DE LA RECHERCHE À L'INDUSTRIE

Measurement of the γ emission probability of ^{173}Yb using transfer reactions

O. Delaune, A. Blanc, P. Chau, V. Méot, O. Roig
CEA, DAM, DIF
J.T. Burke, R. Casperson
LLNL
M. McCleskey, E. Simmons
Texas A&M University

www.cea.fr

Purpose: cross section measurement

Neutron-induced reaction

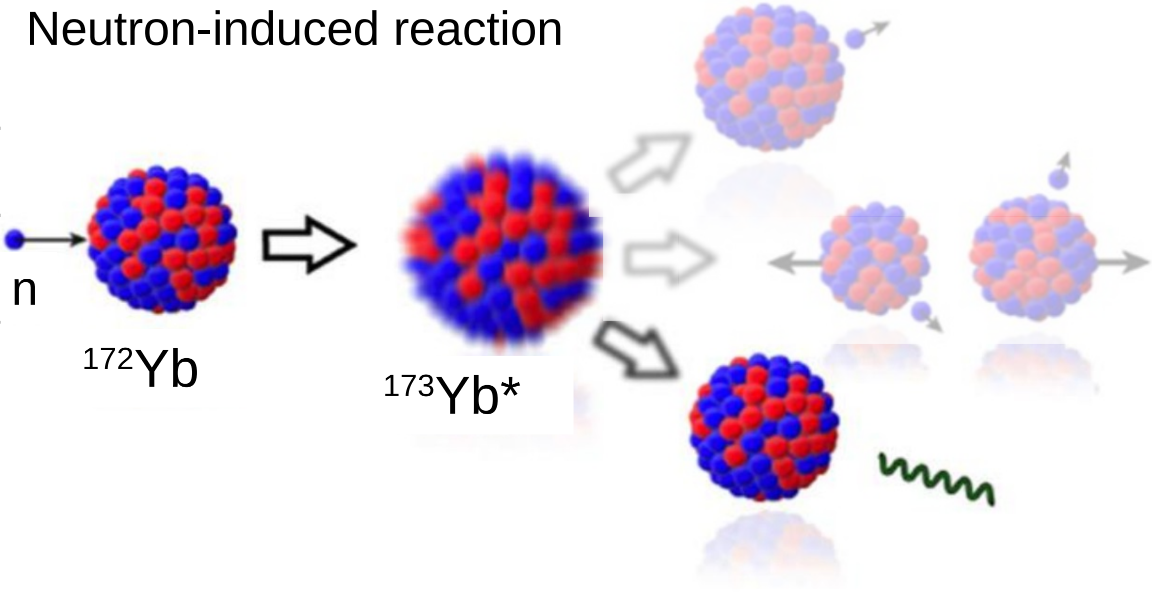


Fig. from Escher *et al.*, Rev. Mod. Phys **84** (2012) 353

^{172}Yb(n,γ)^{173}Yb

Difficulty: radioactive target

Purpose: cross section measurement

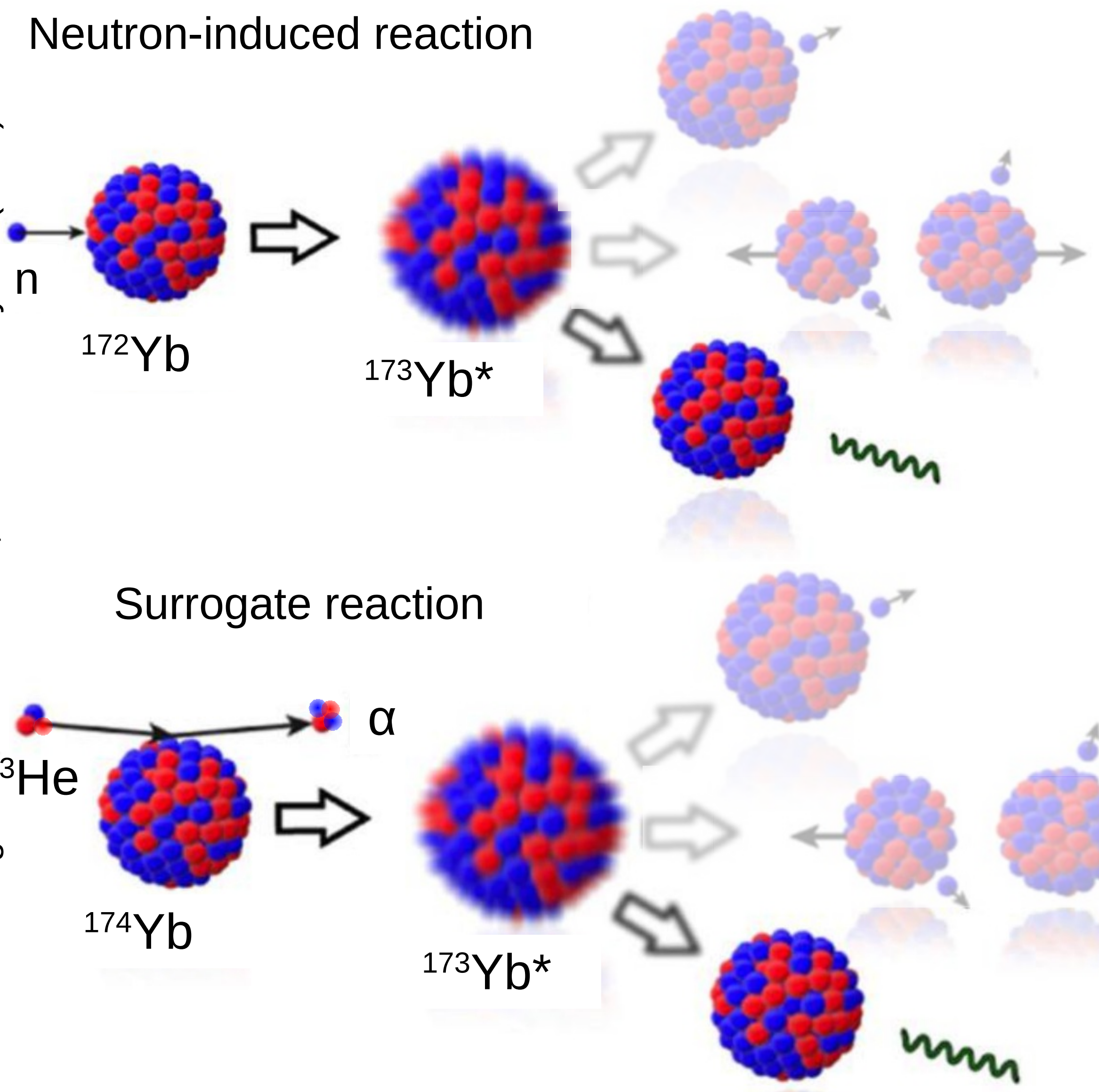


Fig. from Escher *et al.*, Rev. Mod. Phys **84** (2012) 353

^{172}Yb(n,γ)^{173}Yb

Difficulty: radioactive target

"Solution (?)": determine the radiative neutron capture cross sections from the measurement of the γ deexcitation probability

^{174}Yb(^{3}He,αγ)^{173}Yb

Surrogate reaction method validity

$$\sigma^{A-1}_{(n,\gamma)}(E_n) \approx \sigma^{A}_{CN}(E_n)\ P^{A}_{\gamma}(E^*)$$

Probability to produce the compound nucleus

Probability to decay

Optical model

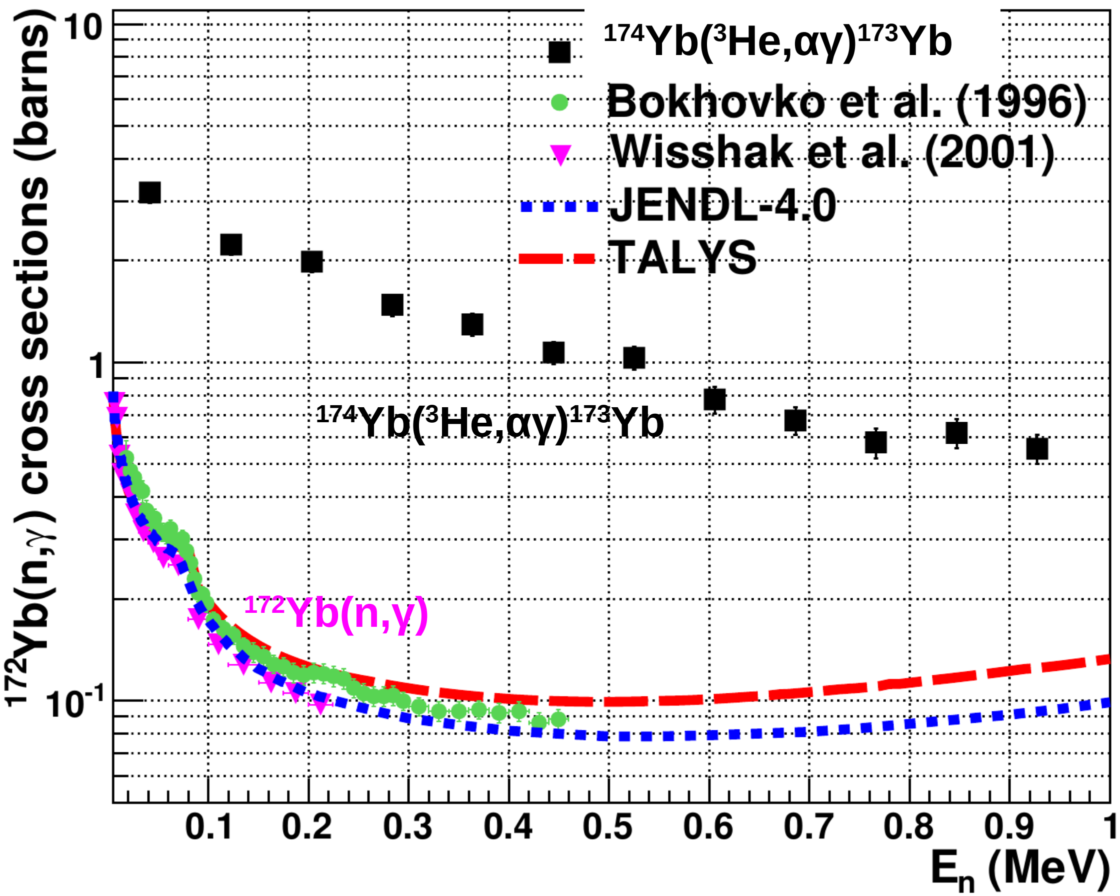
$$=\Sigma_{J,\pi} F(E^*,J,\pi) G_{dec}(E^*,J,\pi)$$

F: probability that the nucleus be produced in a state J,π

G_{dec}: branching ratio for a given decay mode (n or γ)

Is that $F_{neutron}(E^*,J,\pi) = F_{surrogate}(E^*,J,\pi)$?

Surrogate reaction method validity



$\sigma(^{172}$Yb(n,γ)) known[1]

$F_{n\gamma}(E^*,J,\pi) \neq F_{3He,\alpha\gamma}(E^*,J,\pi)$
→ spin distribution higher[2]

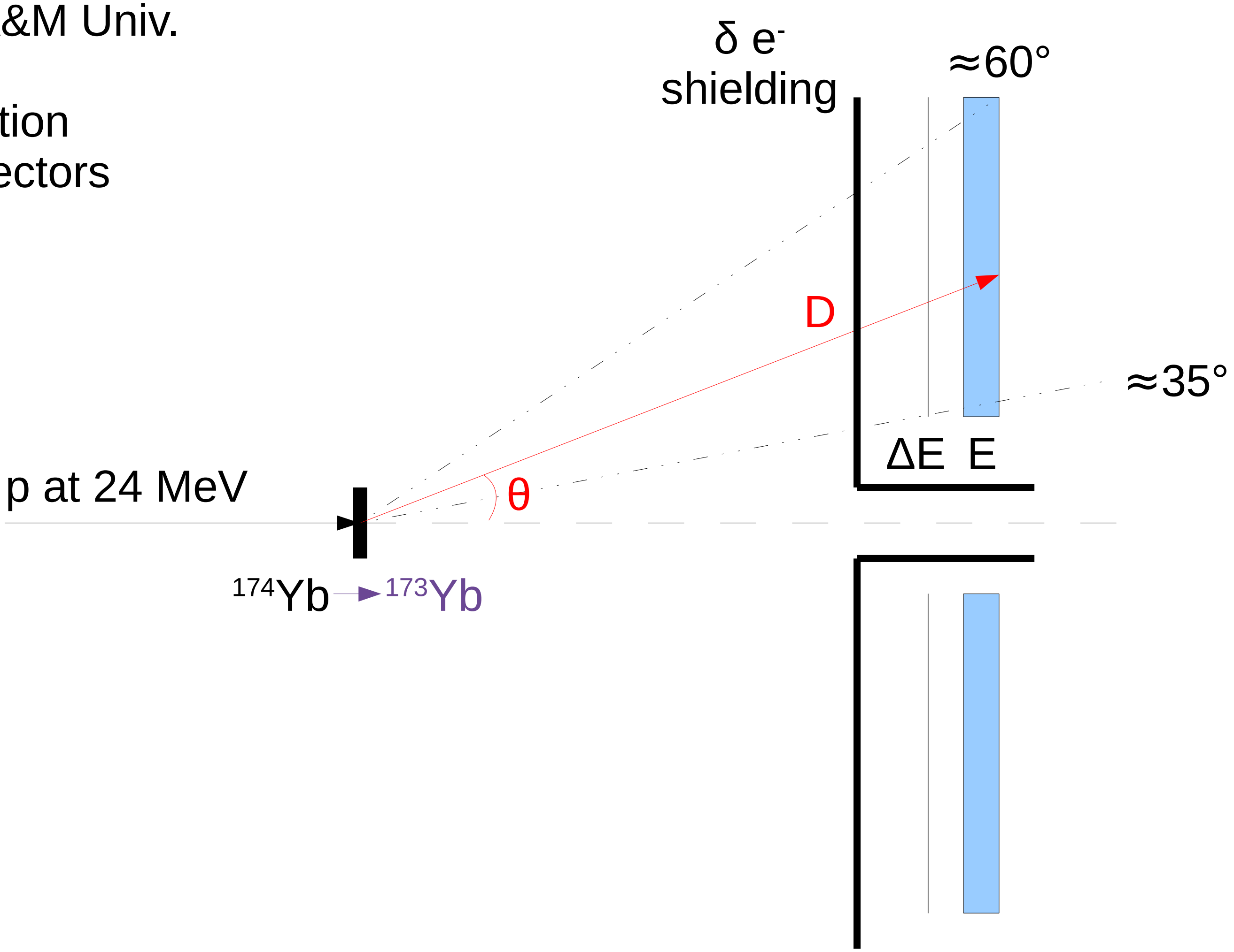
(p,d) reaction: decrease of the transferred angular momentum?

[1] K. Wisshak *et al.*, Phys. Rev. C **61** 065801 (2000)
[2] G. Boutoux *et al.*, Phys. Lett. B **712** 319 (2012)

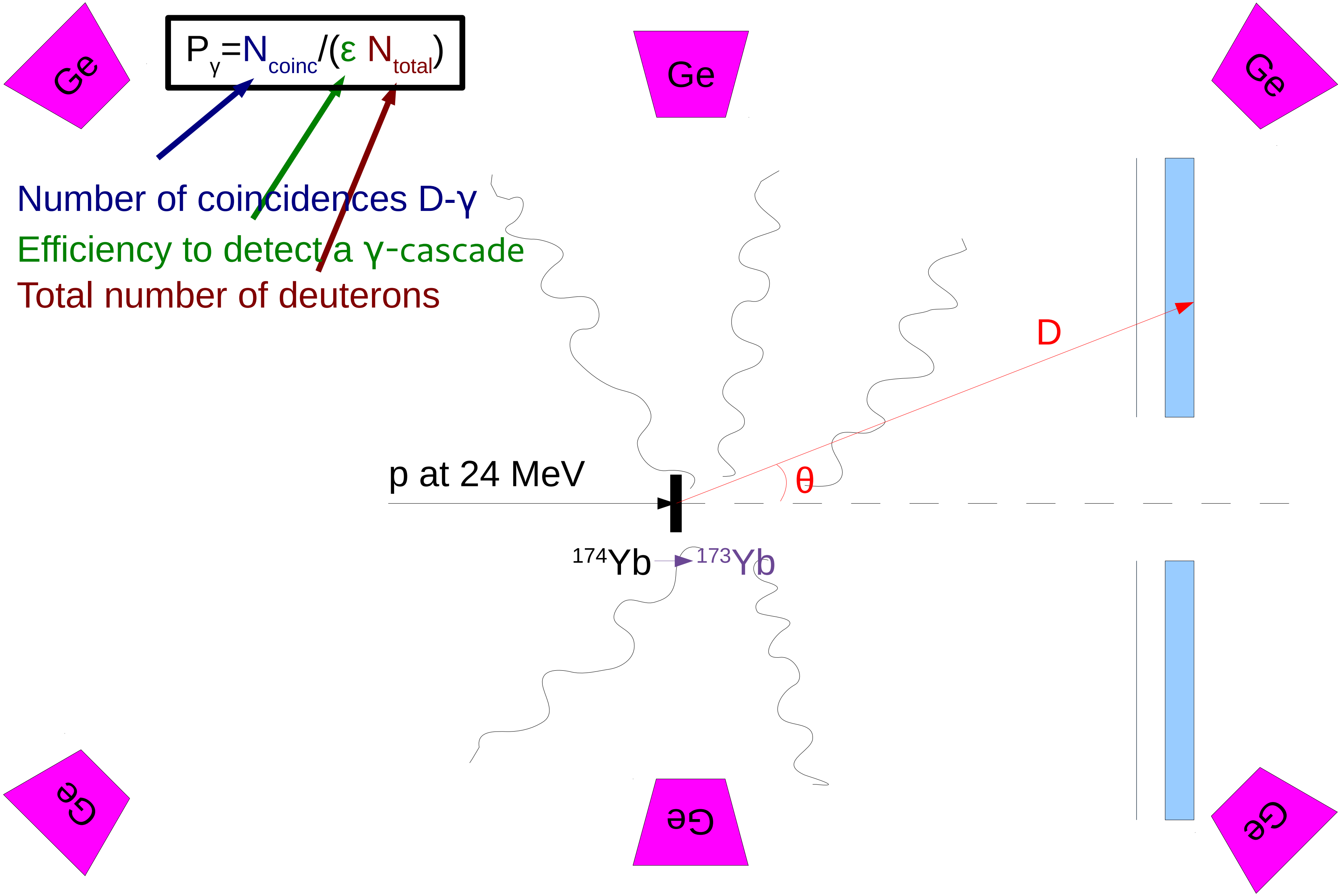
Experimental setup

Performed at Texas A&M Univ.

STARLiTeR collaboration
STARS/LiBerAce detectors



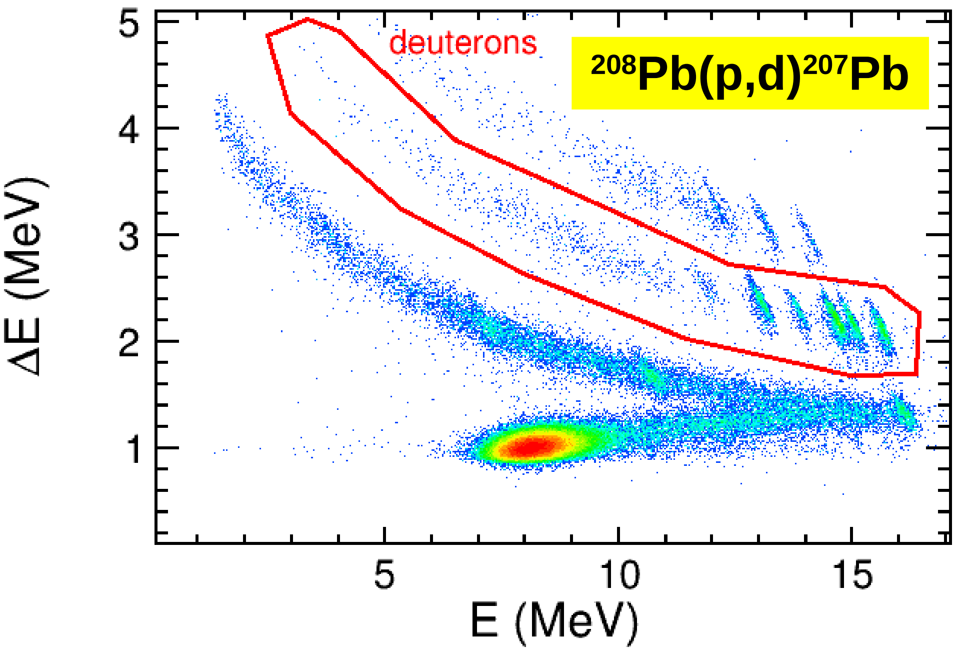
Experimental setup



Energy calibration

- **<u>Silicon calibration</u>**

Calibration of the ΔE and the E detectors using an α source (^{226}Ra)
From ~ 4,5 to 8 MeV



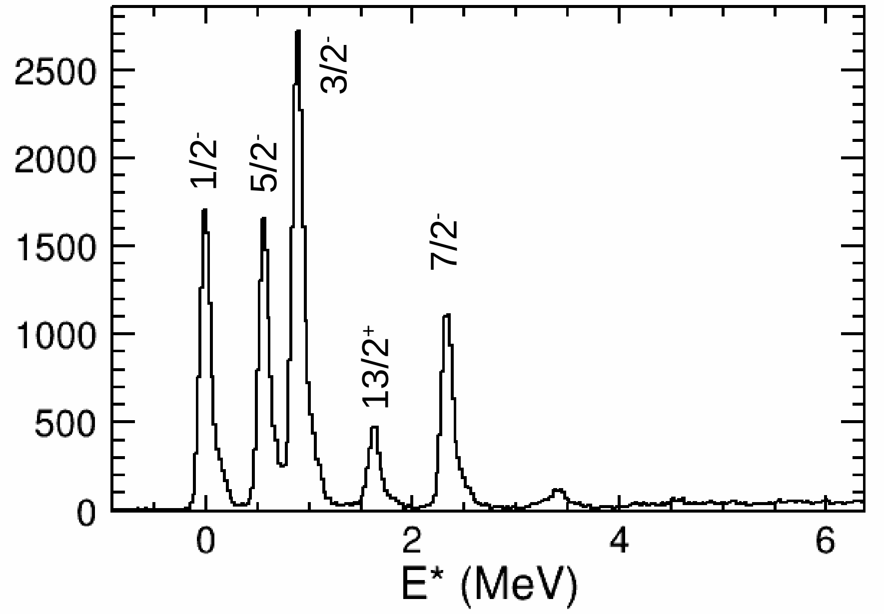
Calibration check using the excited states of ^{207}Pb
Check of the beam energy

- **<u>Germanium calibration</u>**

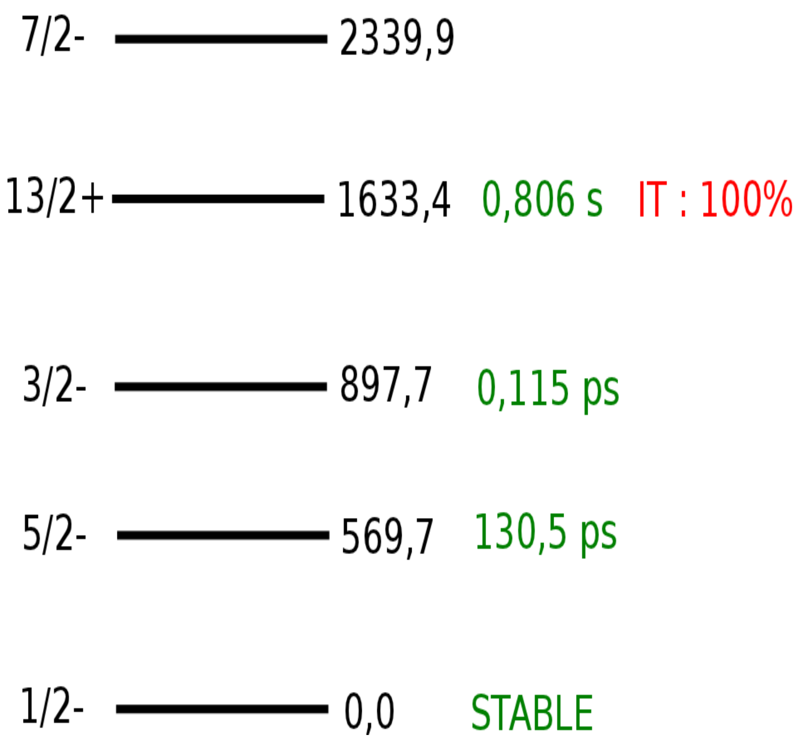
Calibration using several sources (^{60}Co, ^{22}Na, ^{133}Ba, ^{109}Cd, ^{54}Mn)
From ~ 160 to 1300 keV

^{207}Pb excitation energy calibration

^{208}Pb(p,d)^{207}Pb

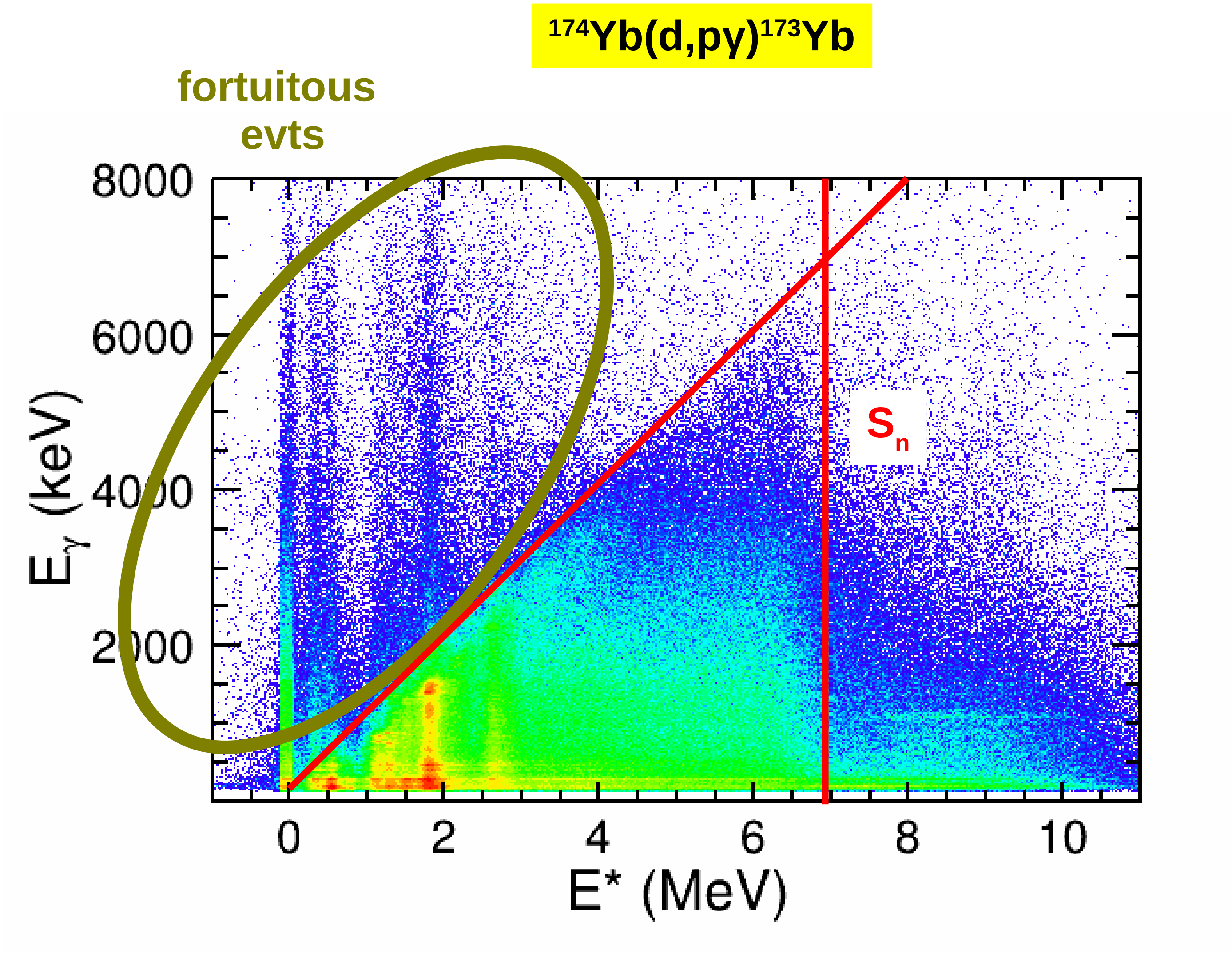


FWHM ≈ 120-130 keV over all the range



$$E^* = Q + T_{beam} - T_{deuteron} - 1/M_{recoil}(M_{beam}T_{beam} + M_{deuteron}T_{deuteron} - 2\cos(\theta_{deuteron})\sqrt{(M_{beam}T_{beam}M_{deuteron}T_{deuteron})})$$

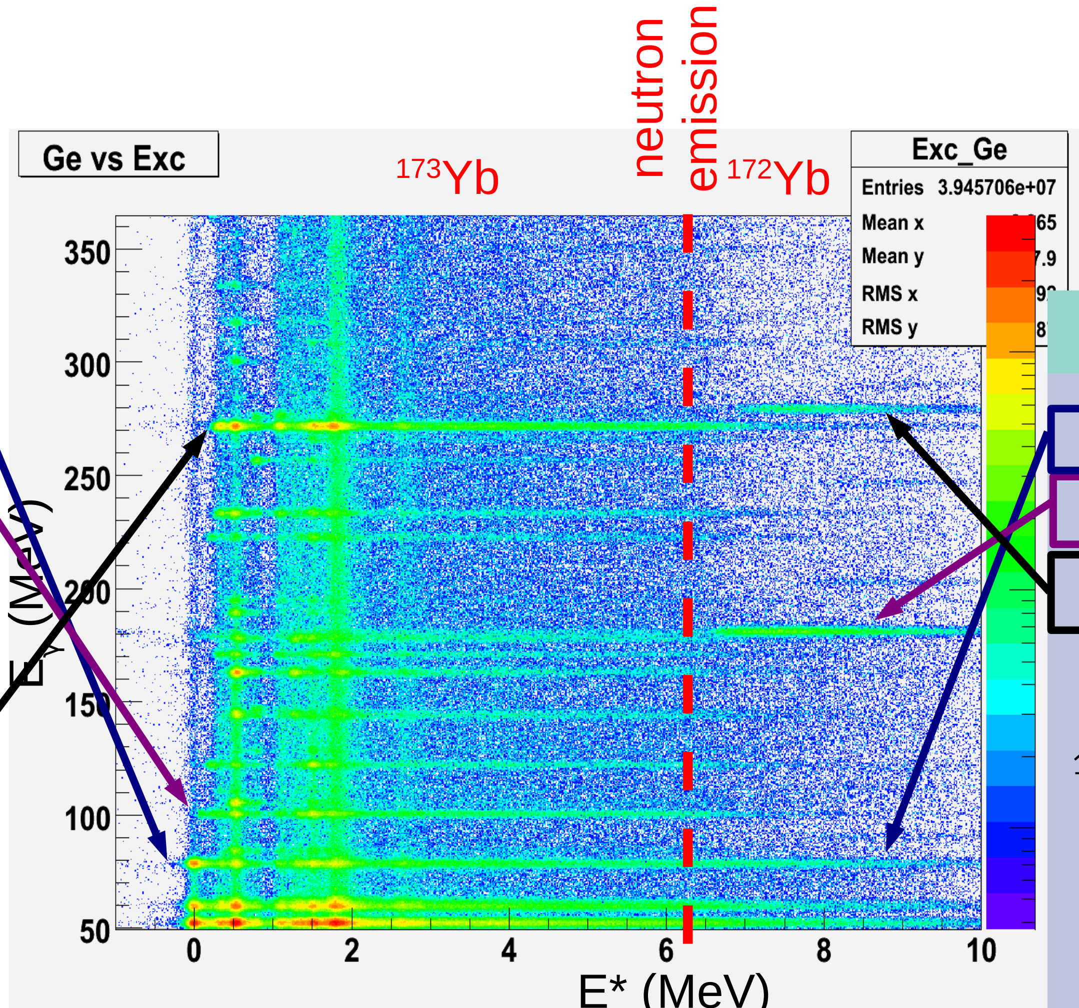
Consistency of the ^{173}Yb excitation energy



Consistency of the excitation energy

^{173}Yb

Elevel (keV)	Eγ (keV)
0.0	
78.647 *12*	78.63 *3*
179.364 *9*	100.724 *20* 179.365 *11*
301.859 *14*	122.55 *3* 223.163 *20*
350.764 *10*	171.393 *13* 272.105 *15* 350.774 *18*



^{172}Yb

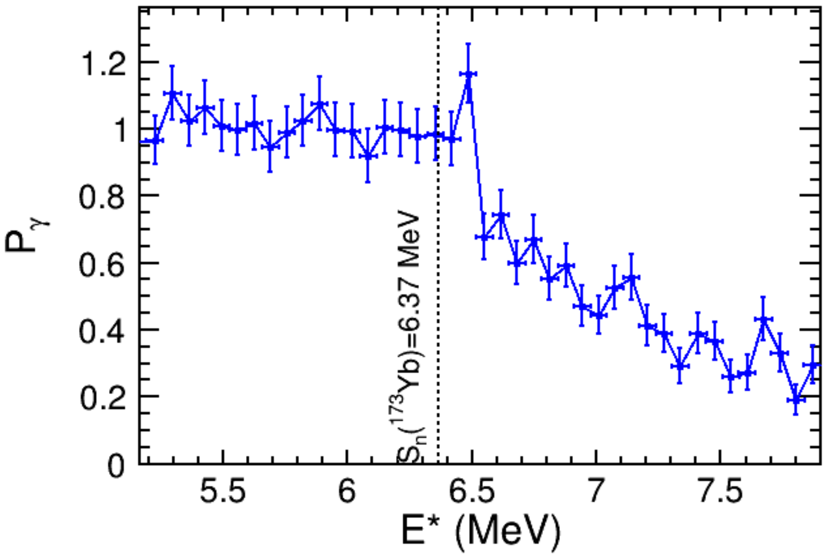
Elevel (keV)	Eγ (keV)
0.0	
78.7427 *6*	78.7426 *6*
260.268 *5*	181.528 *4*
539.977 *6*	279.717 *5*
912.12 *7*	372.06 *10*
1042.914 *18*	964.09 *5* 1042.926 *22*
1117.874 *5*	857.636 *7* 1039.149 *10* 1117.94 *3*

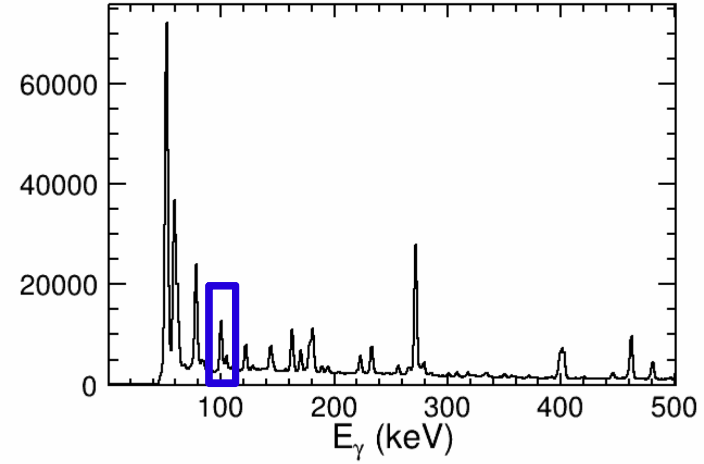
P_γ extraction of ^{173}Yb

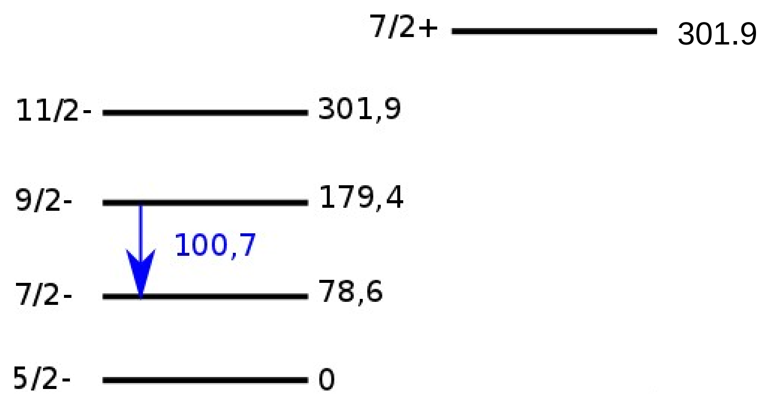
Usually (even-even nucleus), one tags on a given γ-transition on which the γ-cascade terminates.

Problem: biaised if some cascades do not pass through this transition
Need to have a very good knowledge of the level scheme

$$P_\gamma = N_{coinc} / (N_{total}\ \varepsilon)$$





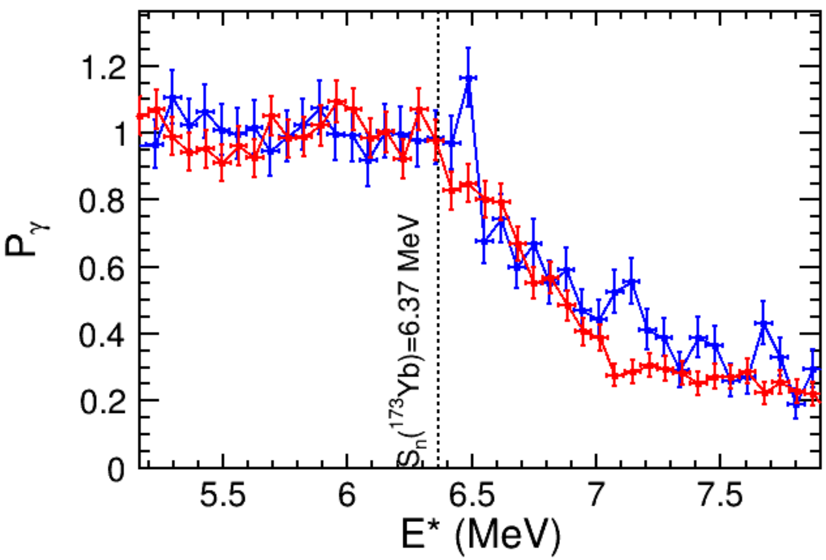


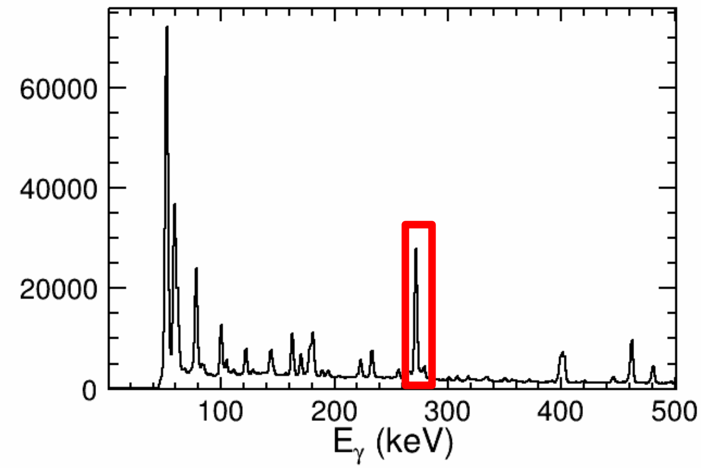
P_γ extraction of ^{173}Yb

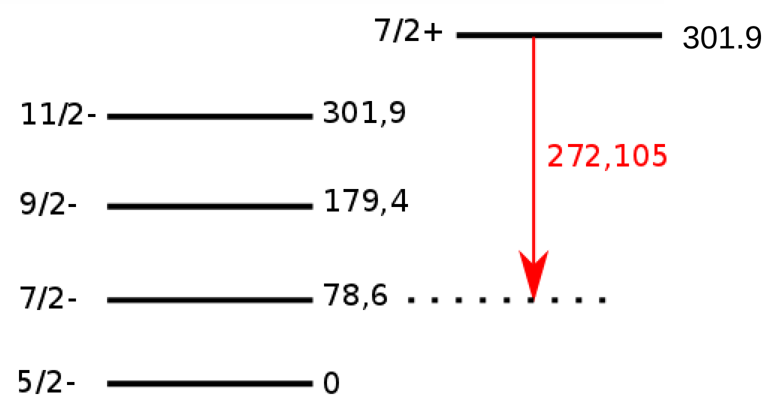
Usually (even-even nucleus), one tags on a given γ-transition on which the γ-cascade terminates.

Problem: biaised if some cascades do not pass through this transition
Need to have a very good knowledge of the level scheme

$$P_\gamma = N_{coinc}/(N_{total}\ \varepsilon)$$





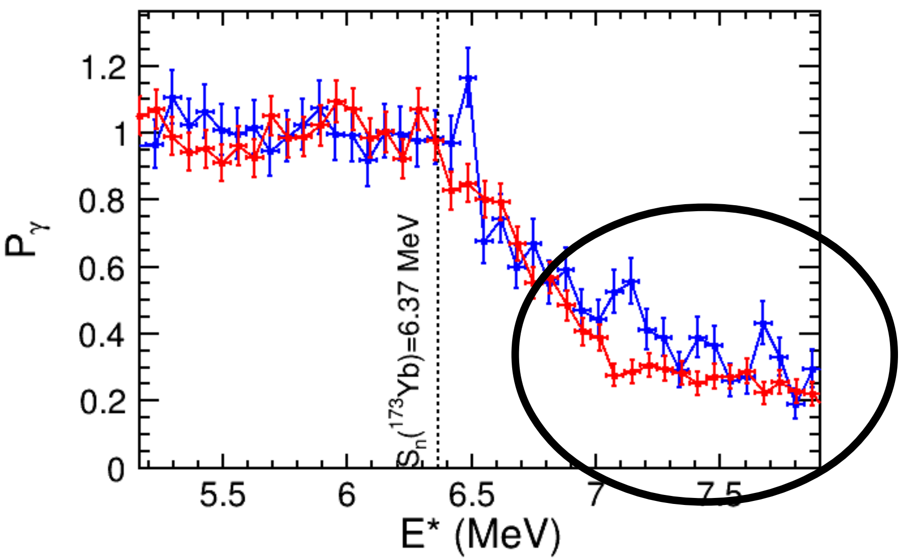


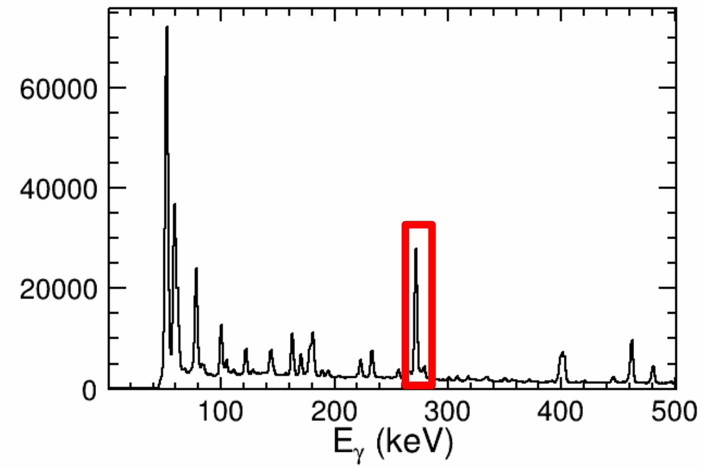
P_γ extraction of ^{173}Yb

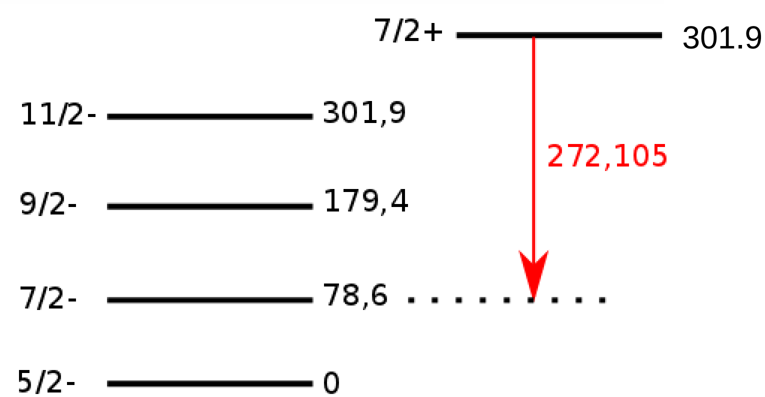
Usually (even-even nucleus), one tags on a given γ-transition on which the γ-cascade terminates.

Problem: biaised if some cascades do not pass through this transition
Need to have a very good knowledge of the level scheme

$P_\gamma = N_{coinc} / (N_{total}\ \varepsilon)$

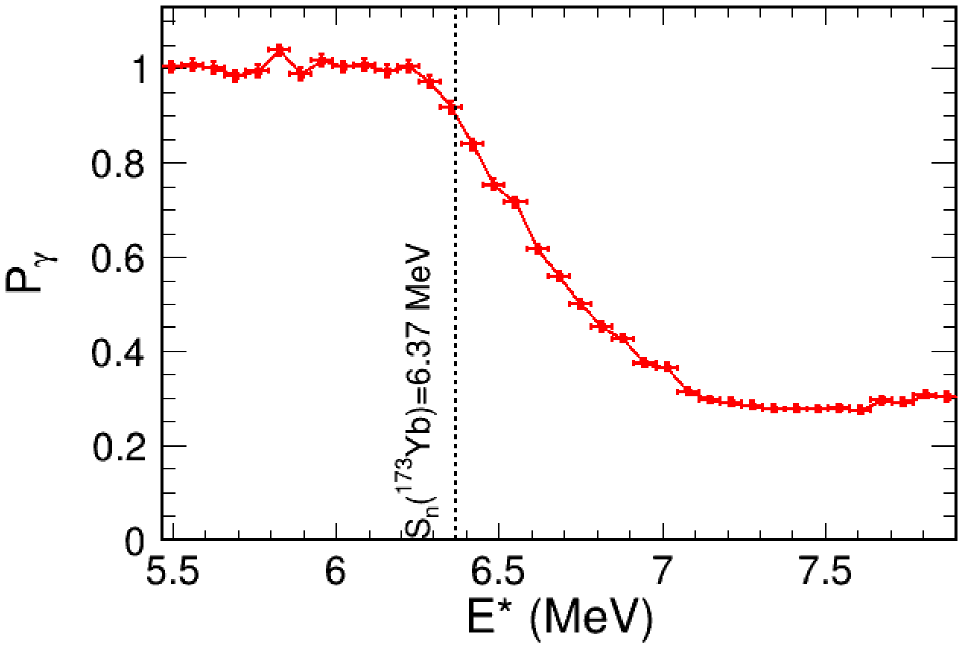


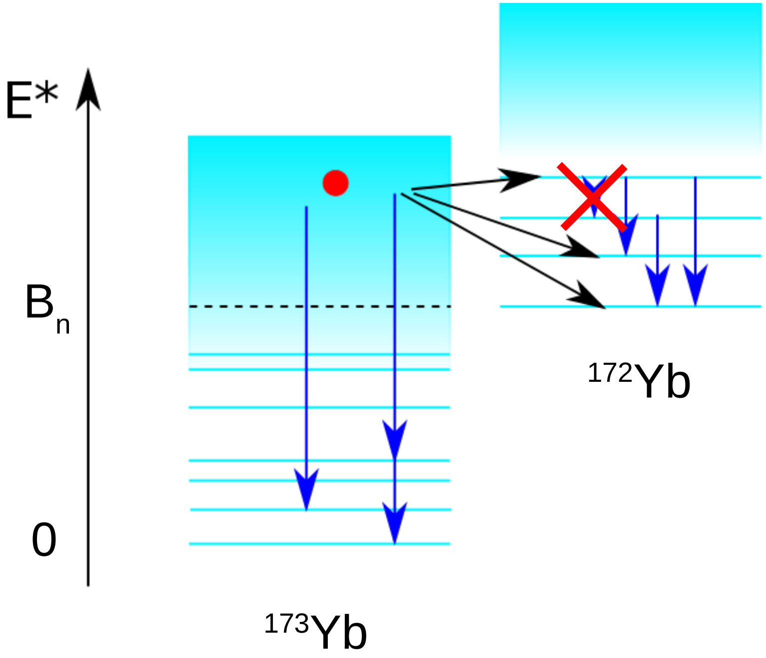




Use of an original method
to bypass this problem

P_γ of ^{173}Yb using the “statistical γ-rays”

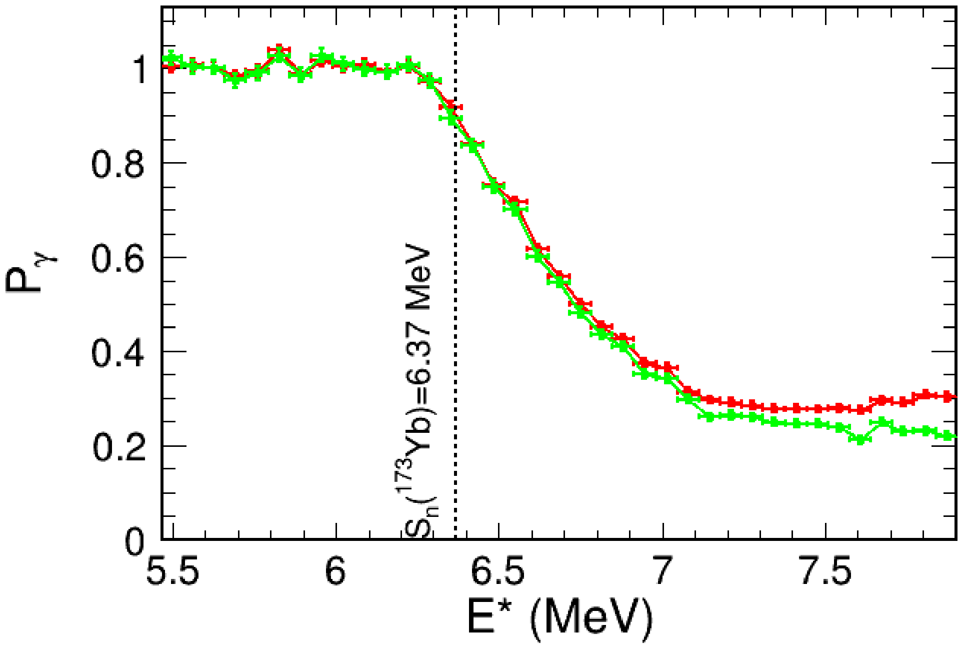


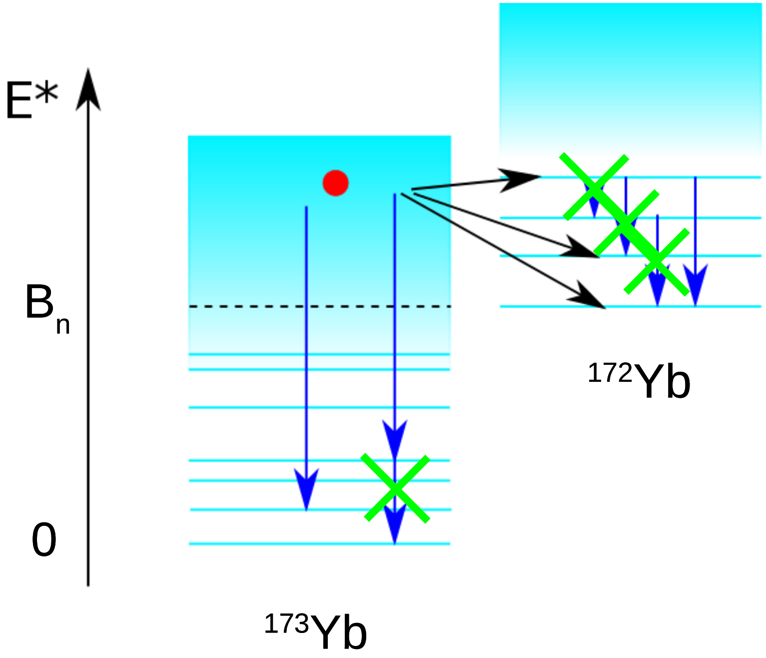


E_γ>0.5 MeV

Electronics: low gain for the Germanium detectors (E_γ up to ~10 MeV)
One counts all the γ-rays with an energy greater than a given energy
Cut in energy to remove all the γ-rays coming from the ^{172}Yb

P_γ of ^{173}Yb using the "statistical γ-rays"

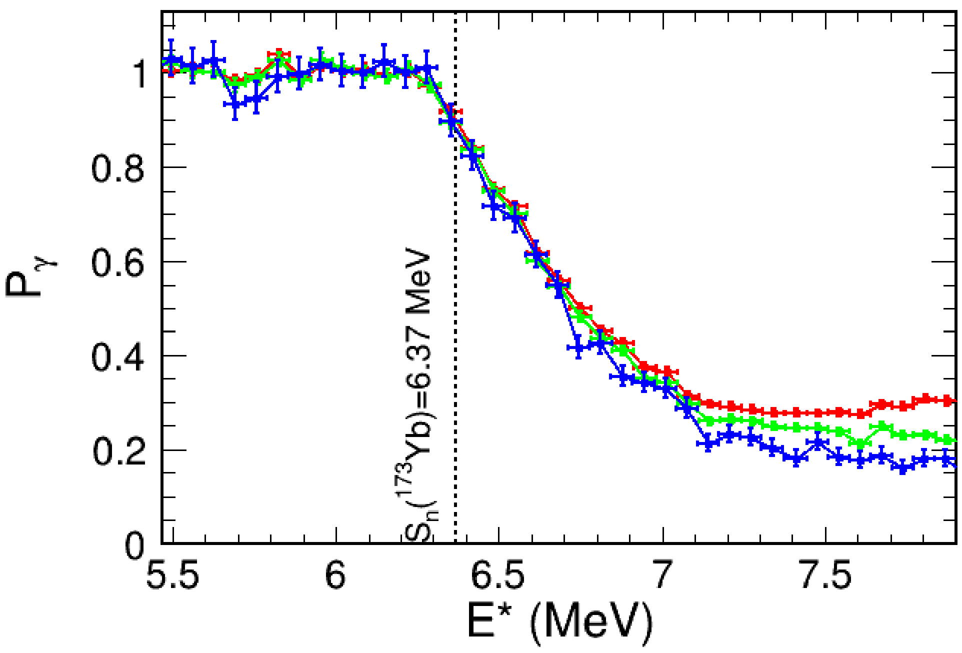


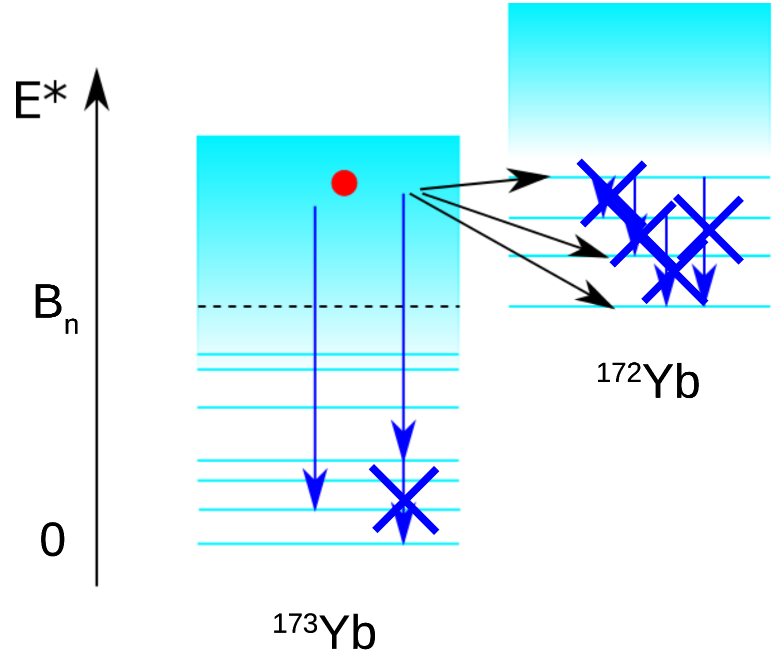


E_γ>1.0 MeV

Electronics: low gain for the Germanium detectors (E_γ up to ~10 MeV)
One counts all the γ-rays with an energy greater than a given energy
Cut in energy to remove all the γ-rays coming from the ^{172}Yb

P_γ of ^{173}Yb using the "statistical γ-rays"





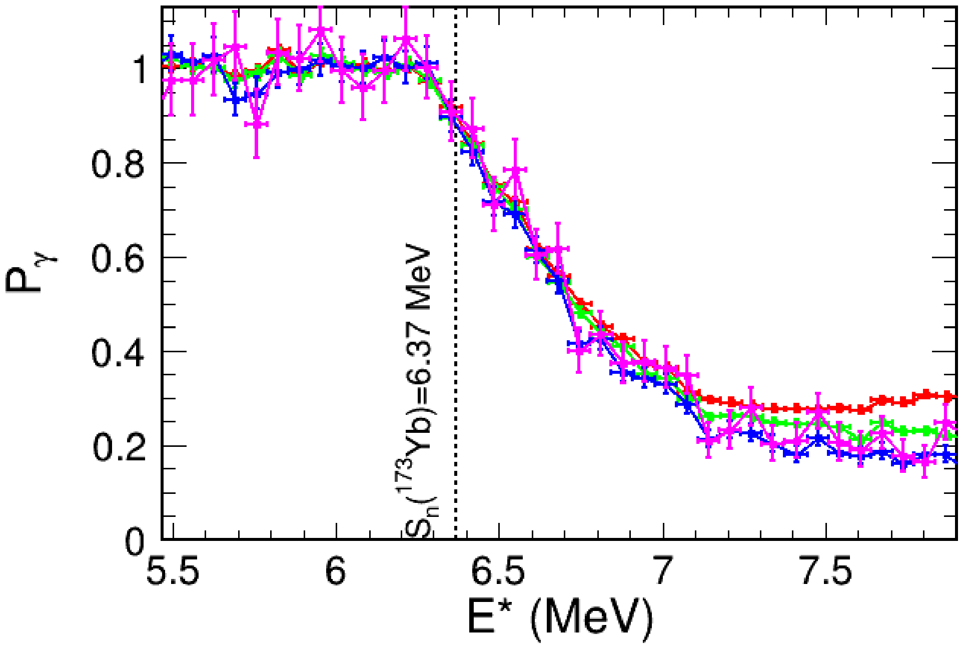
E_γ>3.0 MeV

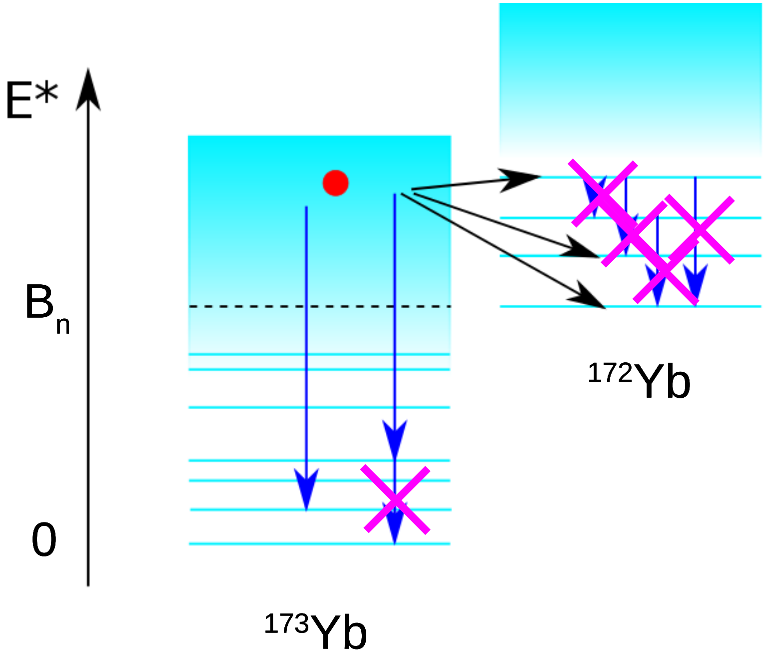
Electronics: low gain for the Germanium detectors (E_γ up to ~10 MeV)

One counts all the γ-rays with an energy greater than a given energy

Cut in energy to remove all the γ-rays coming from the ^{172}Yb

P_γ of ^{173}Yb using the "statistical γ-rays"





Above a given threshold, all the γ-rays coming from the ^{172}Yb are removed

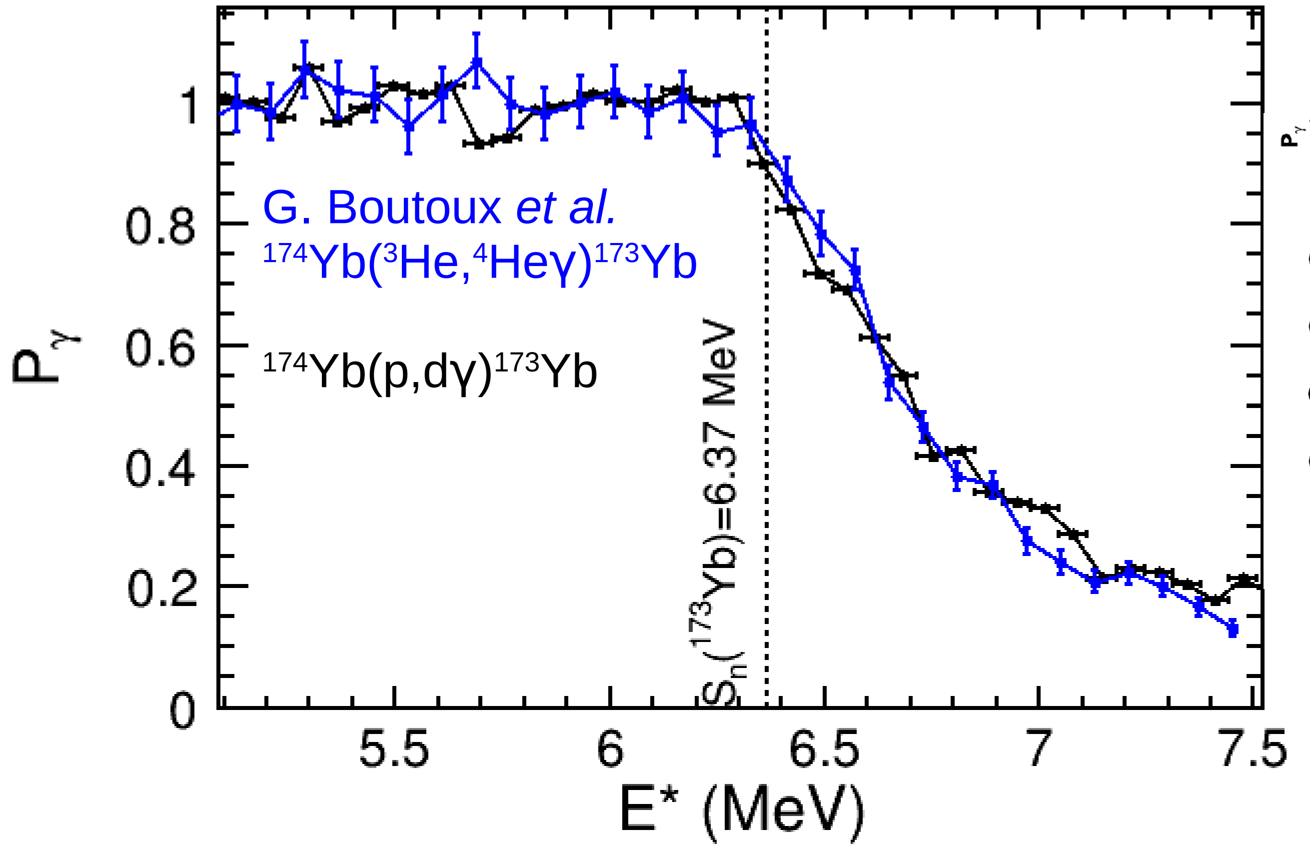
$E_\gamma > 4.0$ MeV

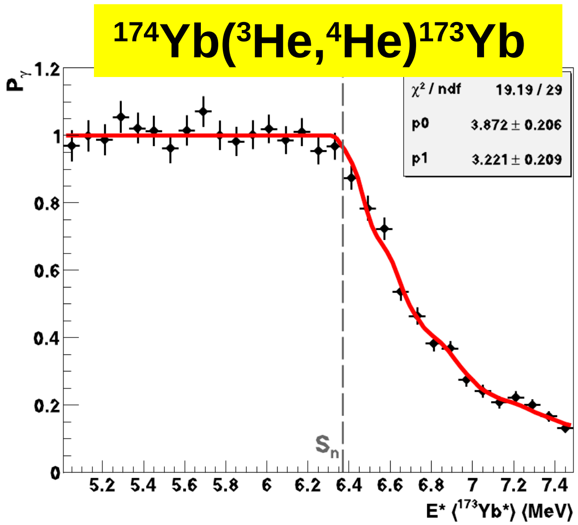
Electronics: low gain for the Germanium detectors (E_γ up to ~10 MeV)

One counts all the γ-rays with an energy greater than a given energy

Cut in energy to remove all the γ-rays coming from the ^{172}Yb

Spin distribution



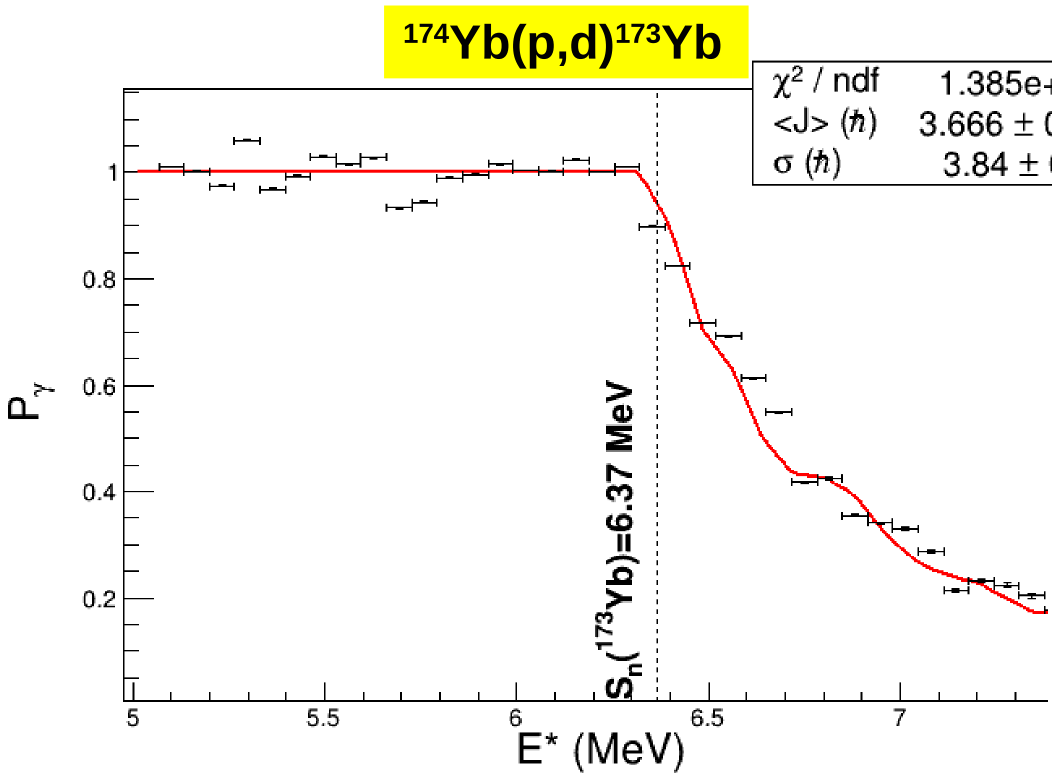


Same P_γ between both reactions

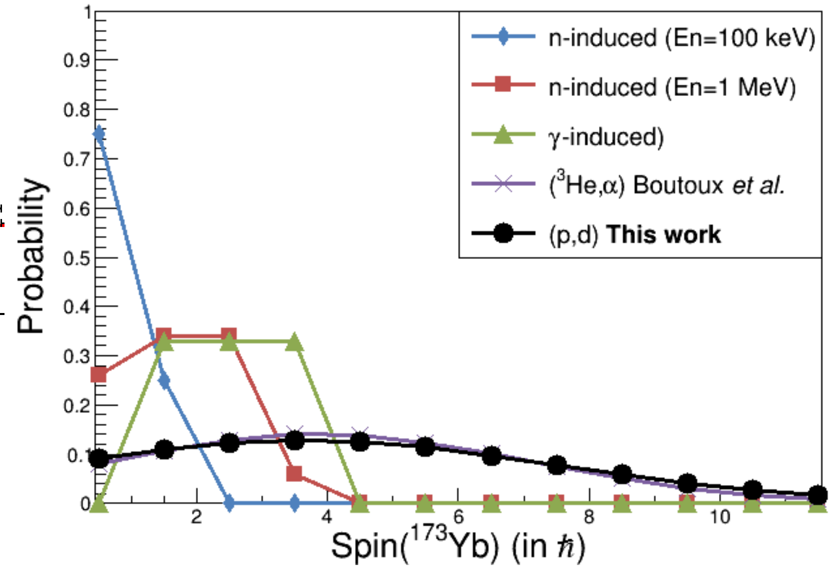
⇨ spin-parity distribution almost identical

(<ℓ> = 3.8ħ, σ=3.2ħ from G. Boutoux *et al.*, Phys. Lett. B **712** 319 (2012))

Spin distribution



Fit hypothesis:
- Gaussian spin distribution
- Same weight for +/- parities

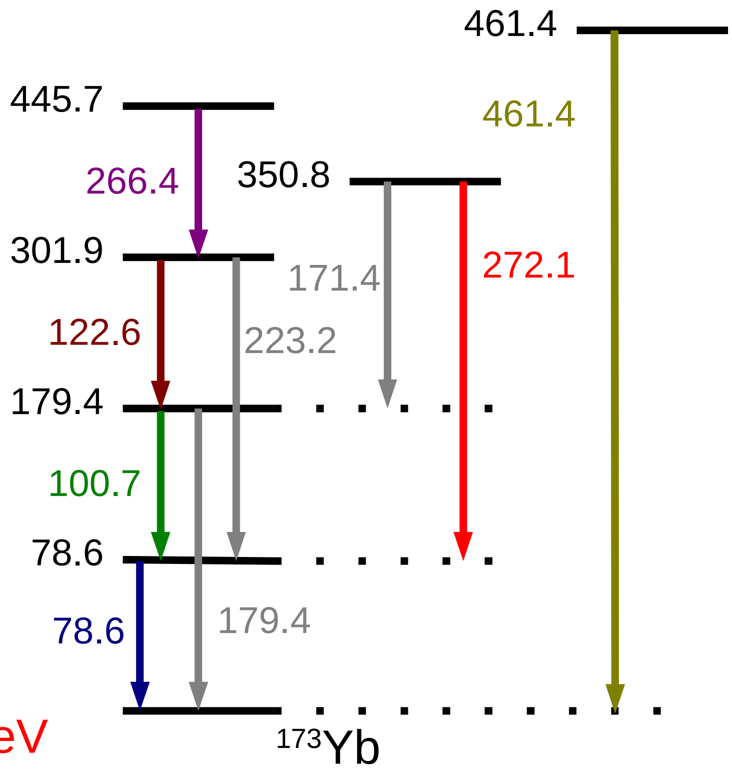


	<J>	σ
(p,d) reaction	3.67±0.01 ħ	3.84±0.03 ħ
(3He,α) reaction	3.87±0.21 ħ	3.22±0.21 ħ

Spin-parity distribution compatible between both reactions

γ-transitions intensities (preliminary)

Transition (keV)	Measurement	TALYS calculation <J>=3.67ℏ, σ=3.84ℏ
78.647 (12)	2.606 (33)	0.80
100.724 (20)	0.842 (13)	0.87
122.55 (3)	0.408 (8)	0.77
266.4 (1)	0.287 (7)	0.71
461.4 (8)	0.409 (8)	0.088



Ratio of γ-transitions intensities with respect to 272.1 keV

The best fit using a TALYS calculation gives <J>=3.7ℏ and σ=2.0ℏ

γ-transitions intensities (preliminary)

Transition (keV)
78.647 (12)
100.724 (20)
122.55 (3)
266.4 (1)
461.4 (8)

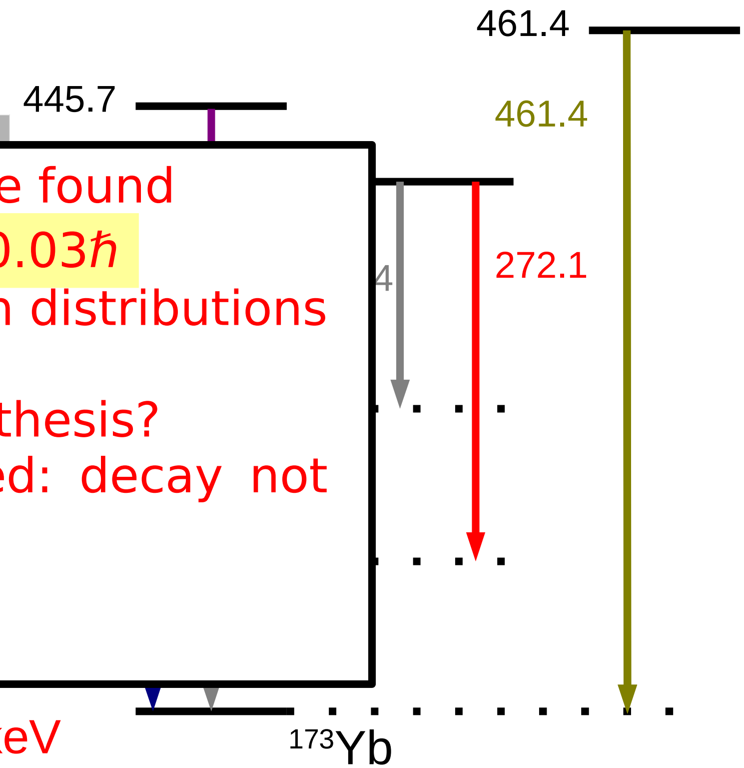
As a reminder, from the P_γ fit, we found

<J>=3.67±0.01ℏ and σ=3.84±0.03ℏ

Inconsistency between both spin distributions

Because of wrong working hypothesis?

- compound nucleus not formed: decay not statistical
- spin distribution not Gaussian
- ...



Ratio of γ-transitions intensities with respect to 272.1 keV

The best fit using a TALYS calculation gives <J>=3.7ℏ and σ=2.0ℏ

Summary

Surrogate reaction $^{174}Yb(p,d)^{173}Yb$ performed at Texas A&M Univ. using the STARS/LiBerAce setup

Extraction of the γ-emission probability P_γ as a function of E* using a new method ("statistical γ-rays")

Comparison with the P_γ extracted from the $^{174}Yb(^3He,\alpha\gamma)^{173}Yb$ reaction: almost the same
→ spin distribution identical between both reactions from the P_γ study
→ a lighter beam does not reduce the spin value

Discrepancies between the spin distributions extracted from the P_γ and from the ratio of γ-transition intensities
→ deep understanding of the surrogate reaction is missing (wrong working hypothesis?)

Perspectives: Oslo method

Extraction of the level density ρ and of the γ-ray strenght function F_γ

$$Fg(<E^*>,<E_\gamma>) \approx \rho(<E^*>)T(<E_\gamma>)$$

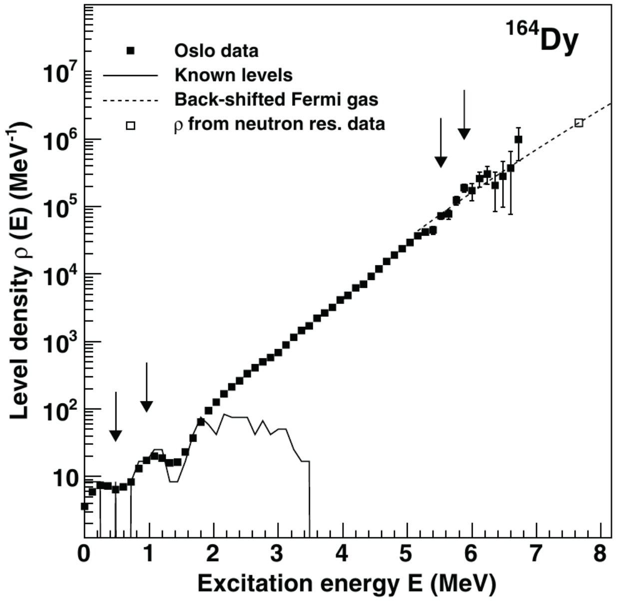
with $T(E_\gamma) \propto F_\gamma$

Decay probability

Transmission function

Extraction of the primary spectrum via an iterative way

Need to normalise the data at low energy (discrete levels) and at high energy (resonances)

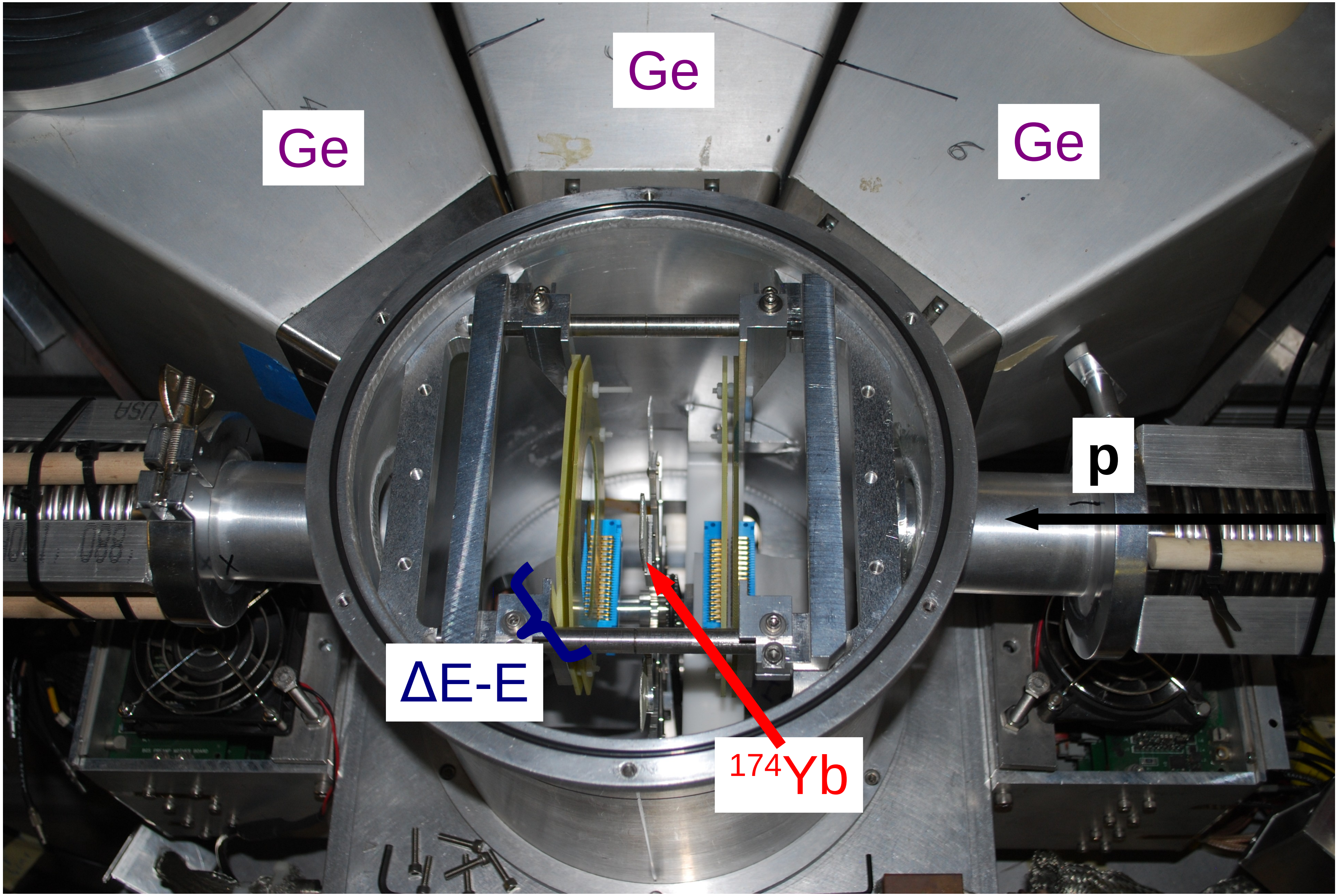


Fg : primary γ-spectrum

E* : mean excitation energyof the residual nucleus

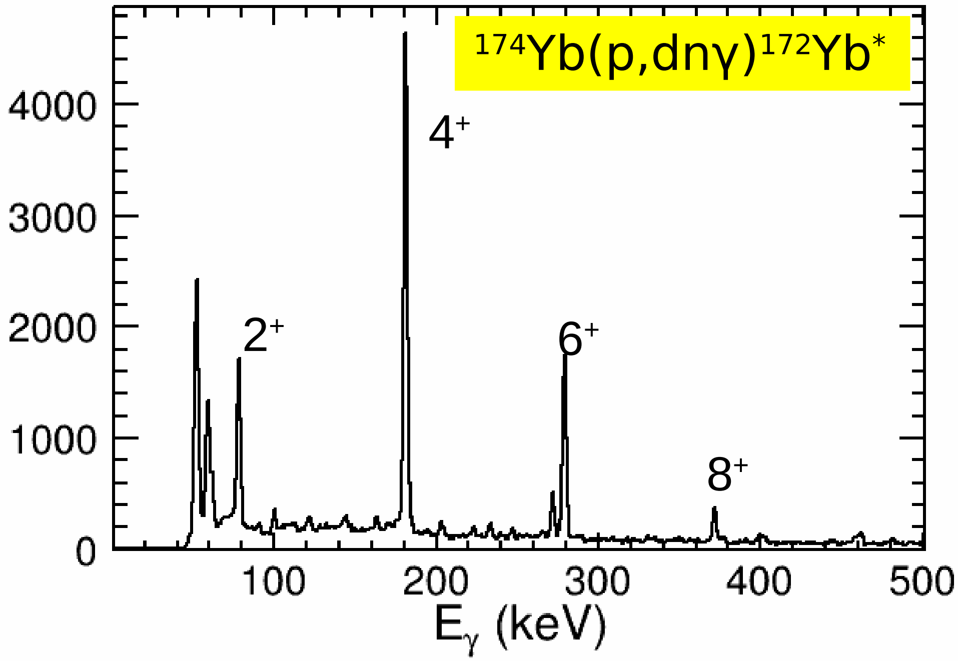
E_γ : mean γ-transition energy coming from the level

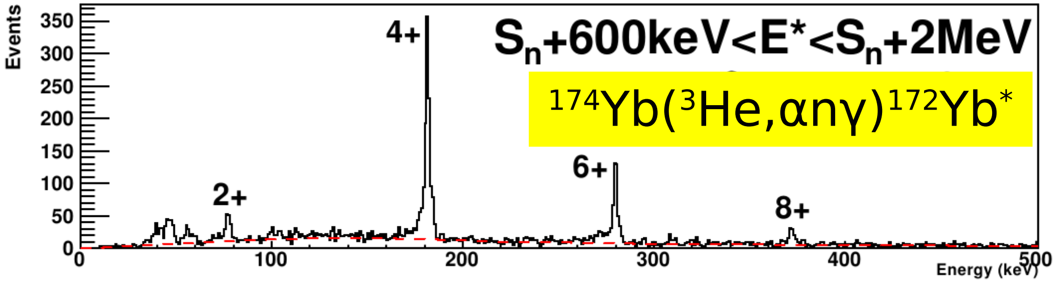
Experimental setup



Populated spins

G. Boutoux *et al.*, Phys. Lett. B **712** 319 (2012)





Target: 0^+

neutron: $1/2^+ + \ell$
→ max spin: 2-3ℏ

(p,d)
→ max spin: higher (up to ≈8ℏ)

(p,d) reaction populates spin as high as the (^{3}He,αγ) reaction

γ-transitions intensities (preliminary)

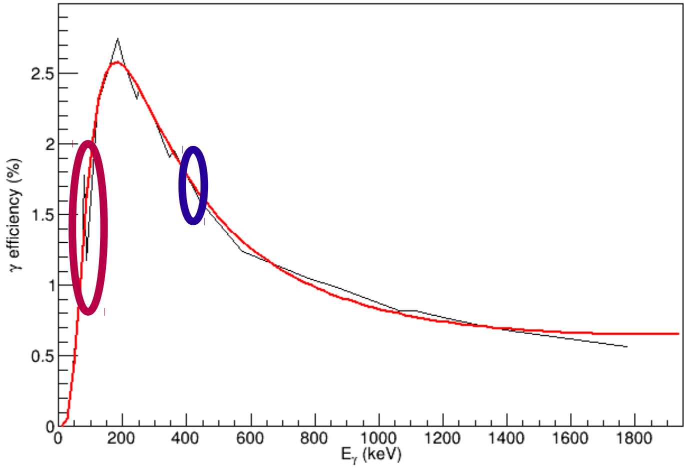
Transition (keV)	Measurement	TALYS calculation $\langle J \rangle = 3.67\hbar$, $\sigma = 3.84\hbar$	TALYS calculation $\langle J \rangle = 3.7\hbar$, $\sigma = 2.0\hbar$
78.647 (12)	2.606 (33)	0.80	0.66
100.724 (20)	0.842 (13)	0.87	0.65
122.55 (3)	0.408 (8)	0.77	0.50
266.4 (1)	0.287 (7)	0.71	0.35
461.4 (8)	0.409 (8)	0.088	0.052

γ-transitions intensities (preliminary)

Transition (keV)	Measurement	TALYS calculation <J>=3.67ħ, σ=3.84ħ	TALYS calculation <J>=3.7ħ, σ=2.0ħ
78.647 (12)	2.606 (33)	0.80	0.66
100.724 (20)	0.842 (13)	0.87	0.65
122.55 (3)	0.408 (8)	0.77	0.50
266.4 (1)	0.287 (7)	0.71	0.35
461.4 (8)	0.409 (8)	0.088	0.052

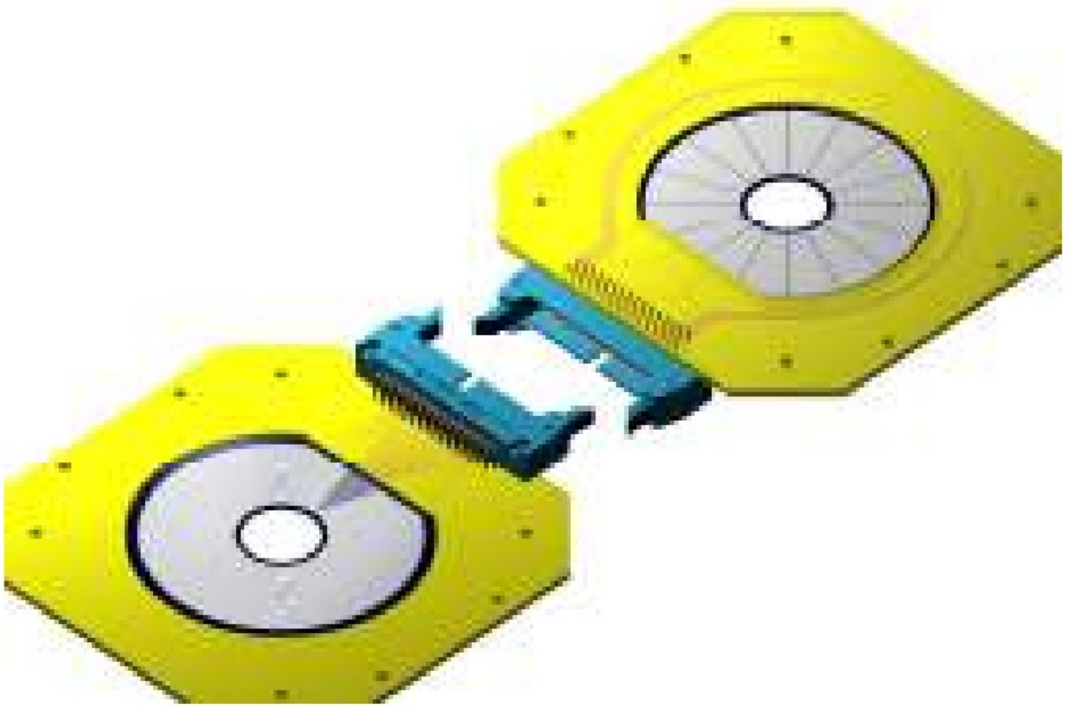
Not yet explained

Discrepancy maybe due to an incorrect estimation of the detection efficiency



Also, rather large differences between TALYS version. Here, we used TALYS 1.2.
Work in progress...

Telescope



ΔE : ~ 150µm
E : ~ 1000µm

Segmented in 24 rings
→ θ
and in 8 sectors
→ φ

Energy and impulsion conservation + T_{deuton}, θ_{deuton}
→ E* of ^{173}Yb

γ-spectrum of ^{173}Yb