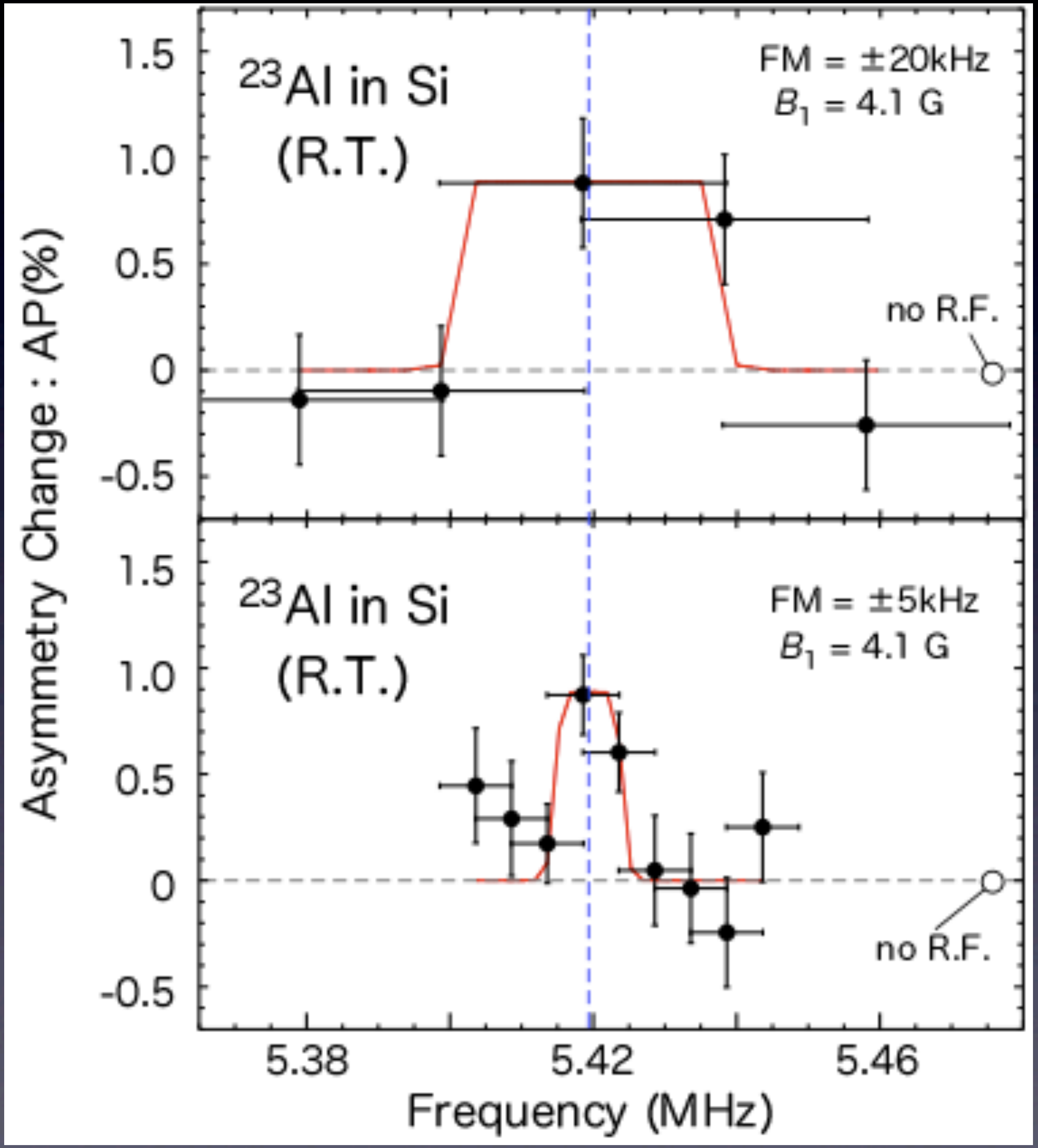

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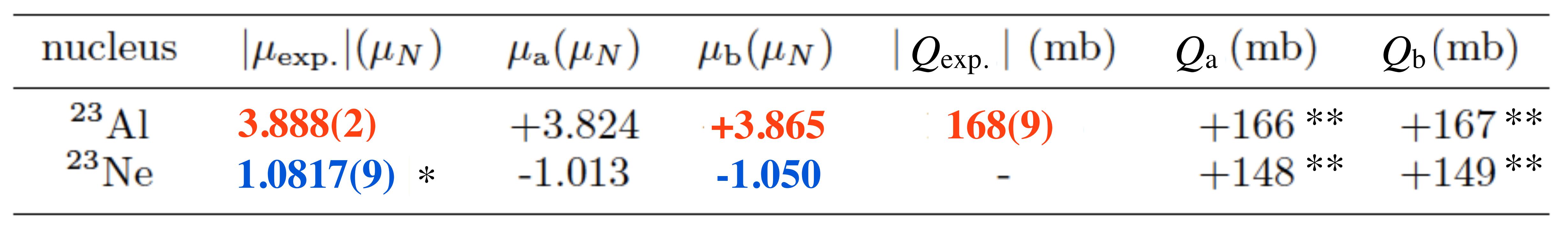
A. Ozawa et al, Phys.Rev. C74, 021301(R) (2006).

Comparing with Mirror Nuclei



nucleus	$\lvert\mu_{\mathrm{exp.}}\rvert(\mu_N)$	$\mu_{\mathrm{a}}(\mu_N)$	$\mu_{\mathrm{b}}(\mu_N)$	$\lvert Q_{\mathrm{exp.}}\rvert$ (mb)	Q_{a} (mb)	Q_{b} (mb)
^{23}Al	**3.888(2)**	+3.824	**+3.865**	**168(9)**	+166 **	+167 **
^{23}Ne	**1.0817(9)** *	-1.013	**-1.050**	-	+148 **	+149 **

* R. Matsumiya et al, OULNS Annual Report 2004, p.51 (2006)
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Shell model calculation : USDa, USDb Hamiltonian
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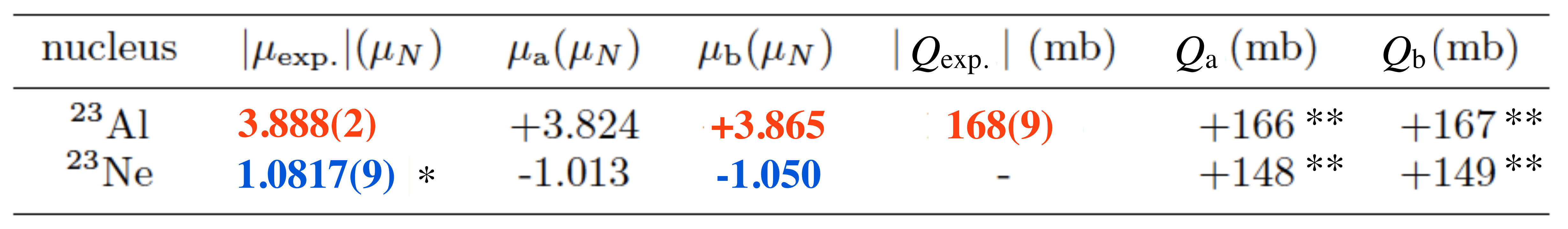

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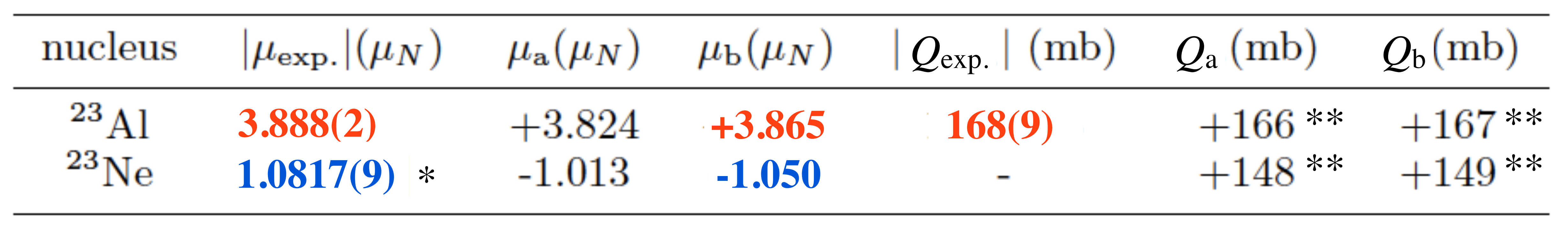

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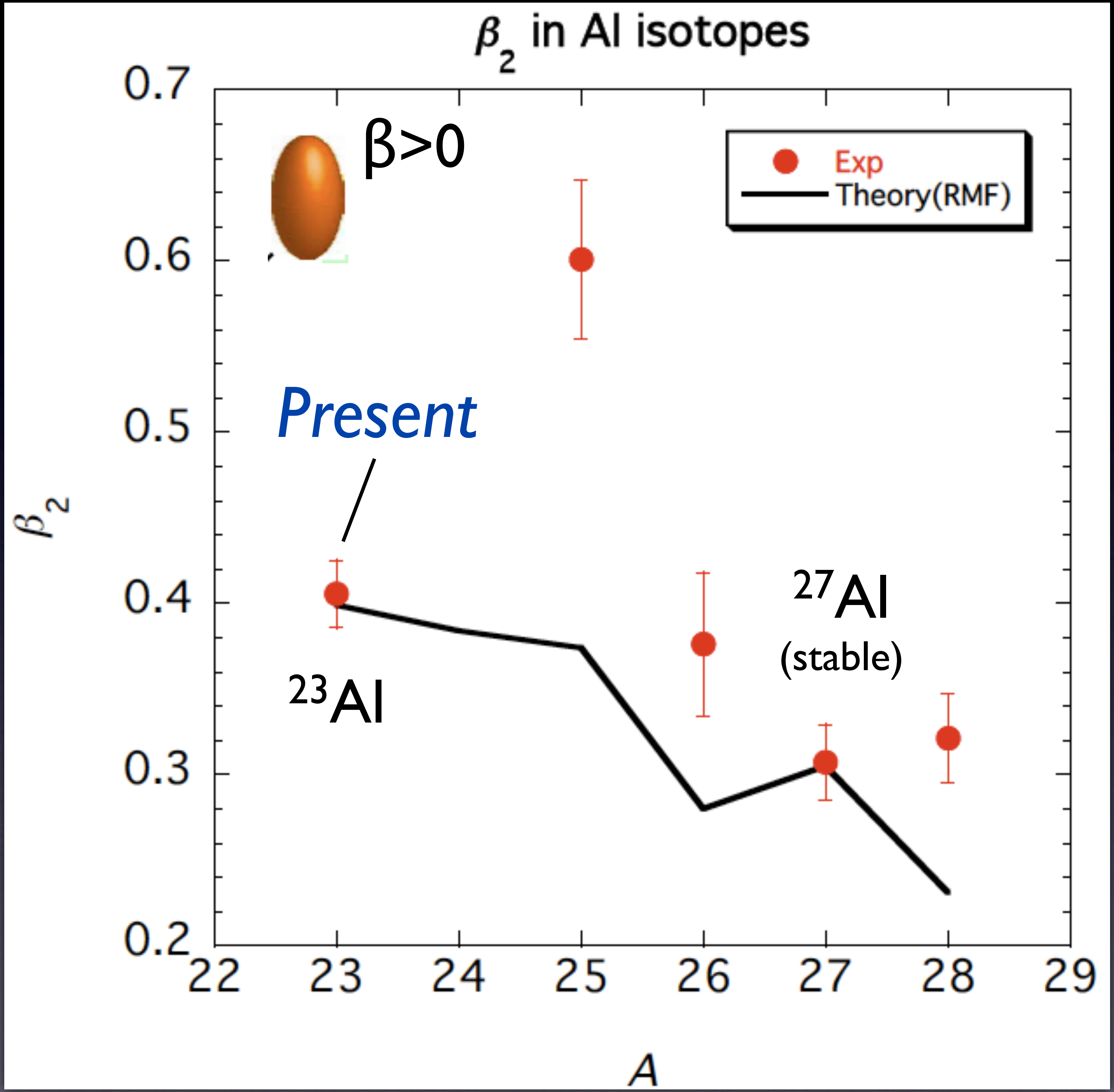
Normal structure

Deformed Parameter β_2 in Al isotopes



Relativistic Mean Field Theory

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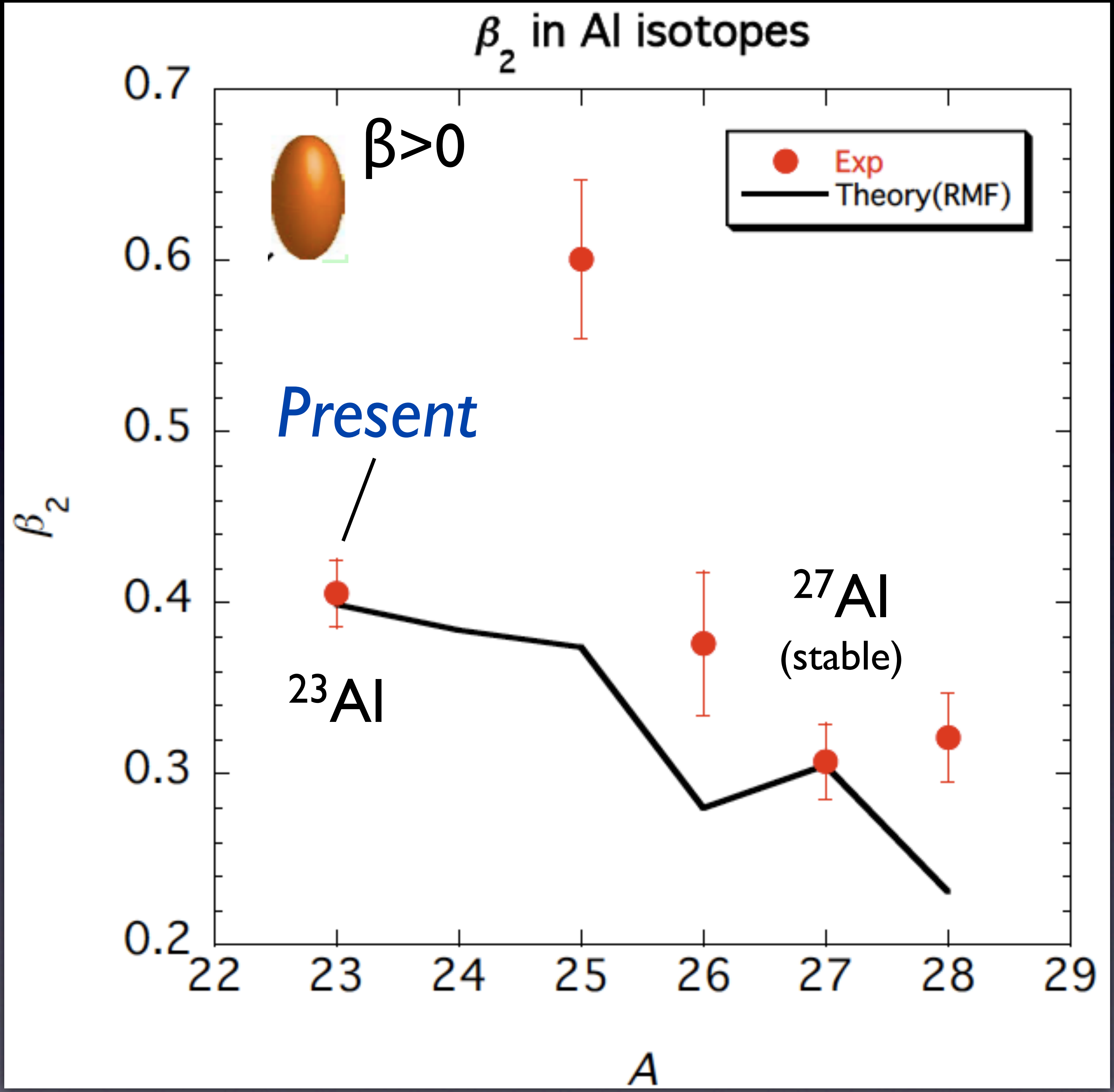

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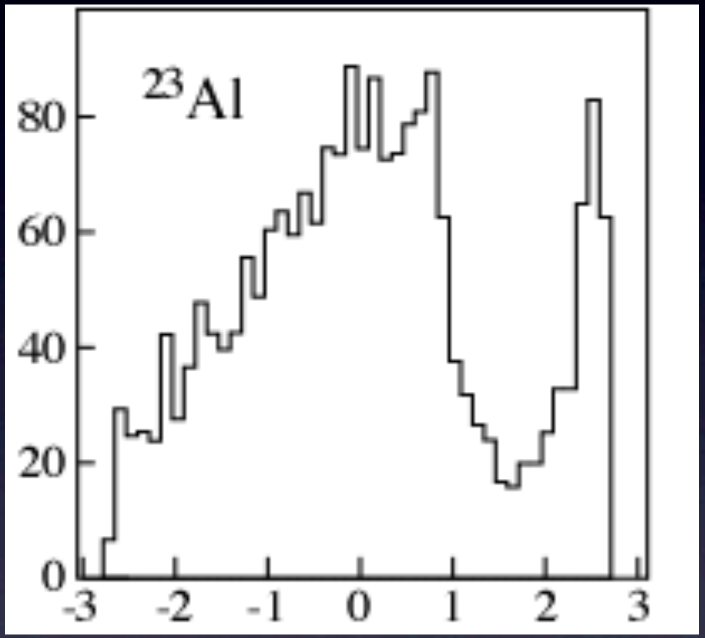
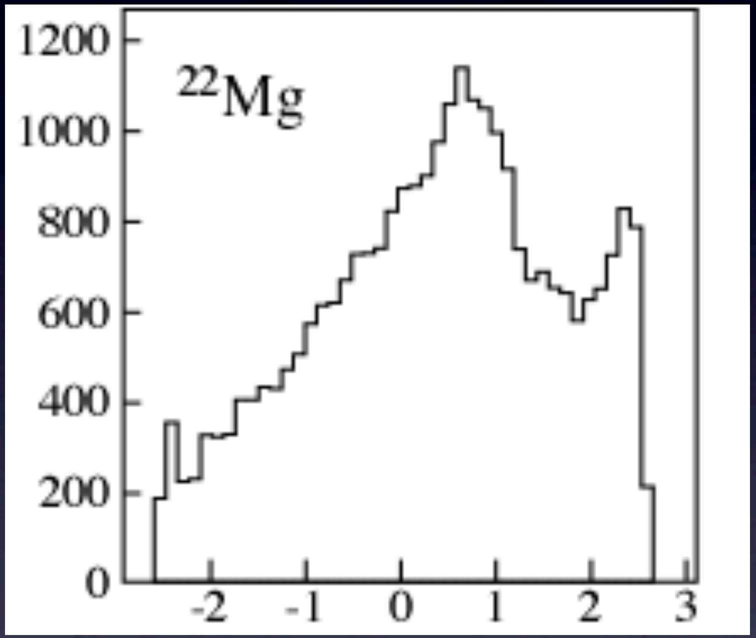
No evident signal of the exotic structure have been seen despite of the extremely small Sp = 125 keV.

Thank you for your attention!


^{23}Al
80
60
40
20
0
-3
-2
-1
0
1
2
3


^{22}Mg
1200
1000
800
600
400
200
0
-2
-1
0
1
2
3