Ground-Breaking Developments in ^{10}B with inelastic proton scattering

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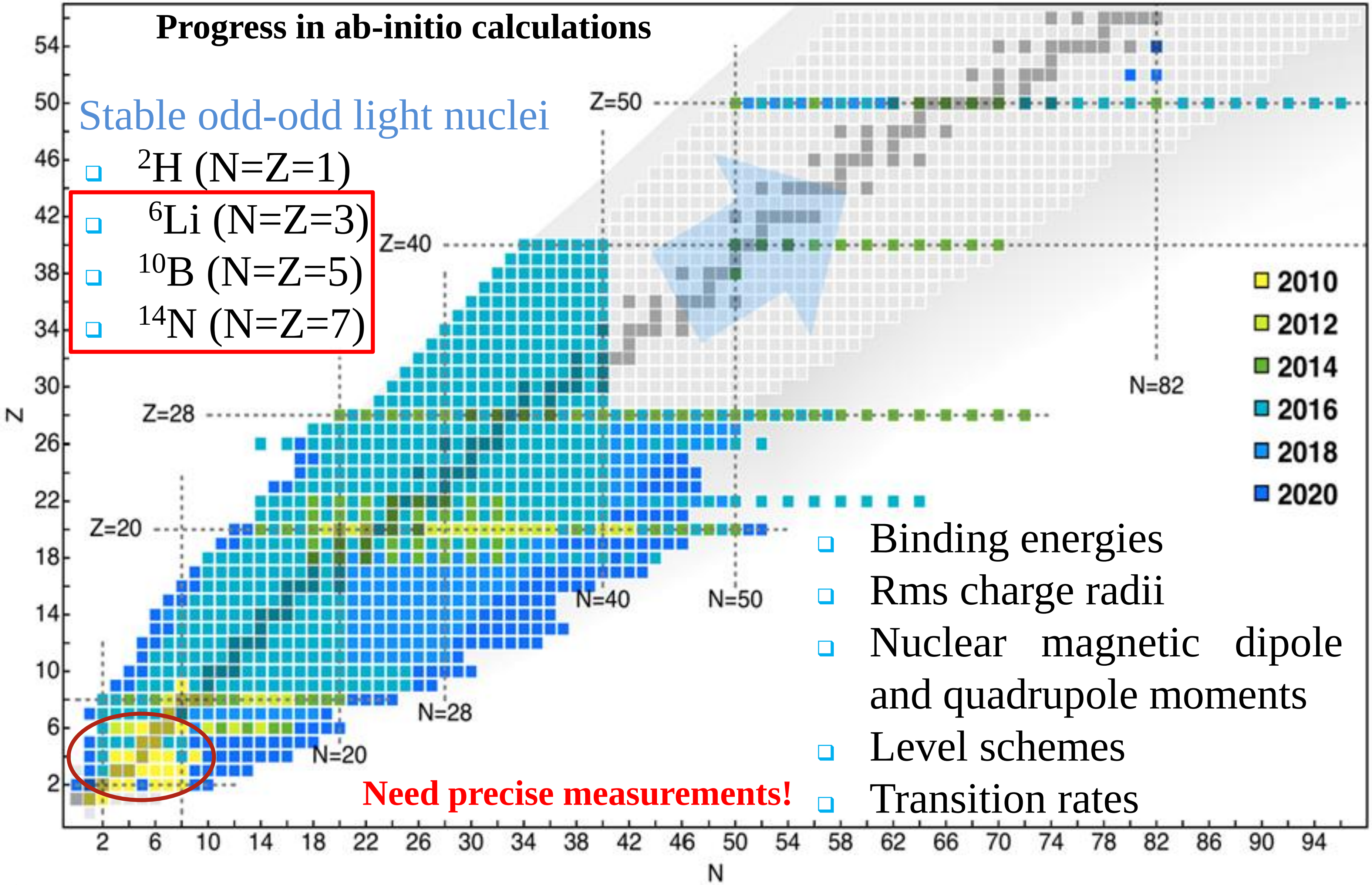
Why do we study the lightest nuclei?

✓ *H. Hergert, Frontiers in Physics, 8, 379 (2020)*



Progress in ab-initio calculations

Stable odd-odd light nuclei

- ^{2}H (N=Z=1)
- ^{6}Li (N=Z=3)
- ^{10}B (N=Z=5)
- ^{14}N (N=Z=7)

- Binding energies
- Rms charge radii
- Nuclear magnetic dipole and quadrupole moments
- Level schemes
- Transition rates

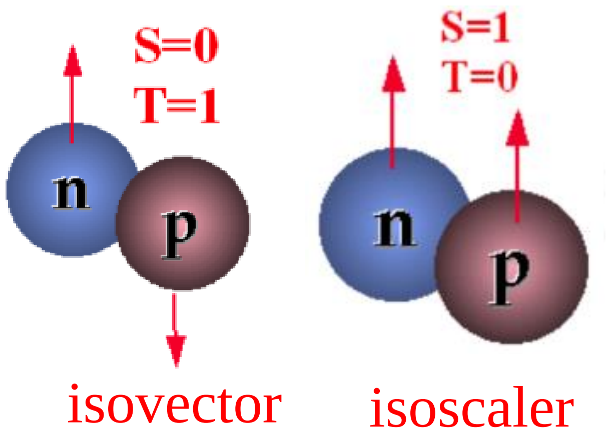
Need precise measurements!

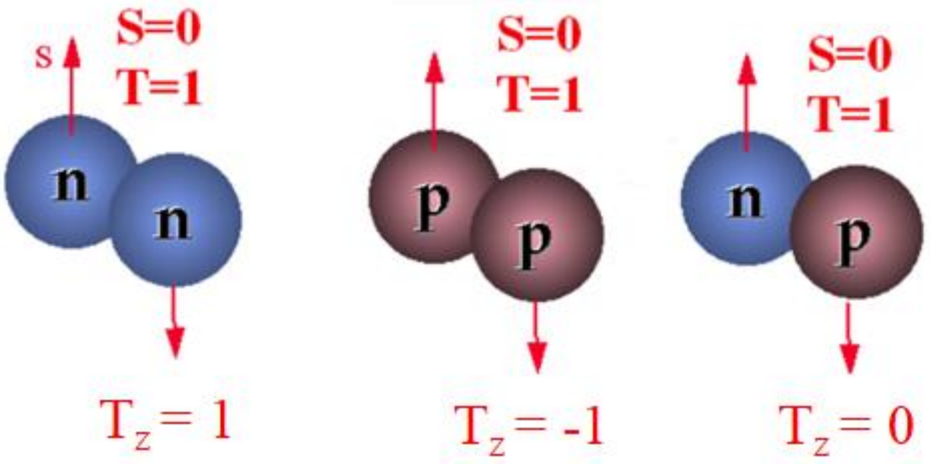
✓ *D. Tilley et al., Nuc. Phys. A, 708, 3 (2002), Nuc. Phys. A, 745, 155 (2004), F. Ajzenberg et al. Nuc. Phys. A, 268, 1 (1976)*

Why do we study the lightest nuclei?

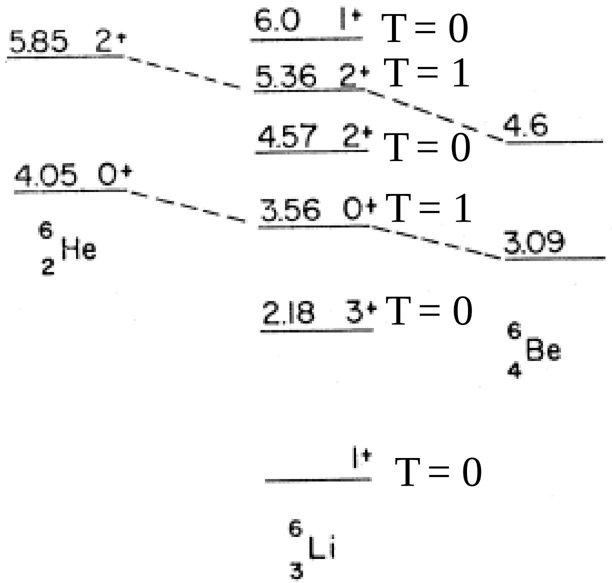
^{2}H pair

✓ *D. Robson , Science, 179, 4069, 133-139 (1973)*

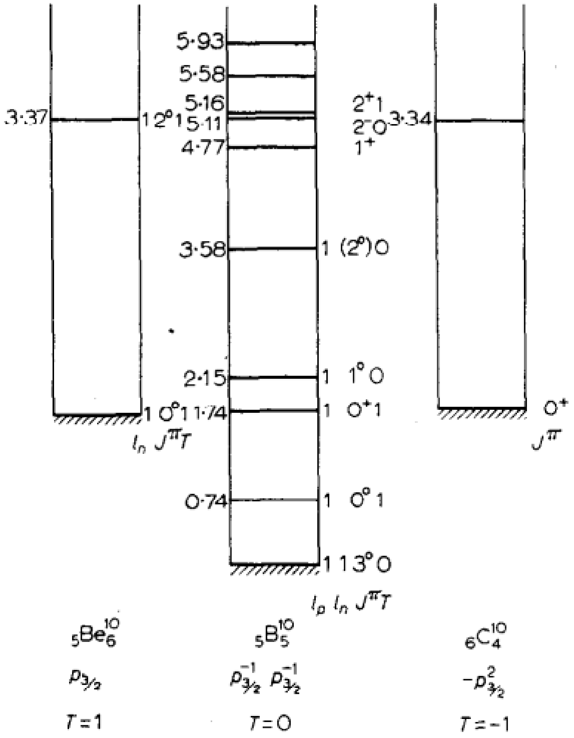




- ❑ A = 6 triplet

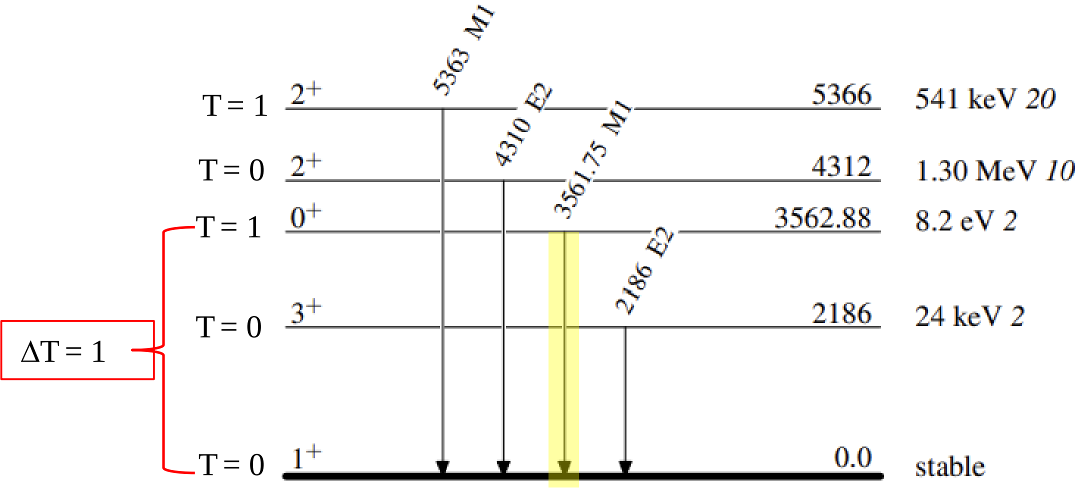


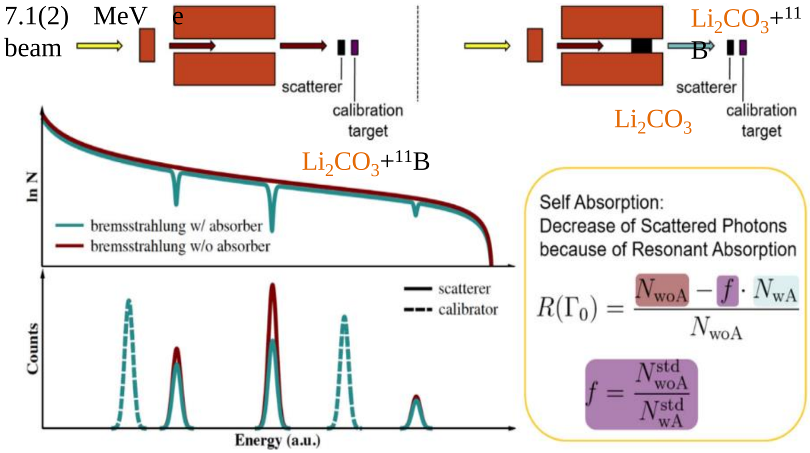
- ❑ A = 10 triplet



✓ *S.A. Kuvin et. all, Phys.Rev. C, 96, 041301 (R) (2017)*

Example case: odd-odd system of ^{6}Li (N=Z=3)





Self Absorption:
Decrease of Scattered Photons
because of Resonant Absorption

$$R(\Gamma_0) = \frac{N_{woA} - f \cdot N_{wA}}{N_{woA}}$$

$$f = \frac{N^{std}_{woA}}{N^{std}_{wA}}$$

$^6_3$Li$_3$

✓ *A. Zilges, D.L. Balabanski et all, Prog. Part. Nucl. Phys., 121, 103903 (2022)*

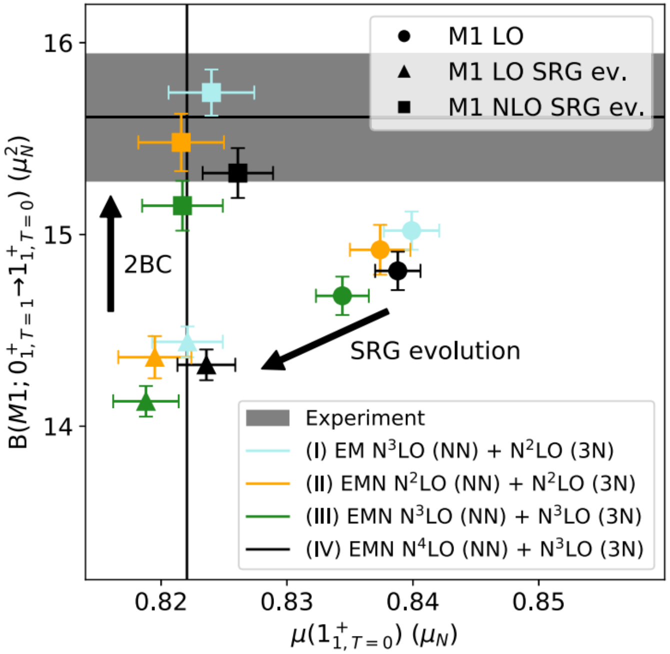
$$\boxed{B(M1; 0^+_{1,T=1} \rightarrow 1^+_{1,T=0}) \propto E_\gamma^{-3} \Gamma_{\gamma,0^+_1 \rightarrow 1^+_1}}$$

$T_{1/2}$=10^{-18} s

$$\boxed{\Gamma_{\gamma,0^+_1 \rightarrow 1^+_1} = 8.17^{+0.14}_{-0.13}(stat.)^{+0.10}_{-0.11}(syst.)\ \mathrm{eV}}$$

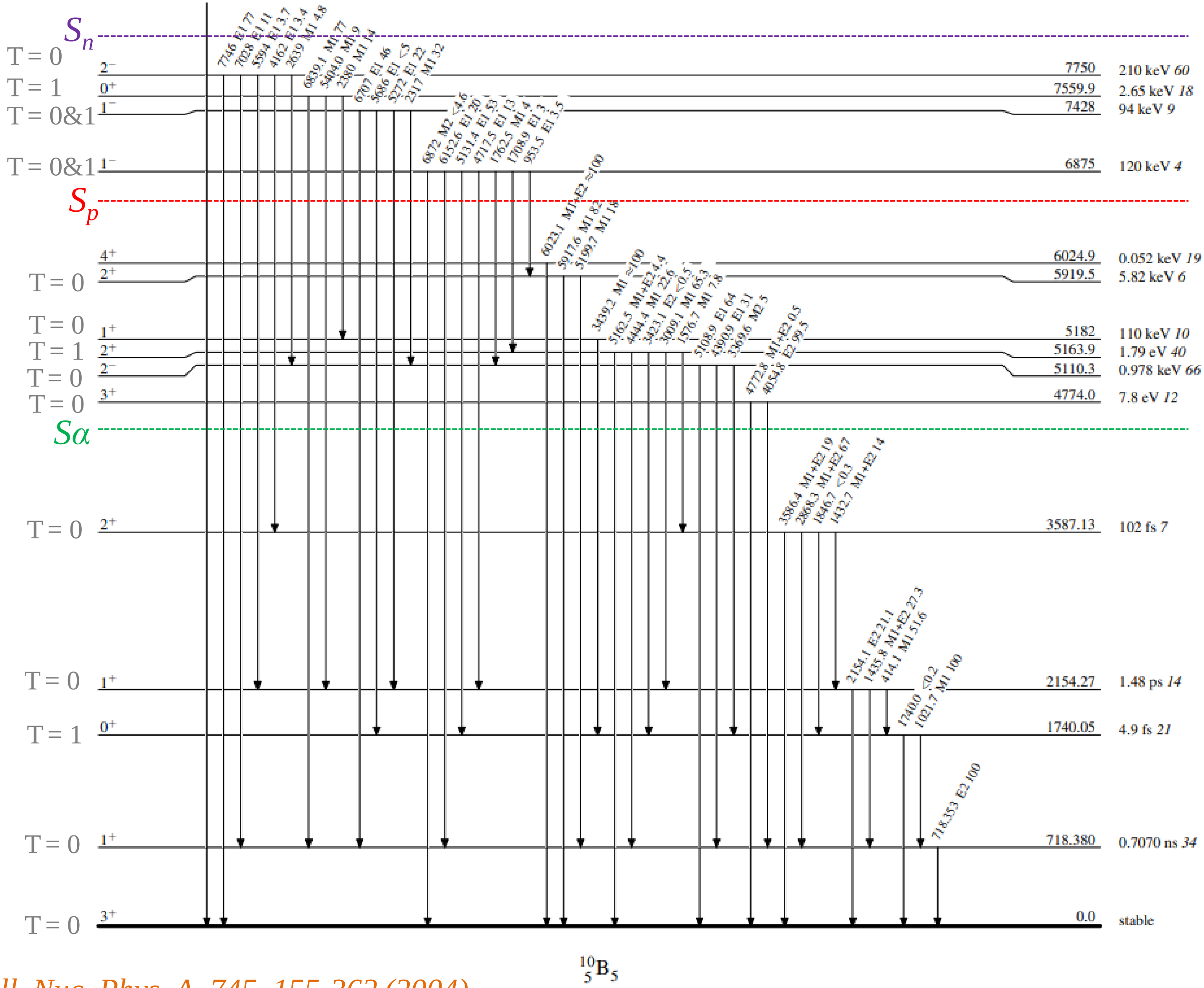
$$B(M1; 0^+_1 \rightarrow 1^+_1) = 15.61(33)\mu_N^2$$

2% relative uncertainity



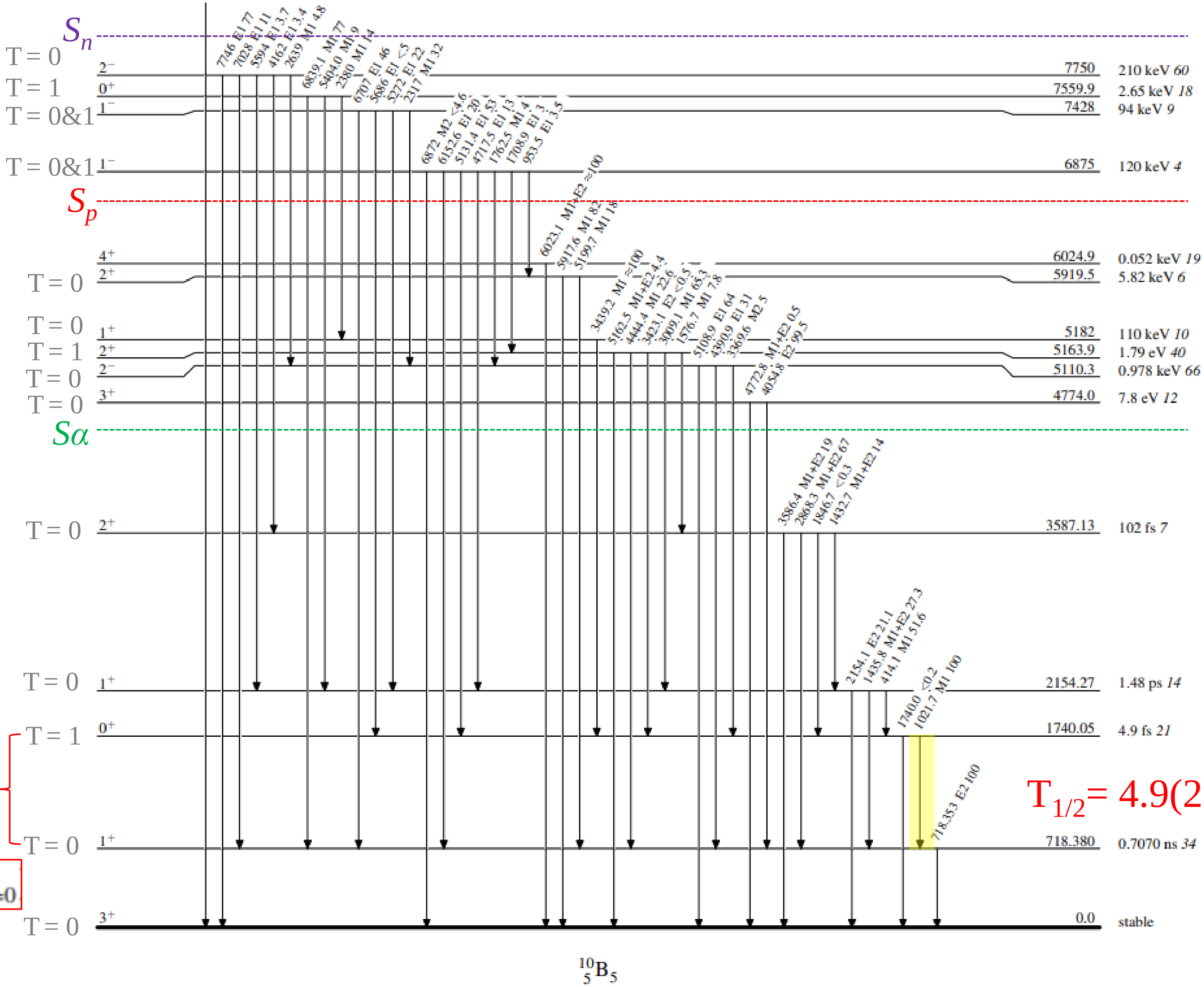
✓ *U. Friman-Gayer et. all, Phys. Rev. Lett., 126, 102501 (2021)*

The next doubly-odd system of ^{10}B (N=Z=5)



- ✓ *D.R. Tilley et. all, Nuc. Phys. A, 745, 155-362 (2004)*

ΔT=1 M1 transition



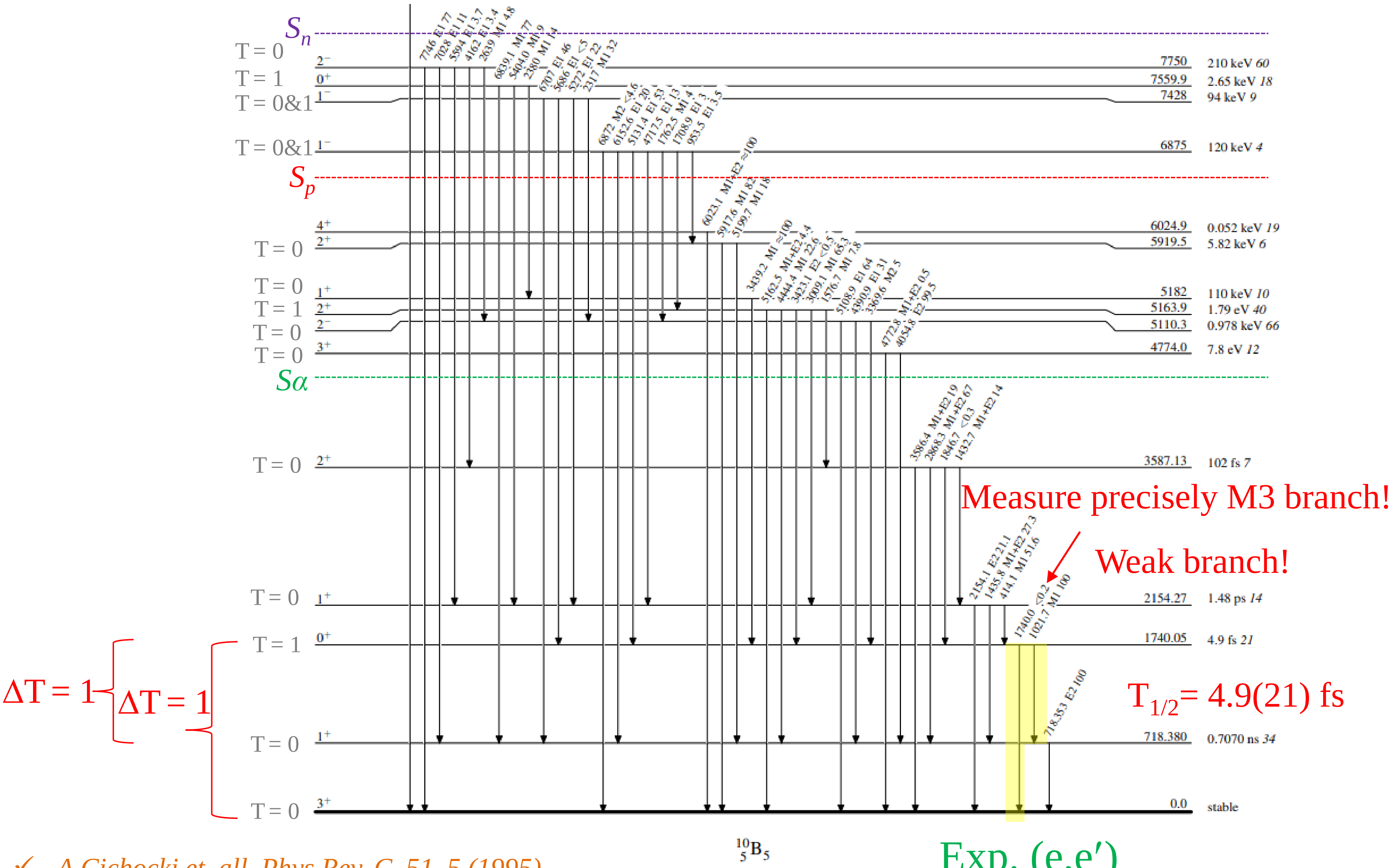
Like in ^{6}Li

$\Delta T = 1$

$M1; 0^+_{1,T=1} \rightarrow 1^+_{1,T=0}$

$T_{1/2}$= 4.9(21) fs

Competing M1 and M3 spin-flip transitions (ΔT=1)



Measure precisely M3 branch!

Weak branch!

$T_{1/2}$= 4.9(21) fs

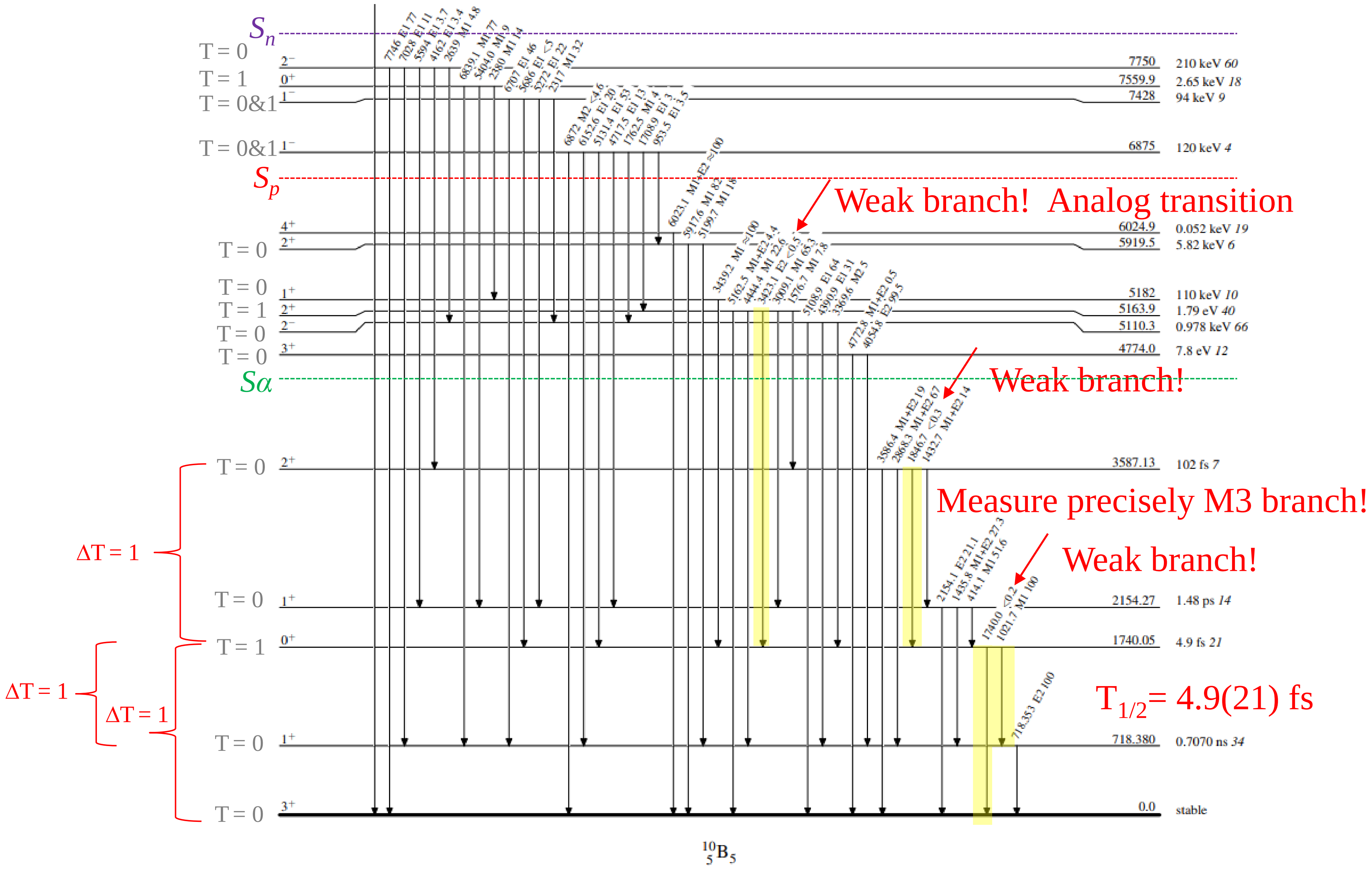
ΔT = 1

ΔT = 1

Exp. (e,e′)

- ✓ *A.Cichocki et. all, Phys.Rev. C, 51, 5 (1995)*

Other Weak Transitions



Weak branch!

Analog transition

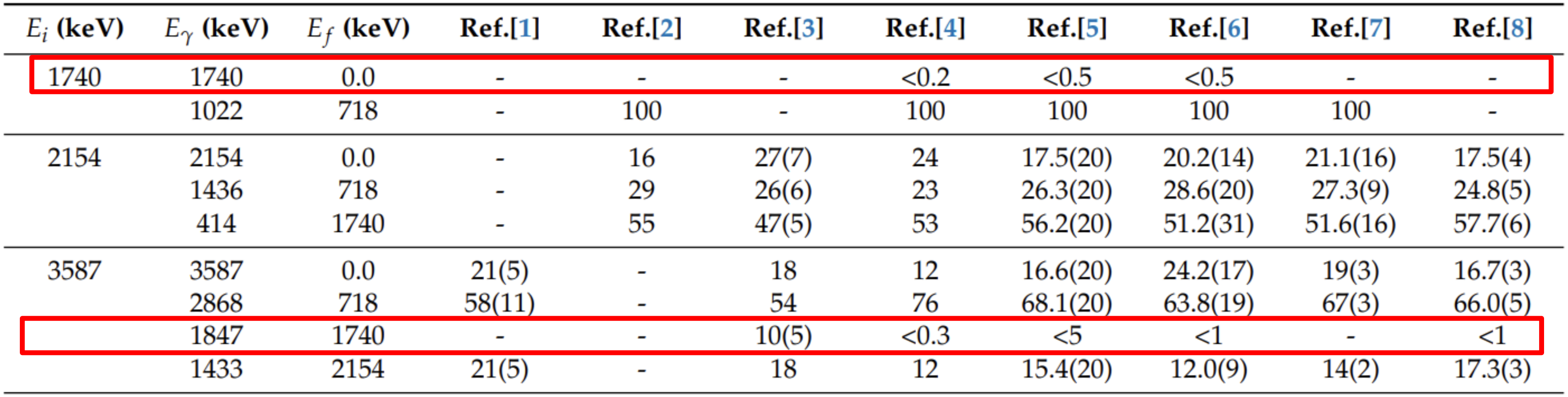
Weak branch!

Measure precisely M3 branch!

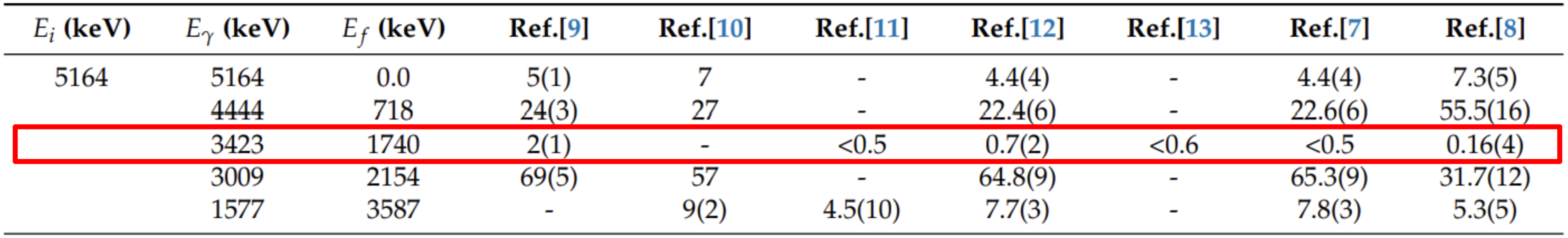
Weak branch!

$T_{1/2}$= 4.9(21) fs

Branching ratios of bound and unbound states in ^{10}B



E_i **(keV)**	E_γ **(keV)**	E_f **(keV)**	**Ref.[1]**	**Ref.[2]**	**Ref.[3]**	**Ref.[4]**	**Ref.[5]**	**Ref.[6]**	**Ref.[7]**	**Ref.[8]**
1740	1740	0.0	-	-	-	<0.2	<0.5	<0.5	-	-
	1022	718	-	100	-	100	100	100	100	-
2154	2154	0.0	-	16	27(7)	24	17.5(20)	20.2(14)	21.1(16)	17.5(4)
	1436	718	-	29	26(6)	23	26.3(20)	28.6(20)	27.3(9)	24.8(5)
	414	1740	-	55	47(5)	53	56.2(20)	51.2(31)	51.6(16)	57.7(6)
3587	3587	0.0	21(5)	-	18	12	16.6(20)	24.2(17)	19(3)	16.7(3)
	2868	718	58(11)	-	54	76	68.1(20)	63.8(19)	67(3)	66.0(5)
	1847	1740	-	-	10(5)	<0.3	<5	<1	-	<1
	1433	2154	21(5)	-	18	12	15.4(20)	12.0(9)	14(2)	17.3(3)

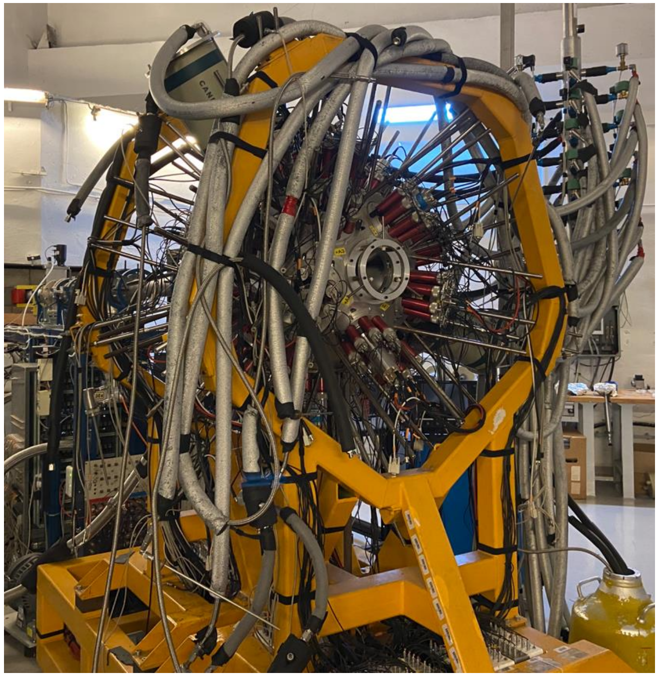


E_i **(keV)**	E_γ **(keV)**	E_f **(keV)**	**Ref.[9]**	**Ref.[10]**	**Ref.[11]**	**Ref.[12]**	**Ref.[13]**	**Ref.[7]**	**Ref.[8]**
5164	5164	0.0	5(1)	7	-	4.4(4)	-	4.4(4)	7.3(5)
	4444	718	24(3)	27	-	22.4(6)	-	22.6(6)	55.5(16)
	3423	1740	2(1)	-	<0.5	0.7(2)	<0.6	<0.5	0.16(4)
	3009	2154	69(5)	57	-	64.8(9)	-	65.3(9)	31.7(12)
	1577	3587	-	9(2)	4.5(10)	7.7(3)	-	7.8(3)	5.3(5)

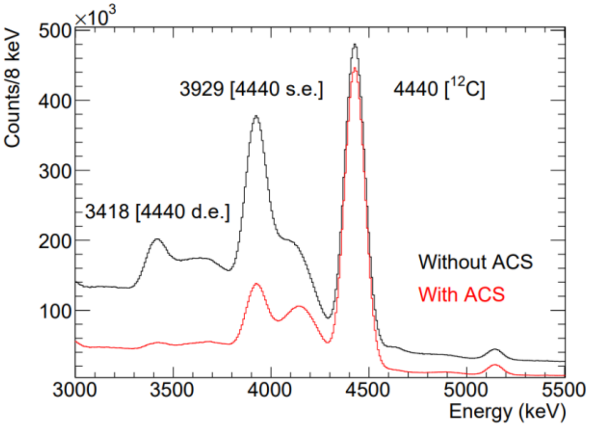
- ✓ *McCutchan, E.A.; et al. Phys. Rev. C* ***2012****, 86, 057306 and references therein*

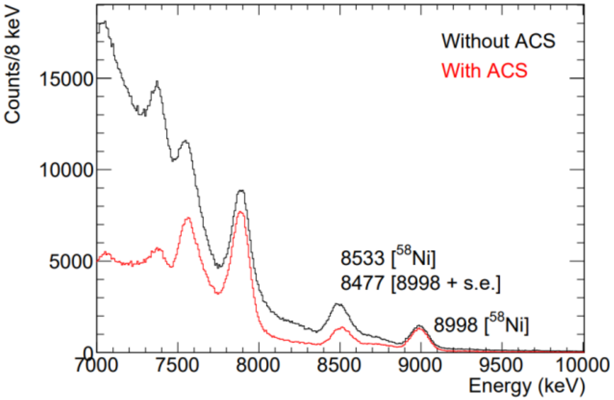
Experimental Details

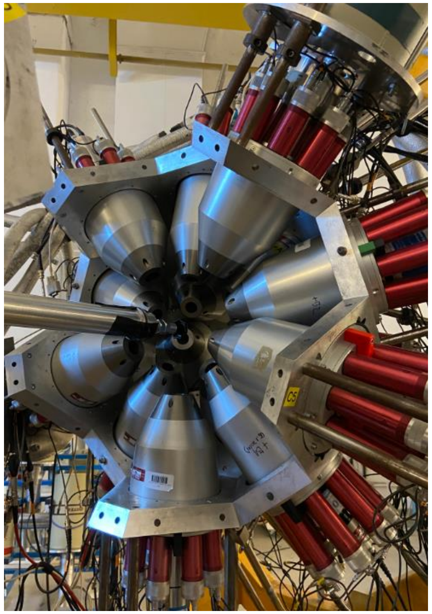
- How to measure the weak γ decay branches?



  - ELIFANT Array
  - 23 large volume (3″x 3″) $LaBr_3$:Ce and $CeBr_3$ detectors of ELI-NP and 2 HPGe
  - The mechanical structure of ROSPHERE consists five rings (+A, +B, C, -B, -A)
  - Combaning the large volume γ-ray detectors with the BGO anti-Compton shields of ROSPHERE array





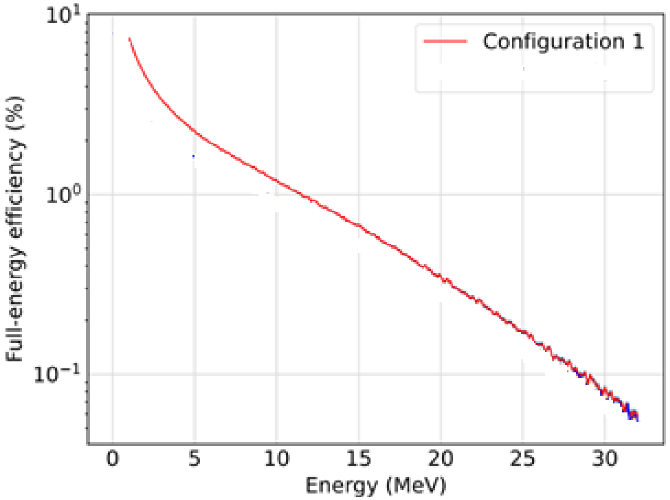


- ✓ *D. Bucurescu et. all, Nucl. Instrum. Methods Phys. Res. A., 837, 1-10 (2016)*
- ✓ *S. A ogaki et. all, manuscript (2023)*

Coursty of P.-A Söderström

Experimental Details

- ❑ The summed full-energy-peak efficiency of the scintillator detectors is 8% at 1.3 MeV, 2.5% at 5 MeV and 1.2% at 10 MeV (w/o front mounted collimators).
- ❑ Collimators reduce the efficiency ~50%
- ❑ Energy resolution is 1.3% at 9 MeV and timing resolution 260 ps for $LaBr_3$:Ce and 450 ps for the $CeBr_3$ detectors
- ❑ Clean spectra and sensitivity to weak branches because of high efficiency
- ❑ Possibility for angular distrubitions in γγ coincidence measurement



✓ *D. Bucurescu et. all, Nucl. Instrum. Methods Phys. Res. A., 837, 1-10 (2016)*

✓ *S. A ogaki et. all, manuscript (2023)*

Coursty of P.-A Söderström

Experimental Details

Reaction: **$^{10}B(p, p')^{10}B^*$**

- ☐ Target thickness: **30mg/cm^2** (~128μm) → **E_p = 8.5 MeV, I_p = 0.8 nA**

9MV Tandem @IFIN-HH

- ☐ mount nose-cone shielding for the BGO
- ☐ applied Compton rejection in the DAQ hardware

Primary goal: **MEASURE THE BRANCHING OF WEAK TRANSITIONS**

(1.85 MeV, $2^+ \rightarrow 0^+$), (1.74 MeV, $0^+ \rightarrow 3^+$) and (3.42 MeV, $2^+ \rightarrow 0^+$)

- ☐ low decay probability → large statistics

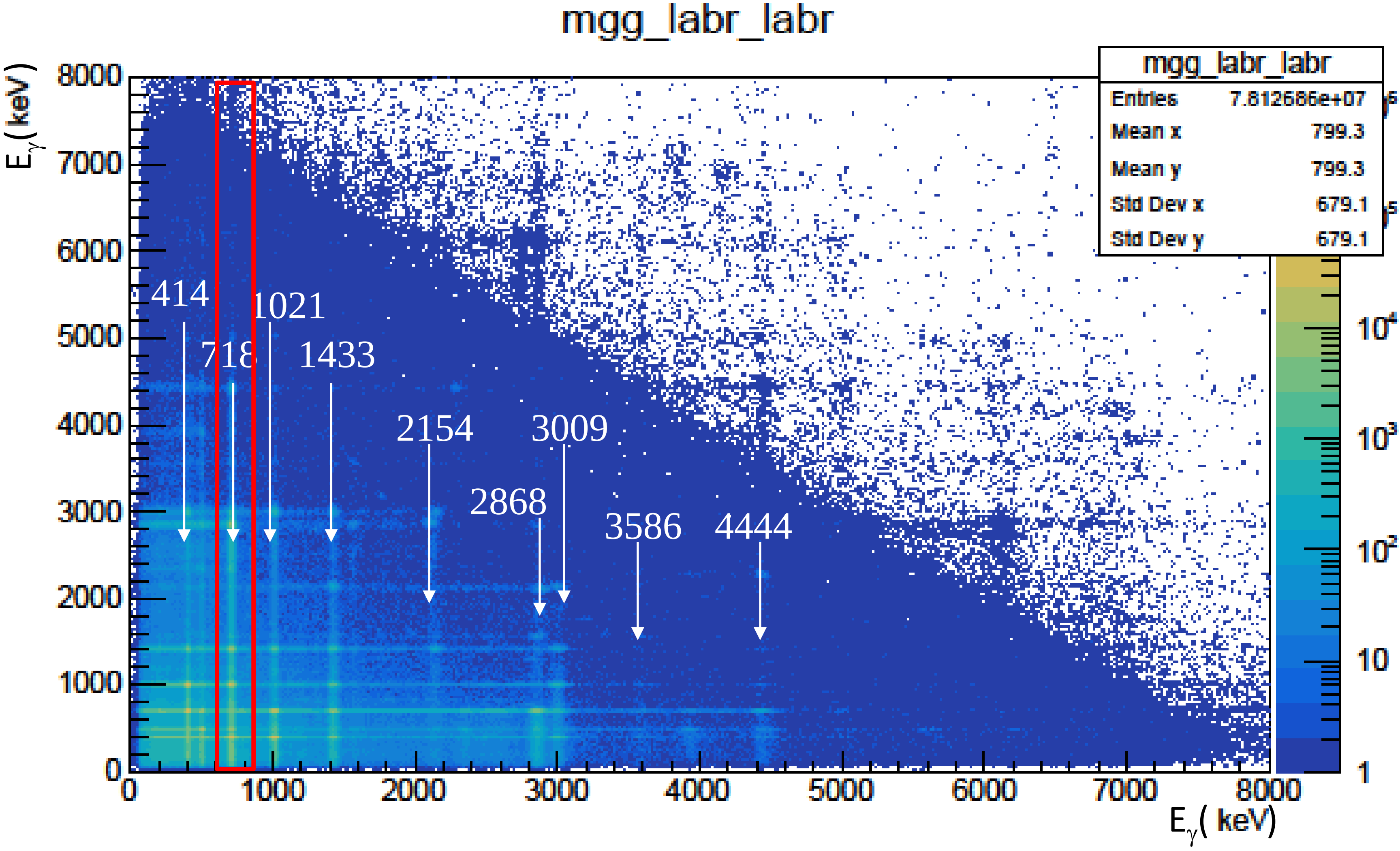
Secondary goal **ANGULAR DISTRIBUTION ANALYSIS**

$2^+ \rightarrow 1^+$ at 1.44 & 2.87 MeV, $2^+ \rightarrow 2^+$ at 5.16 MeV

- ☐ multipole mixing → angular distrubition analysis
- ☐ large decay probability

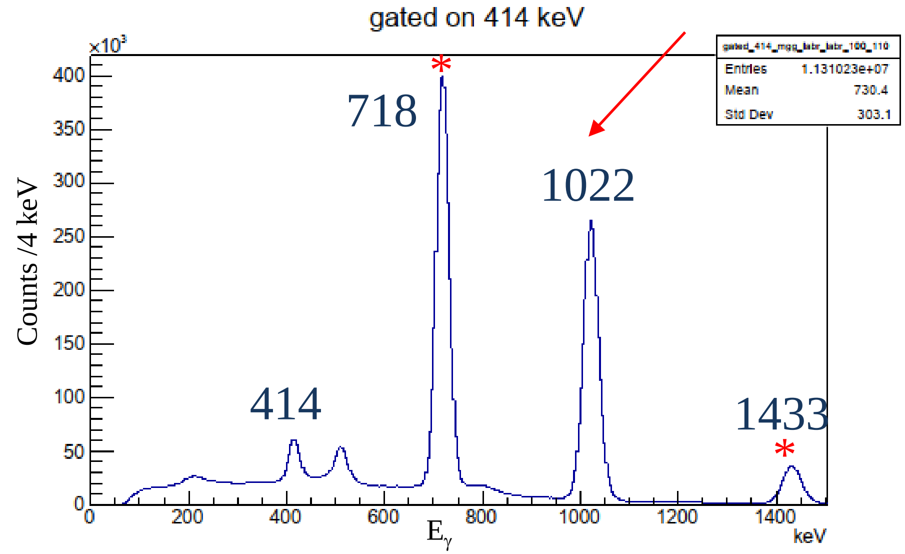
Results from Measurements

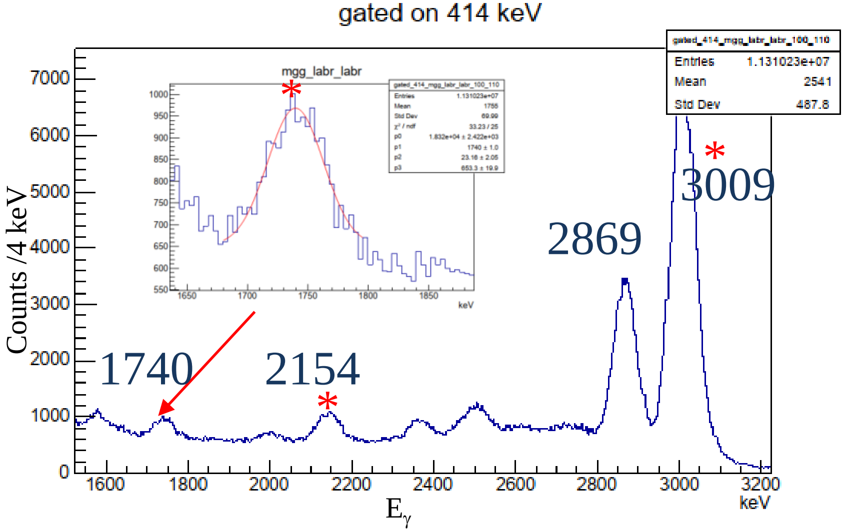
- Gamma-gamma matrix produced within 5 ns coincidence gate

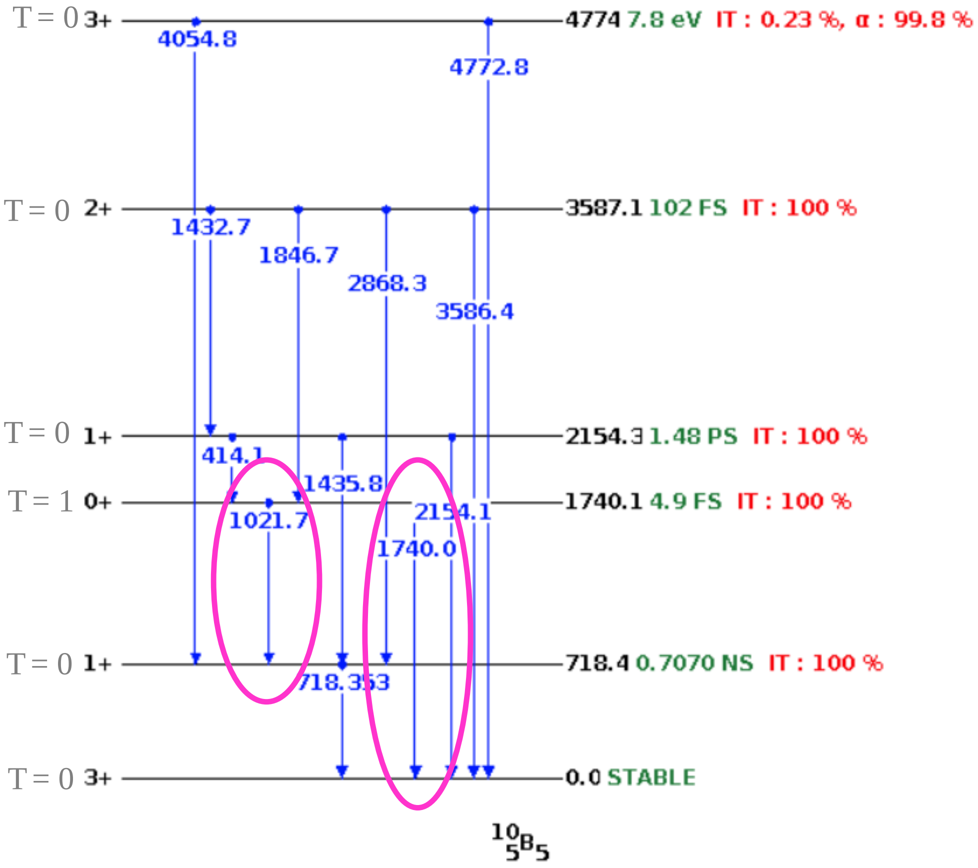


Results from Measurements

- Observation of the decay of the 1.74 MeV T=1 0^+ state

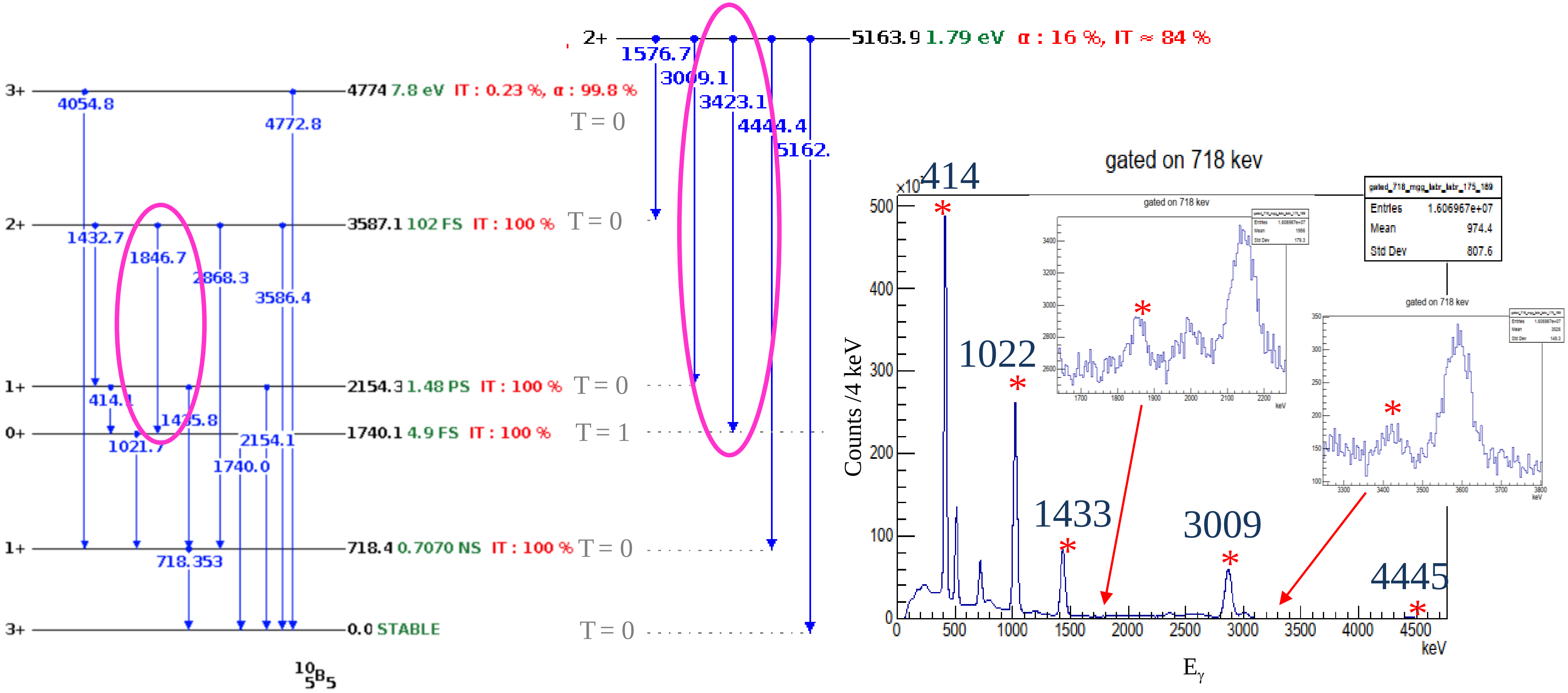






Results from Measurements

- Observation of the decay of the 3.58 MeV (T=0, 2^+) and 5.12 MeV (T=1, 2^+) states



Discussion

- What comes next?
  - Angular correlations of ^{10}B transitions
  - Need of more precise measurement of the lifetime at 1.74 MeV state 1^+ (T =1) → 0^+ (T = 0), 4.9±2.1 fs with self-absorbsition technique
  - Constraction of ab-initio calculations (contact Furong Xu’s group)
    - ✓ *P. Choudhary et. all, Phys. Rev. C 102, 044309 (2020)*
  - Other interesting problems to be addressed
    - Molecular (cluster) states
      - ✓ *M. A. Caprio et. all, Bulgarian Journal of Physics., 46, 445-454 (2019)*
    - Comparision of M1 currents in ^{6}Li and ^{10}B
    - Understanding the structure of 1.74 MeV, T=1, 0^+ state
  - Data on angular distrubution and understand multipolarity and 60 years later positive achivement

Collaboration:

ELI-NP core team:

- D. Balabanski
- P. Constantin
- P.-A. Söderström
- D. Testov
- M. Cuciuc
- S. Aogaki
- A. Pappalardo

IFIN-HH core team:

- C. Mihai
- R. Borcea
- L. Stan
- A. Turturica
- C. Costache
- R. Mihai
- S. Ujeniuc
- N. M. Florea

THANK YOU!

Acknowledgements: This work is carried out under the contract PN 23 21 01 06 sponsored by the Romanian Ministry of Research, Innovation and Digitalization.