PolarEx

A facility for on-line nuclear orientation at ALTO

Rémy Thoër

CSNSM
Université Paris-Sud - CNRS

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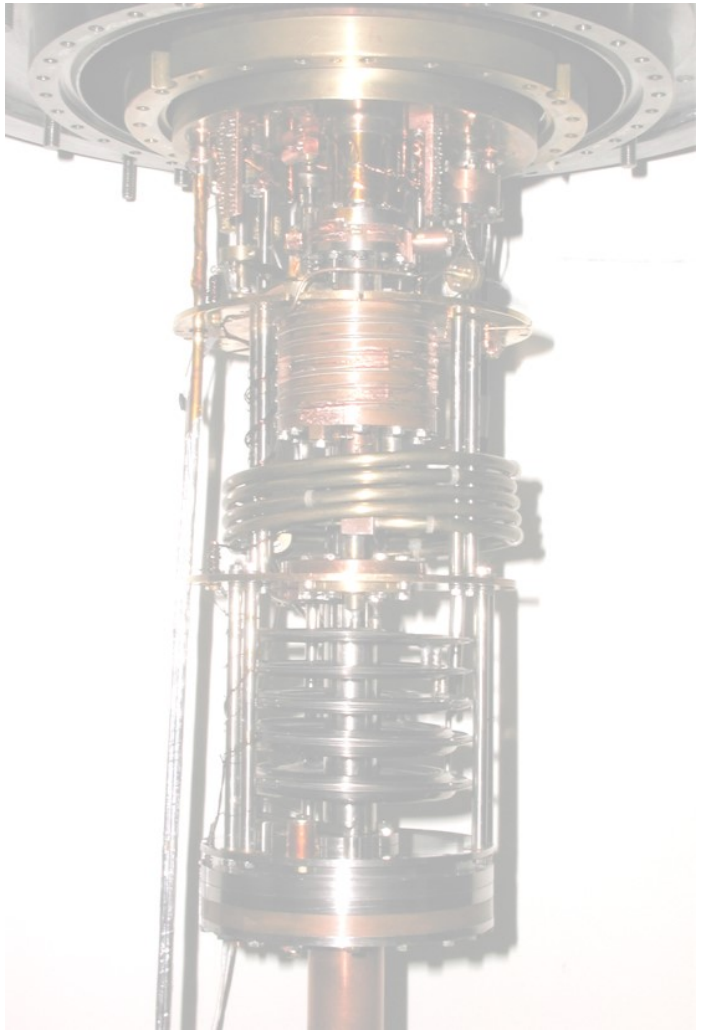
Outline



Polarex : Which Physics ?

Low Temperature Nuclear Orientation (LTNO)

Study of nuclear magnetic properties of nuclei under extreme conditions

$B \sim 10 - 100\ T$
$T \sim 7 - 20\ mK$

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- Indirect measurement of multipolarity mixing ratio δ

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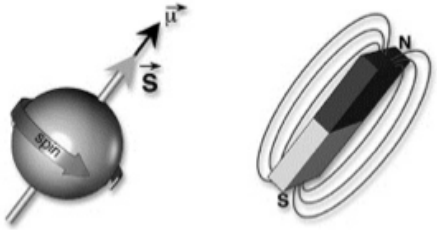

- Indirect measurement of multipolarity mixing ratio δ
- Direct measurement of nuclear magnetic moments μ
- Applications in solid state physics (H_{Hf})

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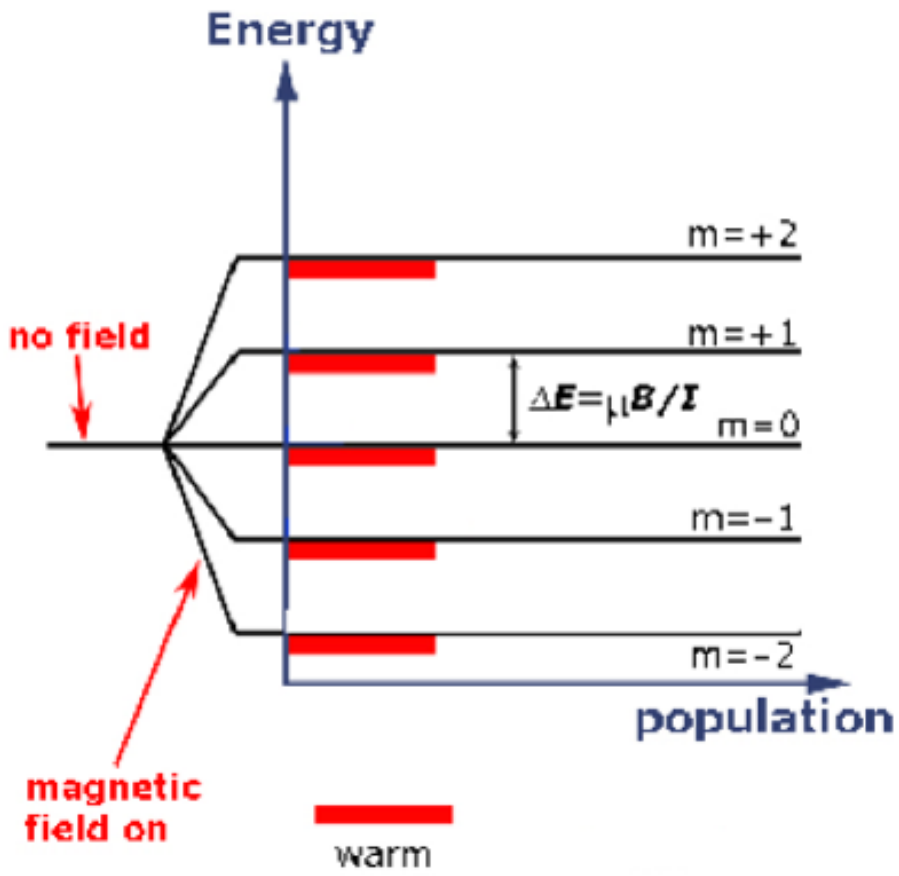
Introduction to LTNO



Magnetic field on
$\Rightarrow$ Zeeman Splitting

$$N \propto e^{\frac{\Delta E}{k_b T}}$$

$$B = B_{applied} + H_{Hf}$$

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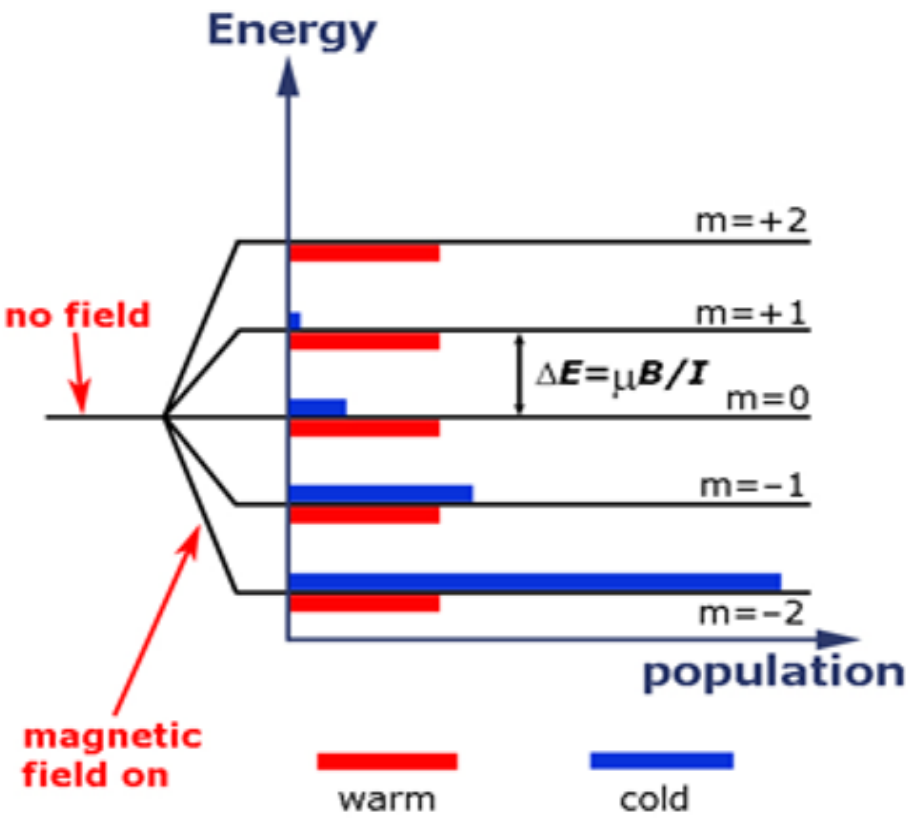

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Very low temperatures
$\Rightarrow$ Boltzmann distribution

$$N \propto e^{\frac{\Delta E}{k_b T}}$$

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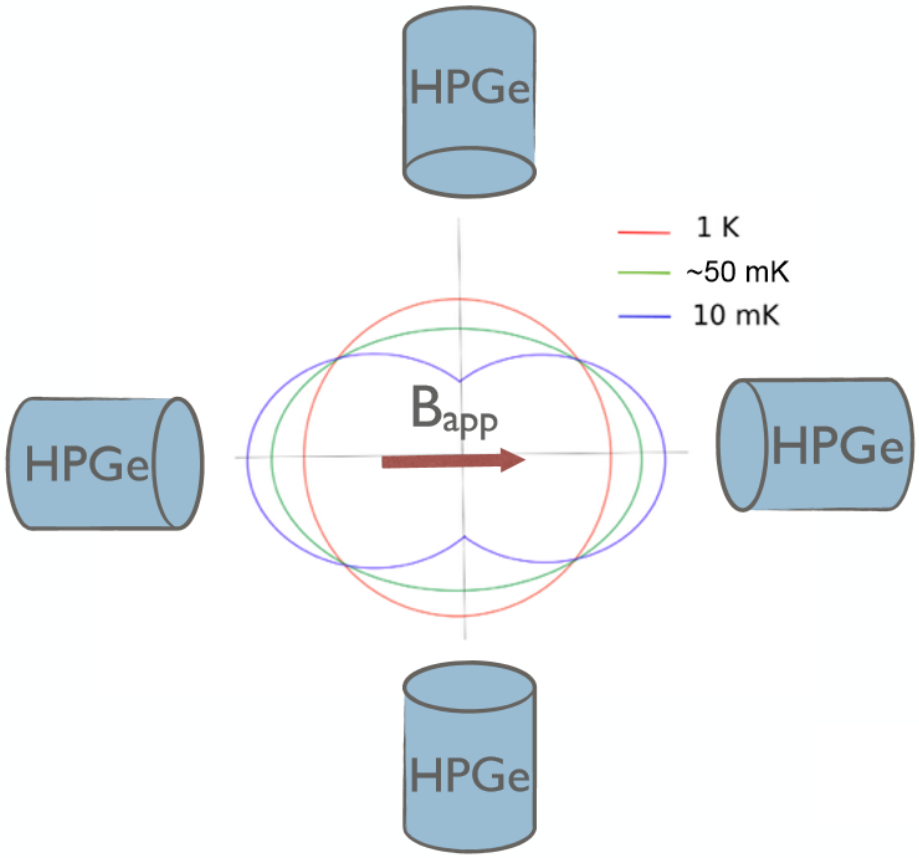
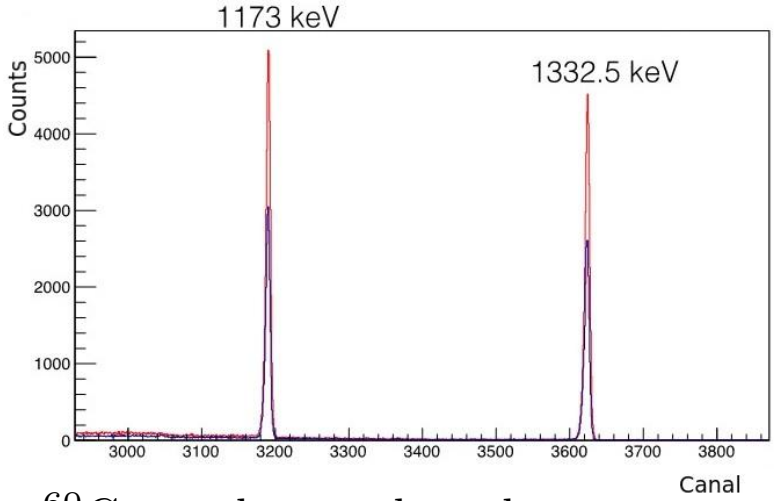


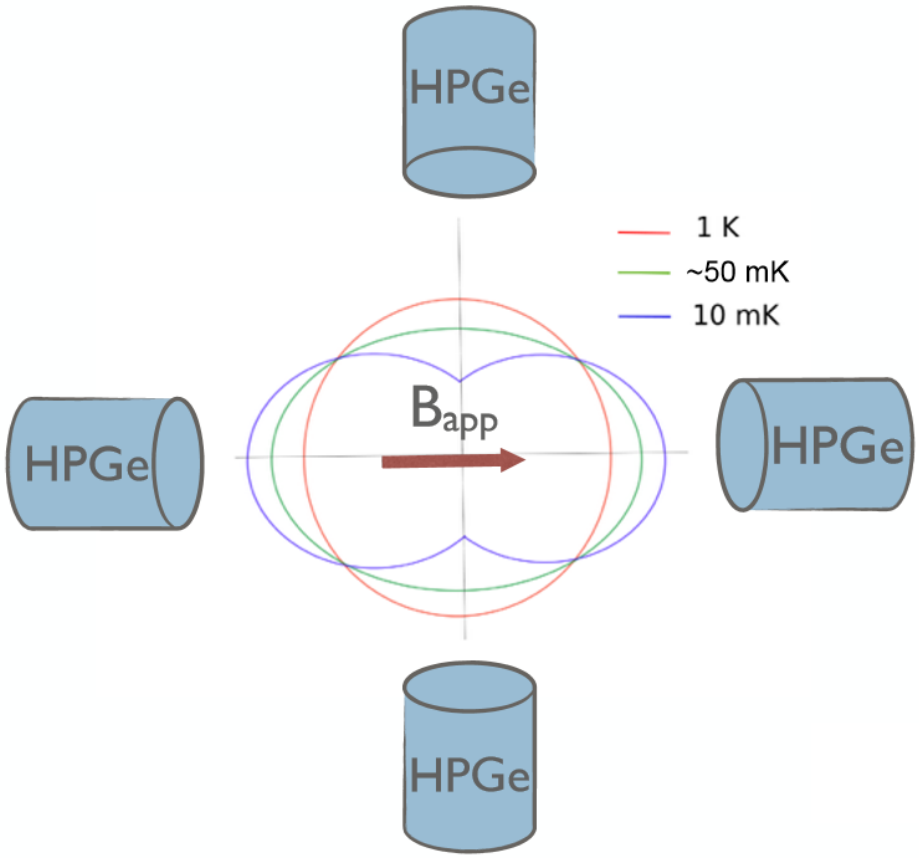
Very low temperatures + High magnetic field

⇒ Angular distribution of the emission is anisotropic $W(\theta)$



^{60}Co used as nuclear thermometer

Introduction to LTNO



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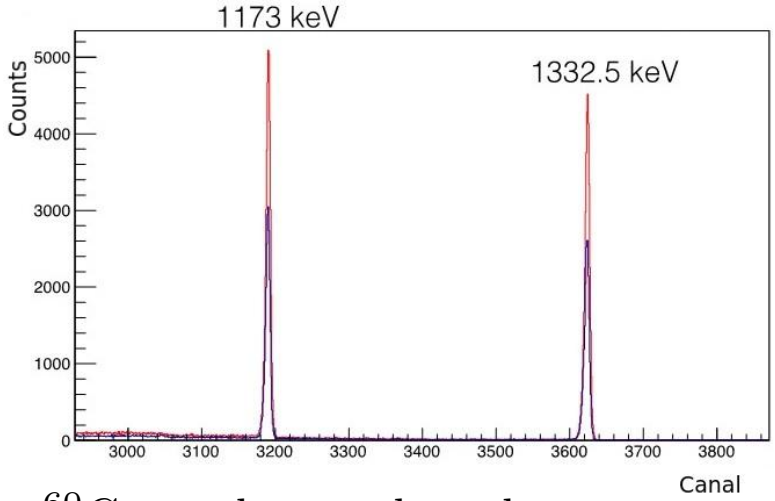

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Angular distribution of the emission

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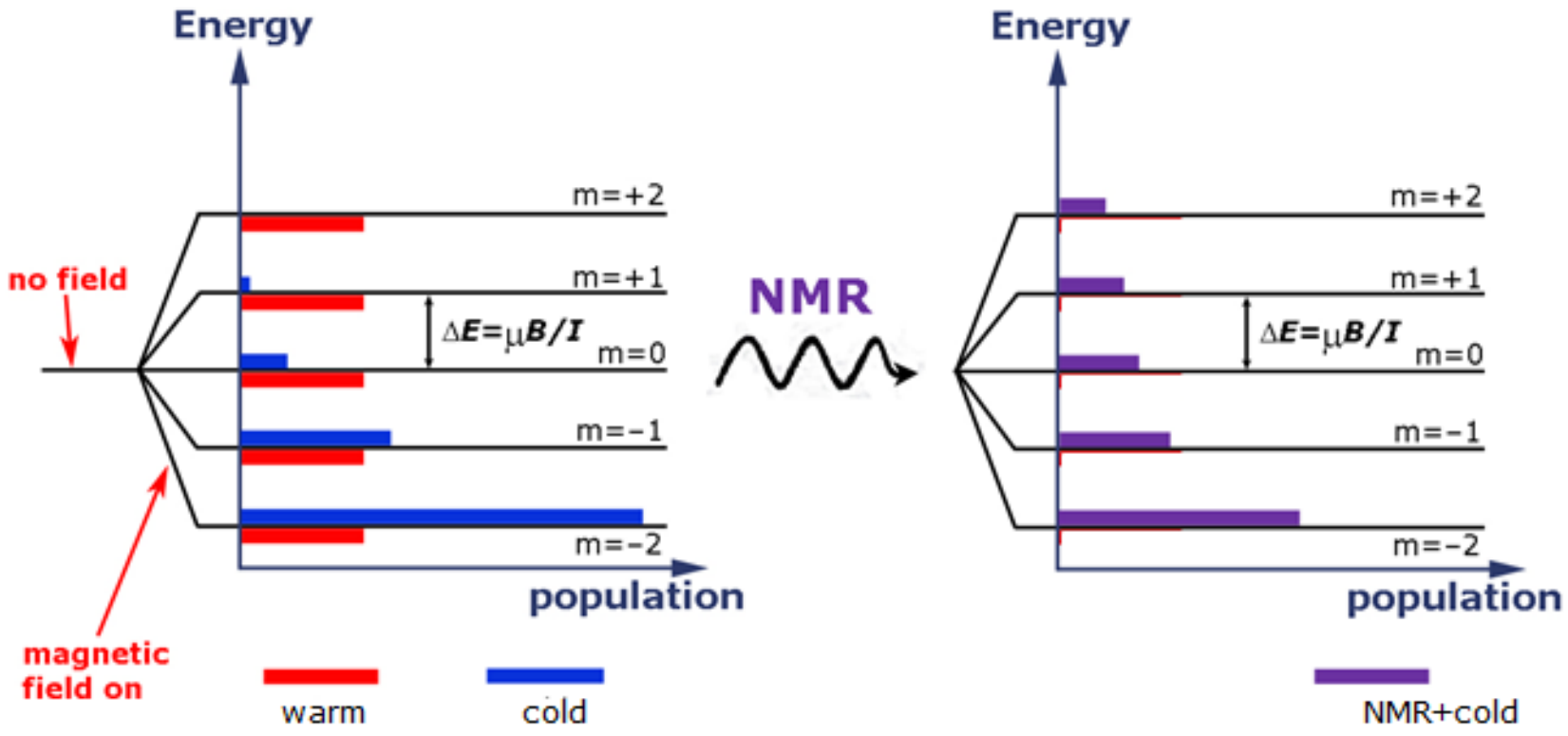


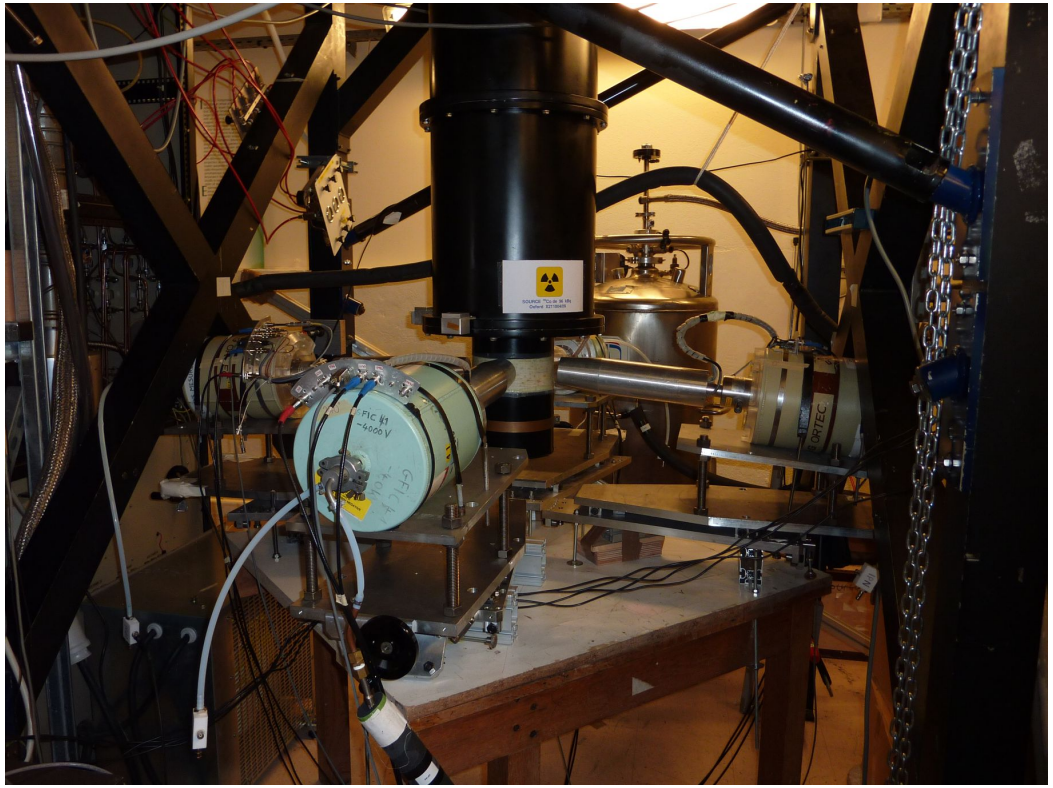
$$B = B_{applied} + H_{Hf}$$

RF on $\Rightarrow$ Destroy the anisotropy

What is Polarex ?

The Set-up

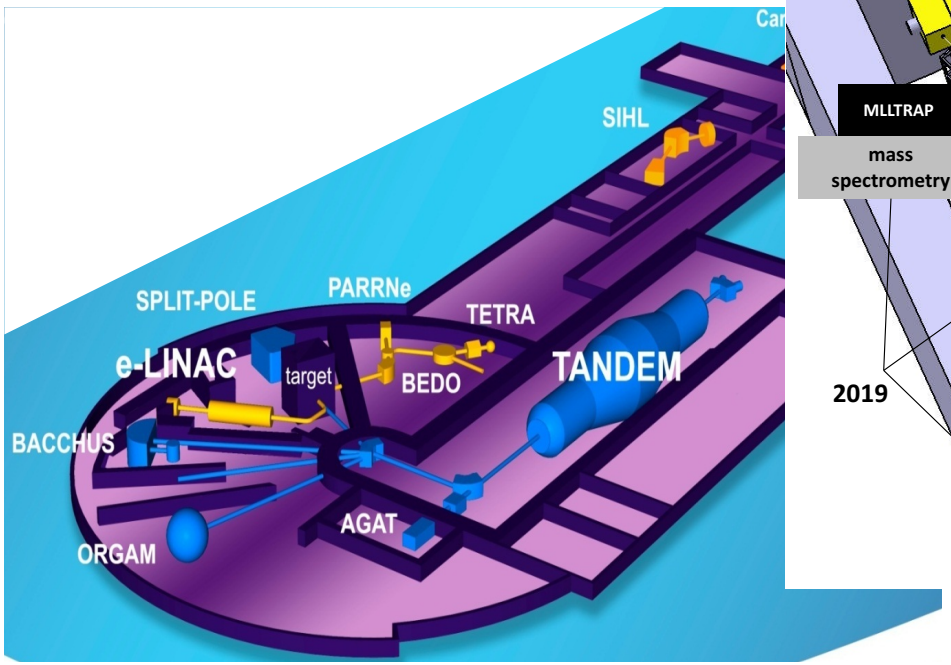
- A ^{3}He - ^{4}He dilution refrigerator
- A supraconductor magnet
- A ferromagnetic foil for the implantation of the nuclei
- 4 HPGe detectors with associated electronic
- Nuclear magnetic resonance

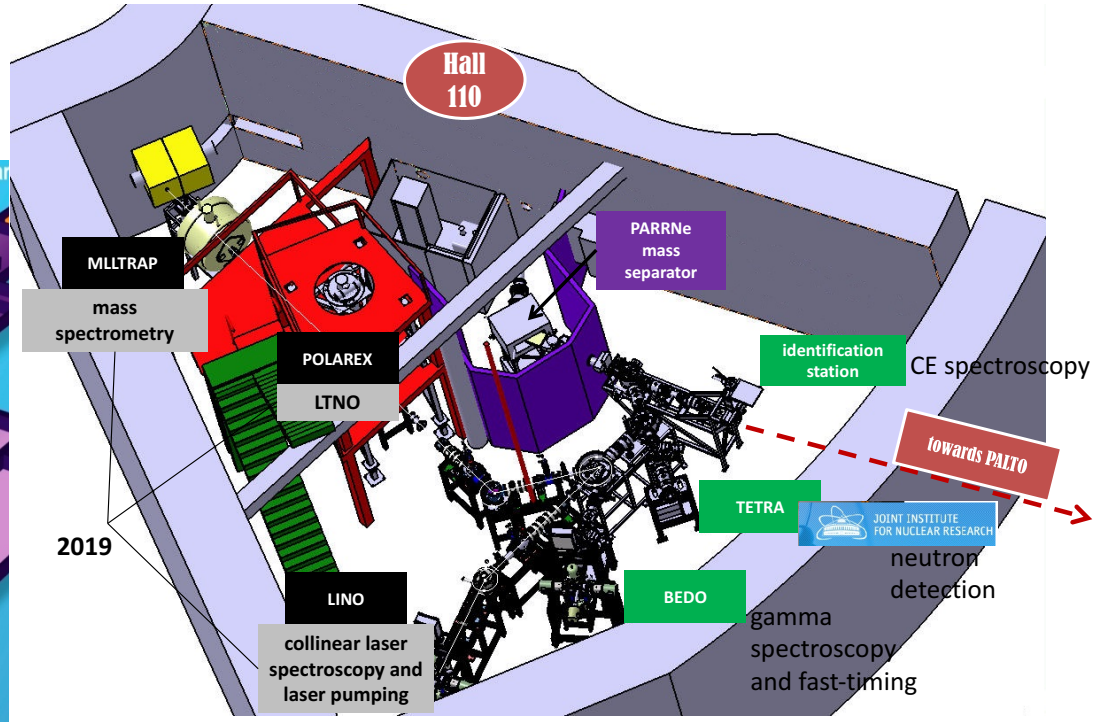


What is Polarex ?

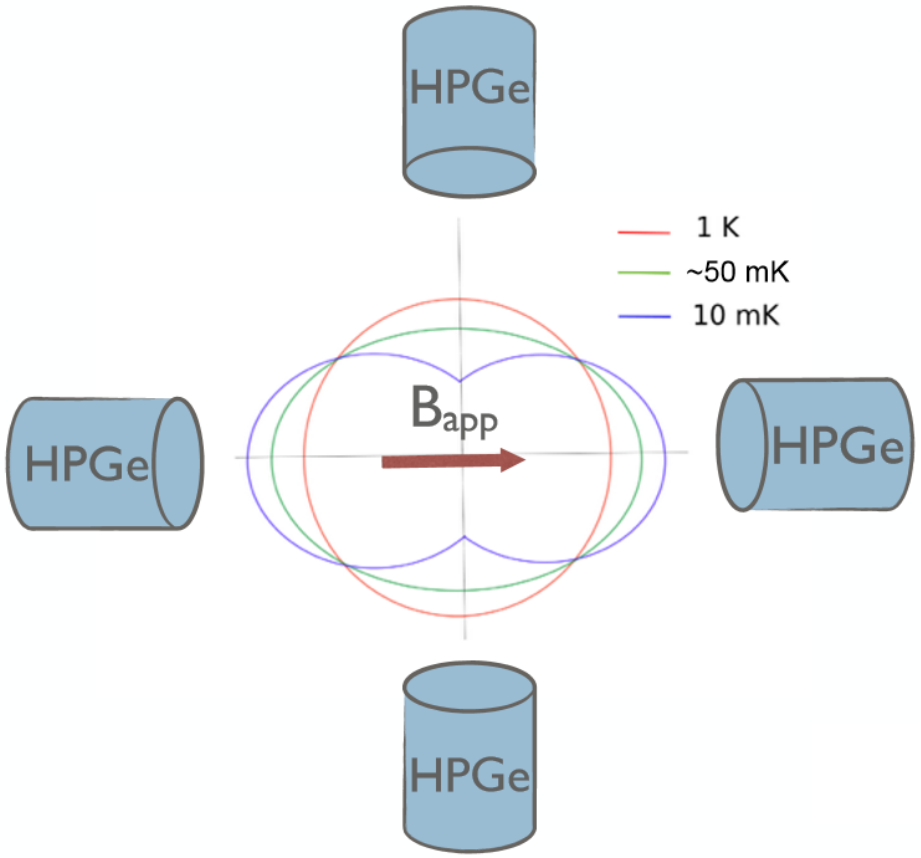
Location

Located at ALTO in Orsay, France
Currently off-line





LTNO Method



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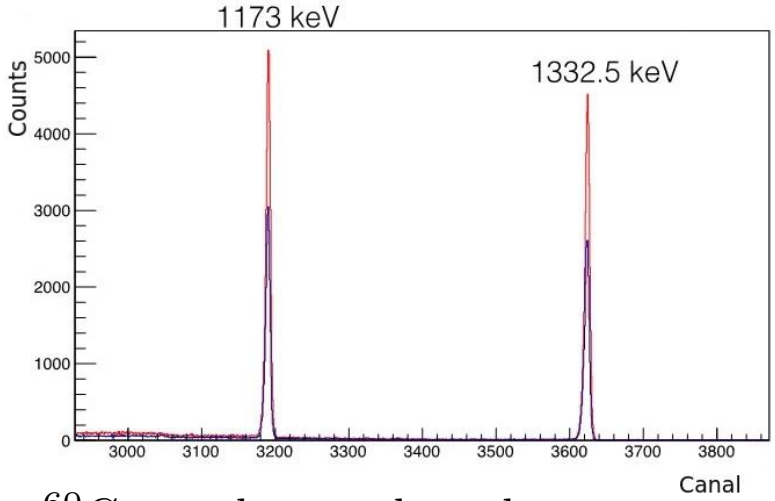

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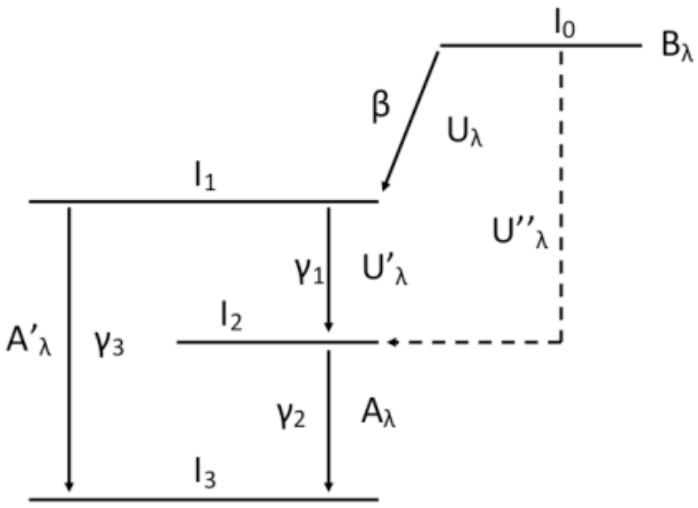
Angular distribution of the emission

$$W(\theta) = \frac{N_{cold}(\theta)}{N_{warm}(\theta)} = 1 + \sum_{\lambda} B_\lambda U_\lambda Q_\lambda A_\lambda P_\lambda(cos\theta)$$



$B_\lambda(I_0, T)$: Orientation parameter
$U_\lambda(I_i, I_f)$: Deorientation coefficient
$Q_\lambda(\theta)$: Solid angle correction
$A_\lambda(\delta)$: Angular distribution
$P_\lambda(cos\theta)$: Legendre polynomial

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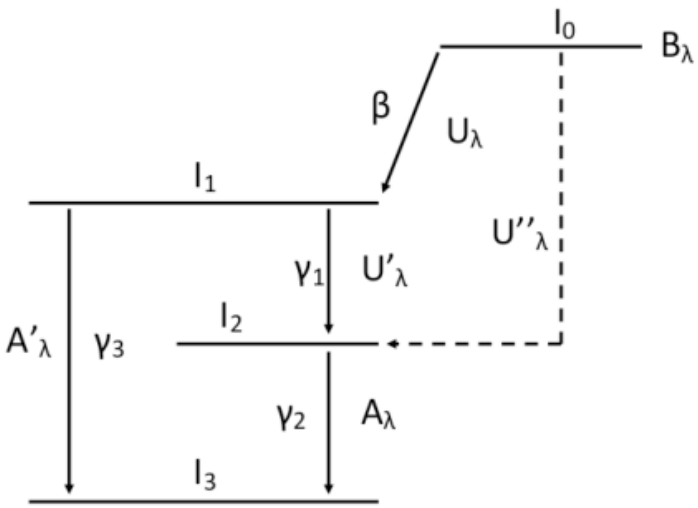

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B_λ depends on the spin and the temperature

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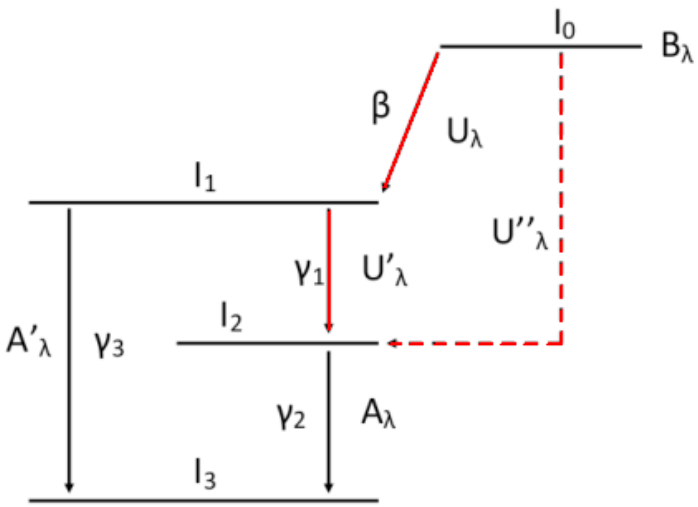

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U_λ occurs at each "hidden" transition

LTNO Method

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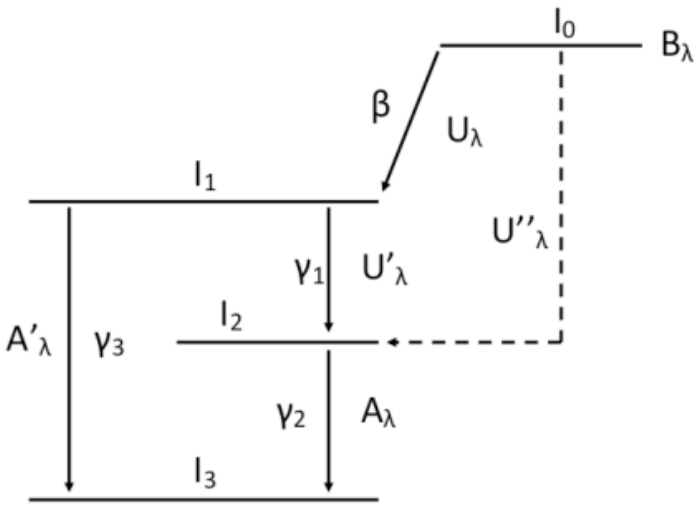

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The multipole mixing ratio δ is taken from A_λ

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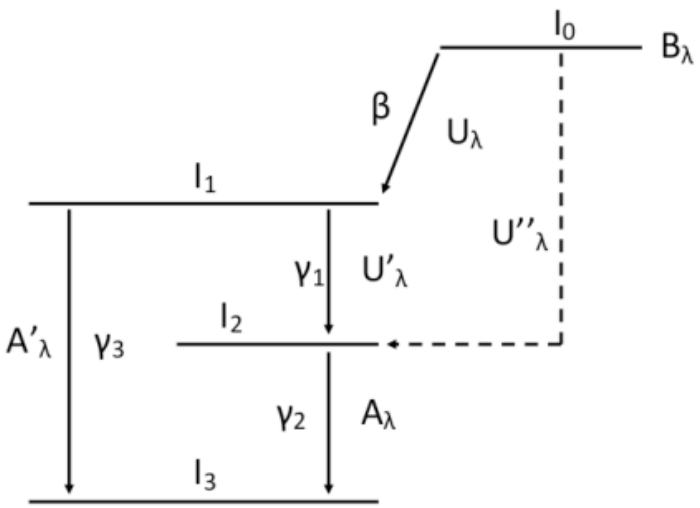

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$$A_\lambda = \frac{F_\lambda(L, L, I_f, I_i) + 2\delta F_\lambda(L, L', I_f, I_i) + \delta^2 F_\lambda(L', L', I_f, I_i)}{1 + \delta^2}$$

Current Analysis : Two Methods for one δ

Angular distribution of the emission

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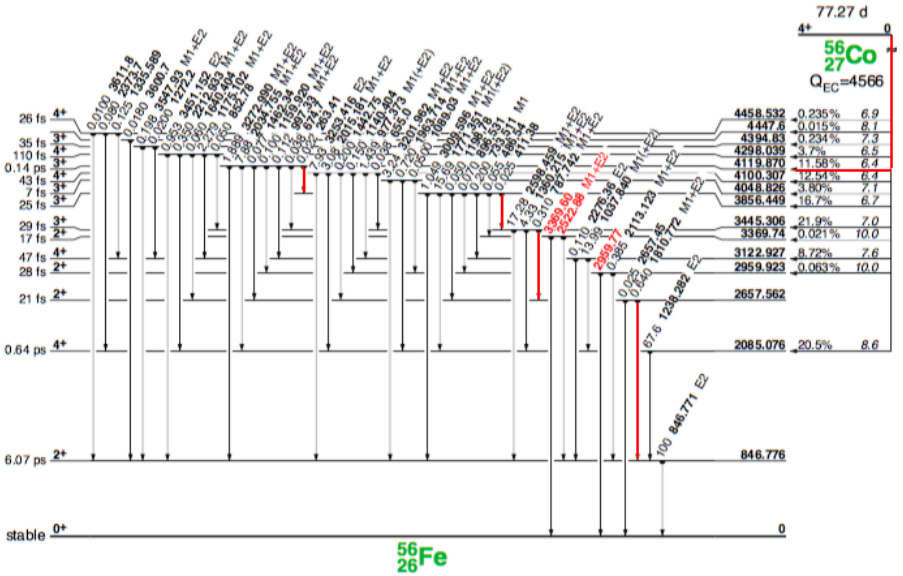
Method 1 : Direct calculation of the parameters



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- Need a good knowledge of the level scheme

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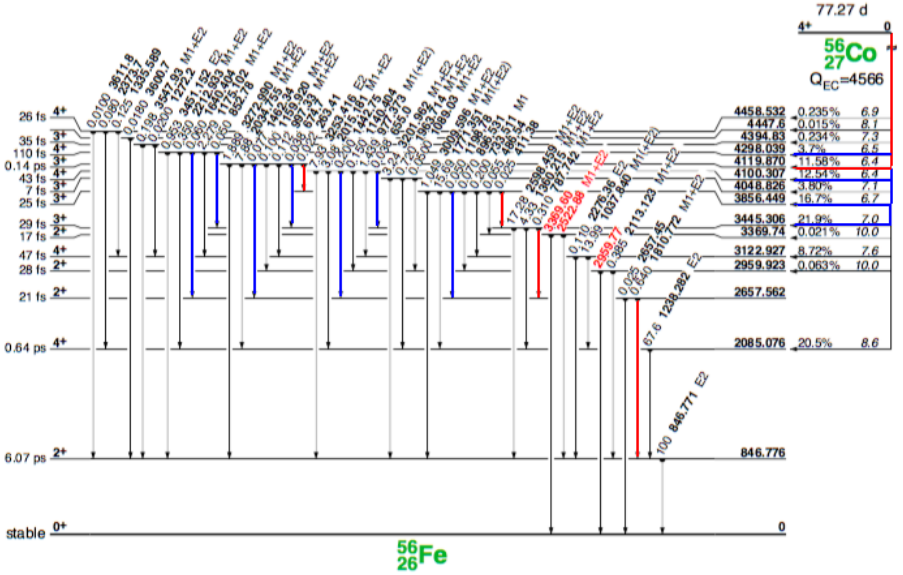

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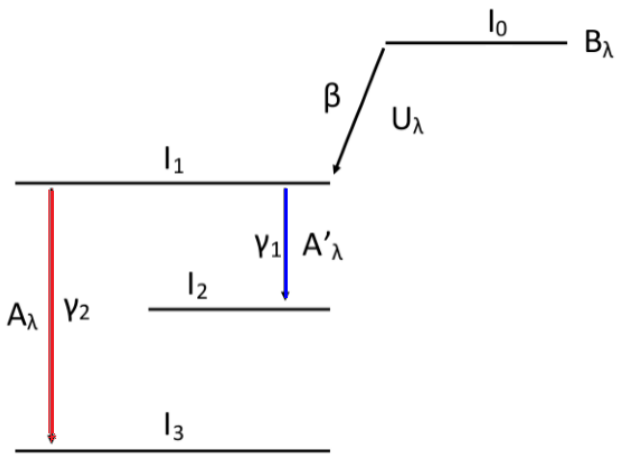
Method 2 : Relative calculation with a pure transition



- Pure multipolarity
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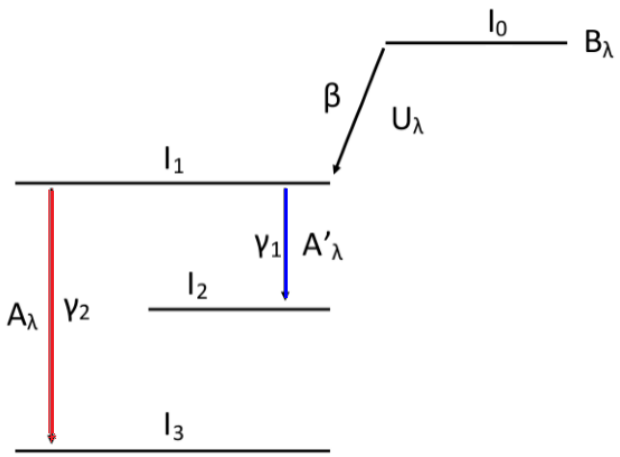
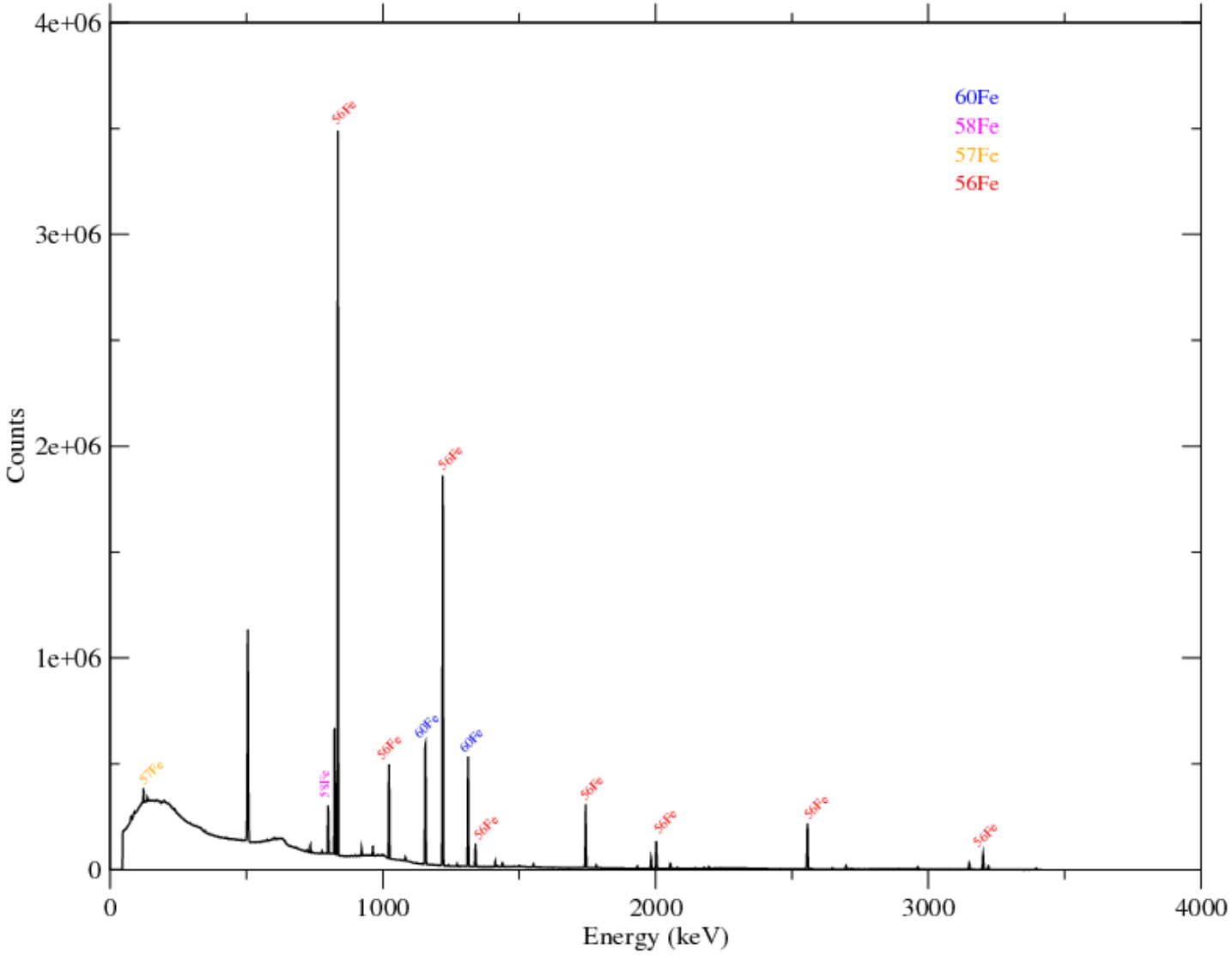


- Pure multipolarity
  - A_λ computed directly
    $A_\lambda = F_\lambda(L, L, I_f, I_i)$
- If the transition is associated to a pure one
  - Same B_λ and U_λ
  - Q_λ depends on the energy
  - Temperature independent

$$\frac{A'_2}{A_2} = \frac{\frac{3}{8}[1 - W'(0)] + [W'(\pi/2) - 1]}{\frac{3}{8}[1 - W(0)] + [W(\pi/2) - 1]}$$

Current Analysis : Sources of ^{54}Mn, ^{56,57,58}Co and ^{59}Fe

Produced by fusion-evaporation d+Fe at 11 MeV/A



Current Analysis : Corrections

- Evaluation of the temperature (^{60}Co inside the refrigerator)

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- Evaluation of the temperature
- Correction of the energy fluctuation in the calibration
  $\Rightarrow$ offset + gain

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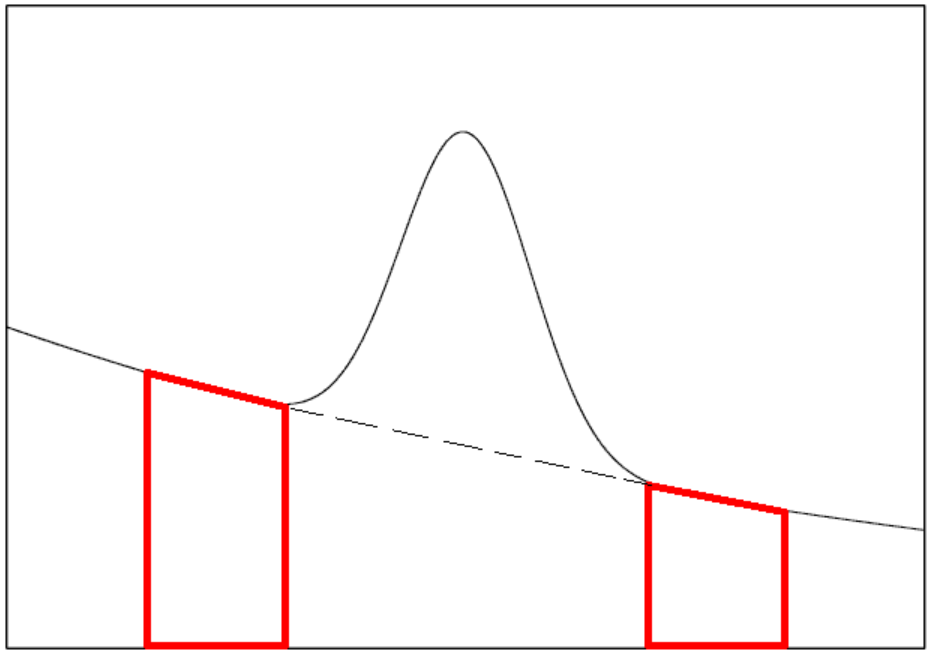
- Background substraction

  $\Rightarrow$ "Trapezium method"



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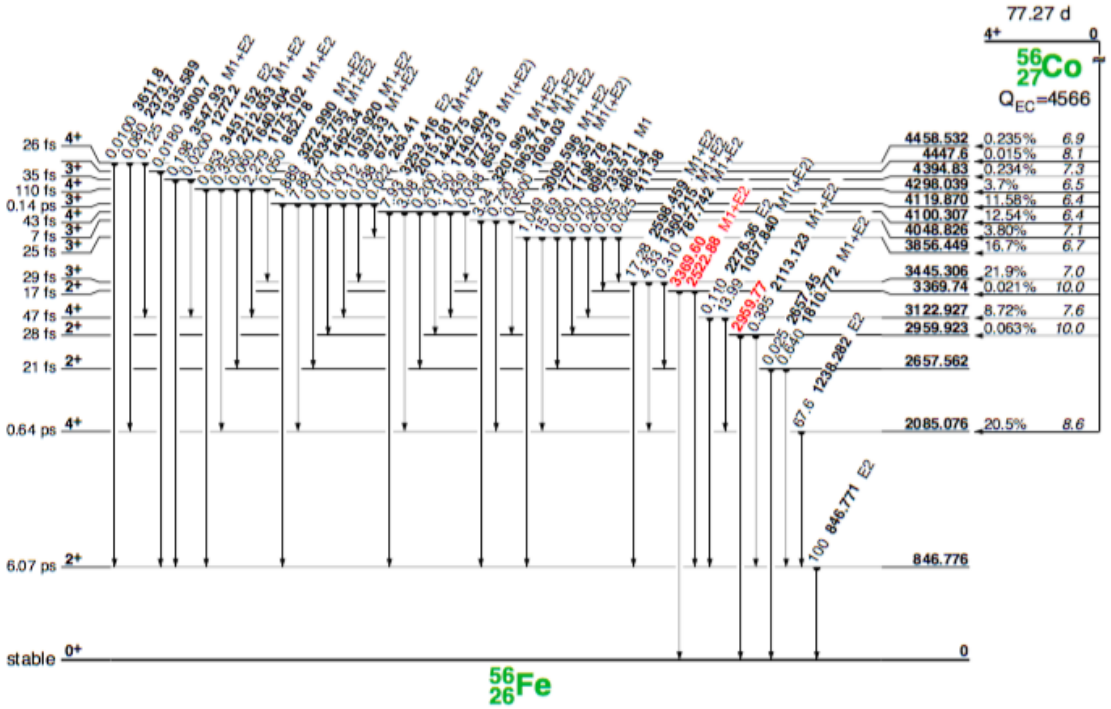
Last on going correction : Coincidence summing effects

Current Analysis : Preliminary results



Level scheme of ^{56}Fe

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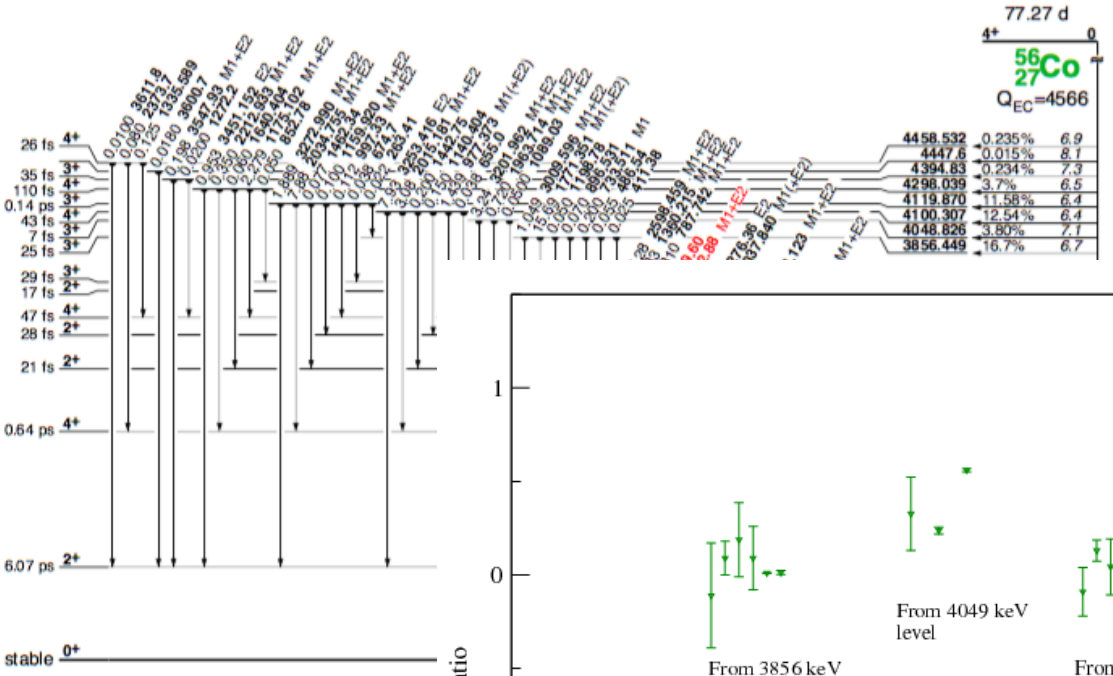

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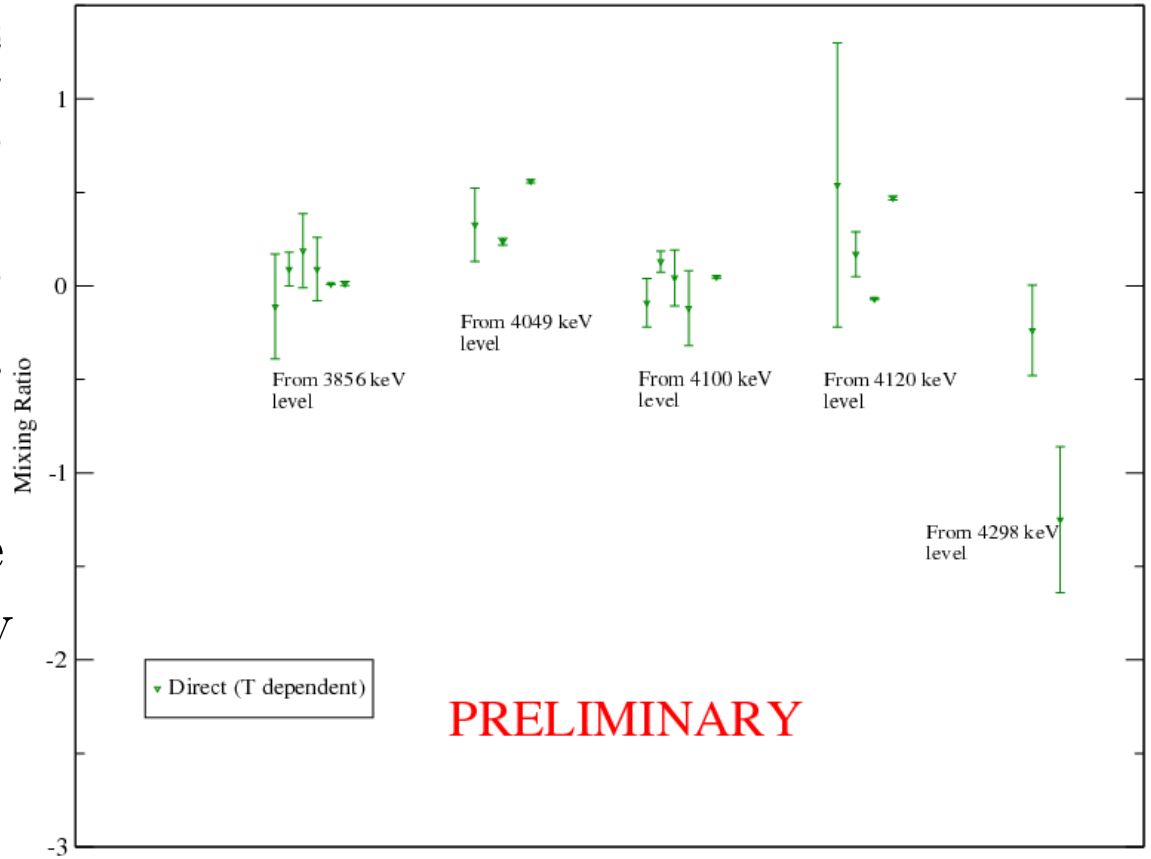

Mixing ratios of the transitions sorted by level of emission

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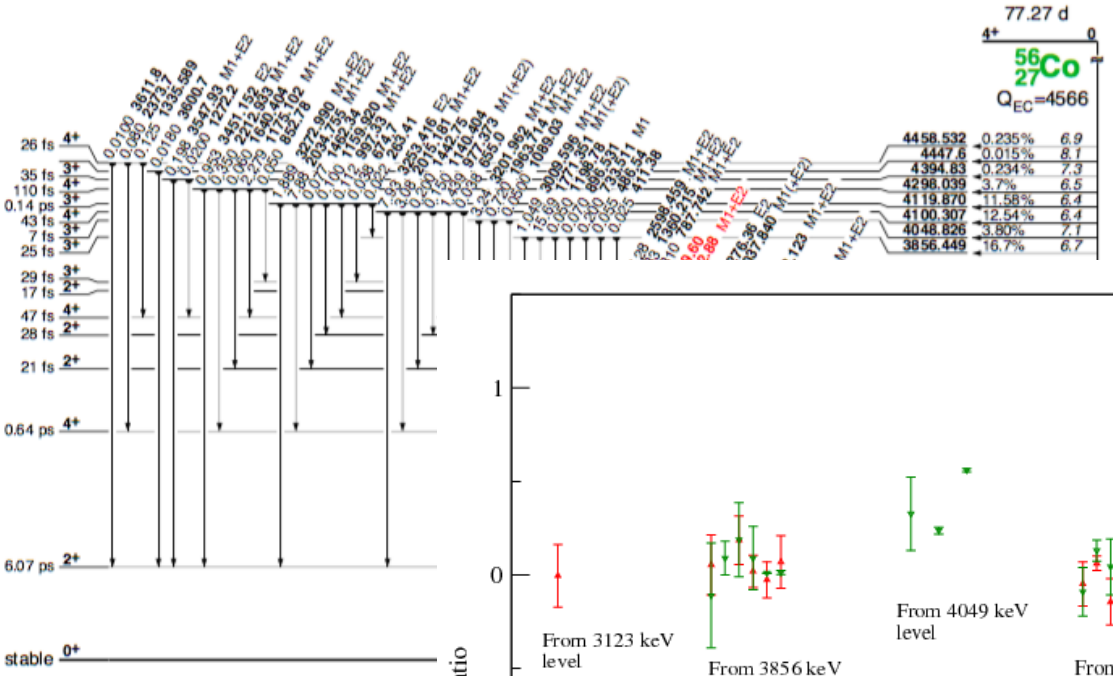

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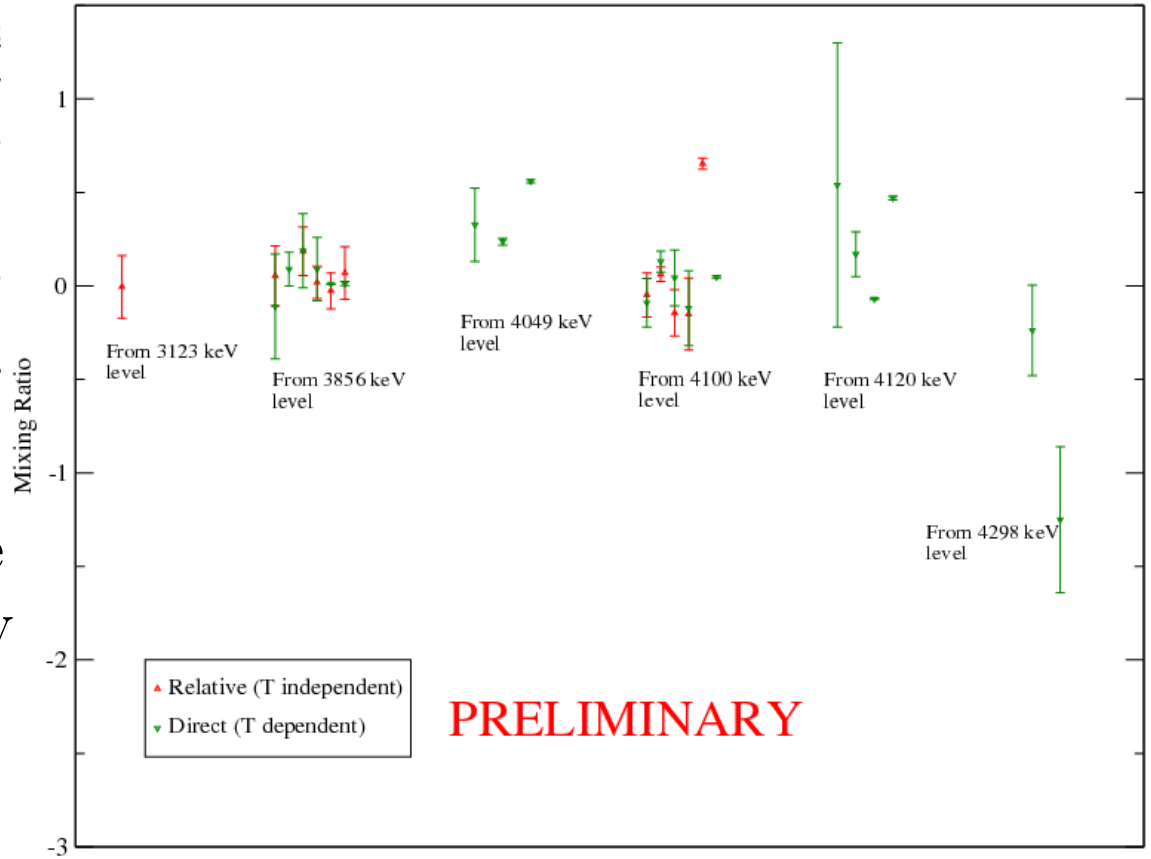

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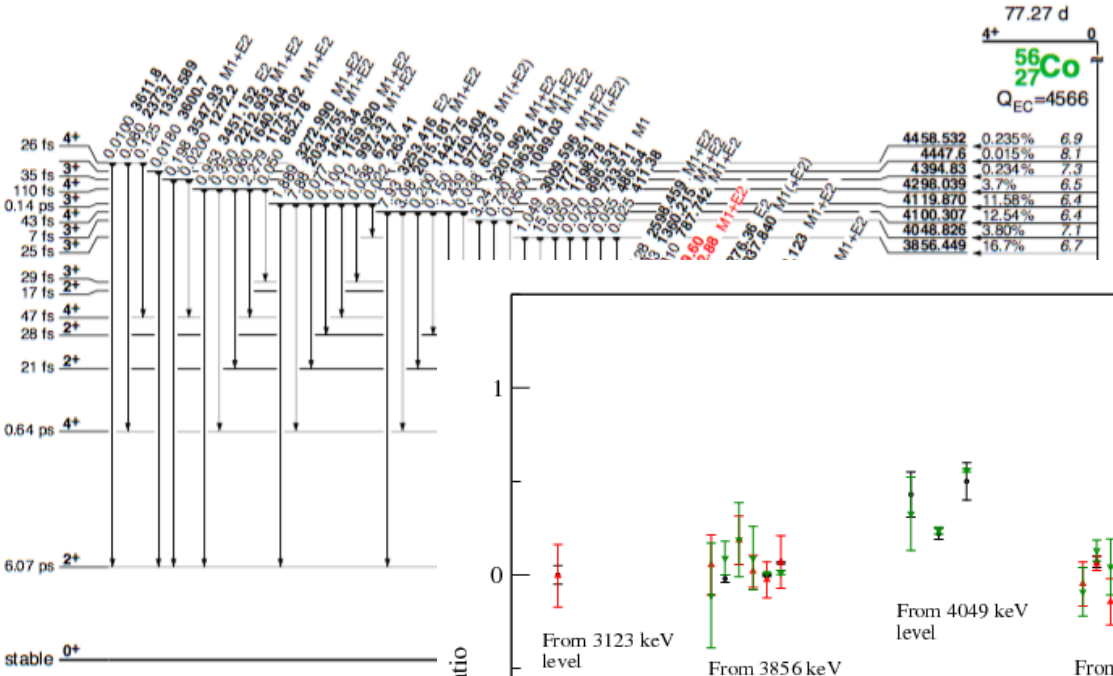

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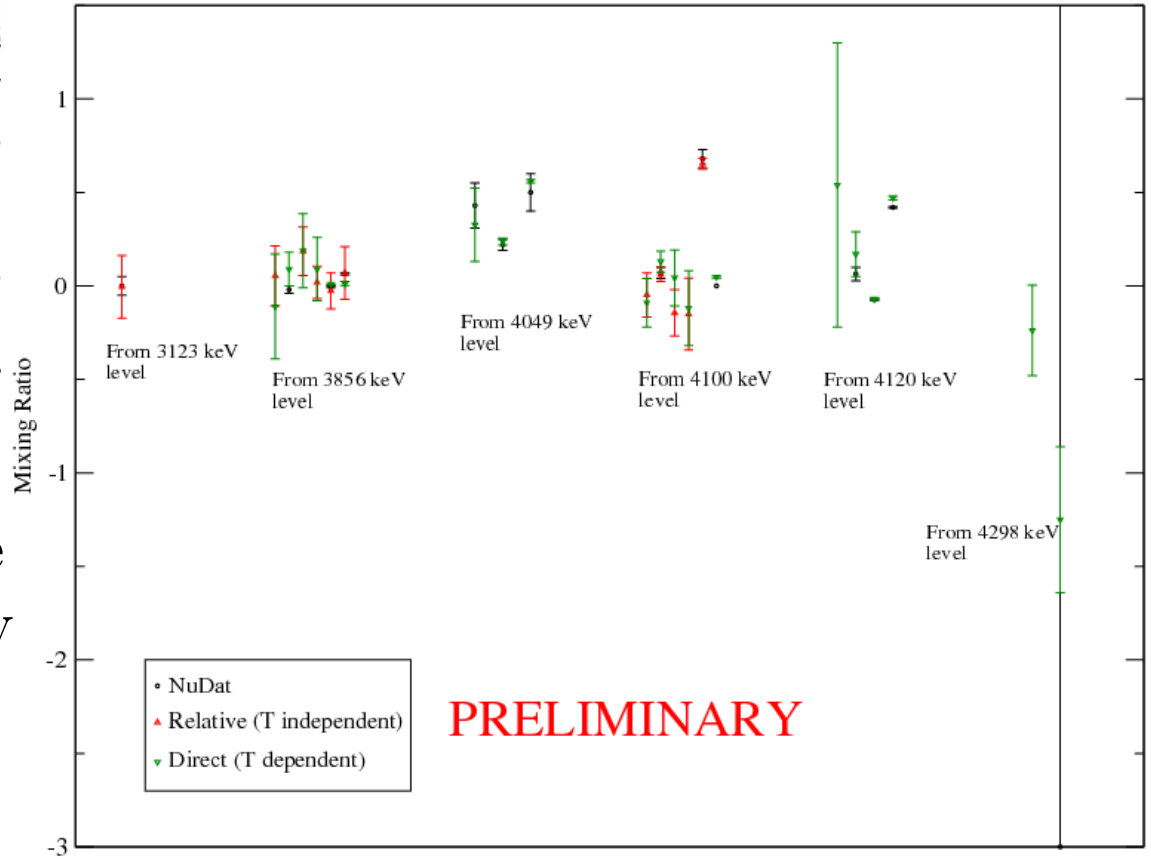

Mixing ratios of the transitions sorted by level of emission

What's next ?

<u>In 2019</u> NMR commissioning : magnetic moment measurement ^{139}Ce

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Off-line physics case : Study of Pm isotopic chain (A=147, 149, 151)

- Measurement of H_{Hf} of Pm in Fe
- Measurement of the magnetic moments of Pm isotope

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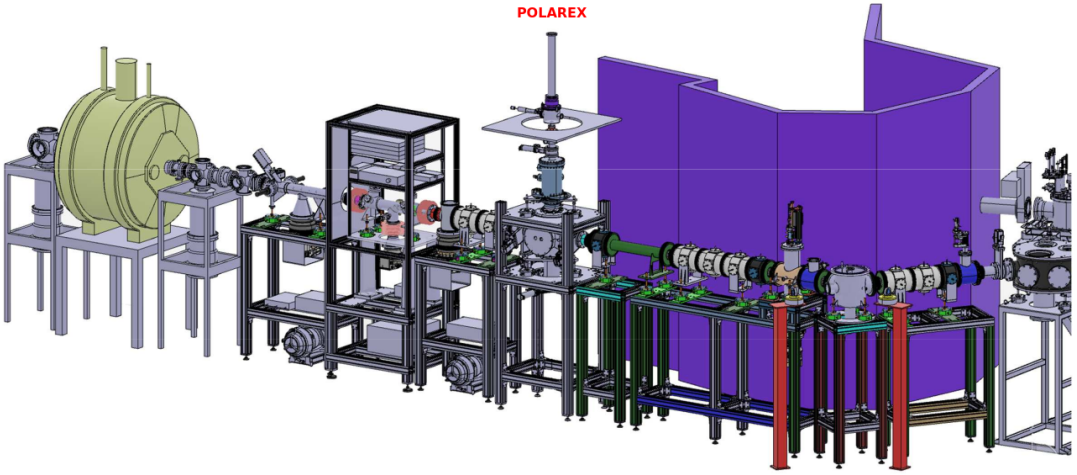
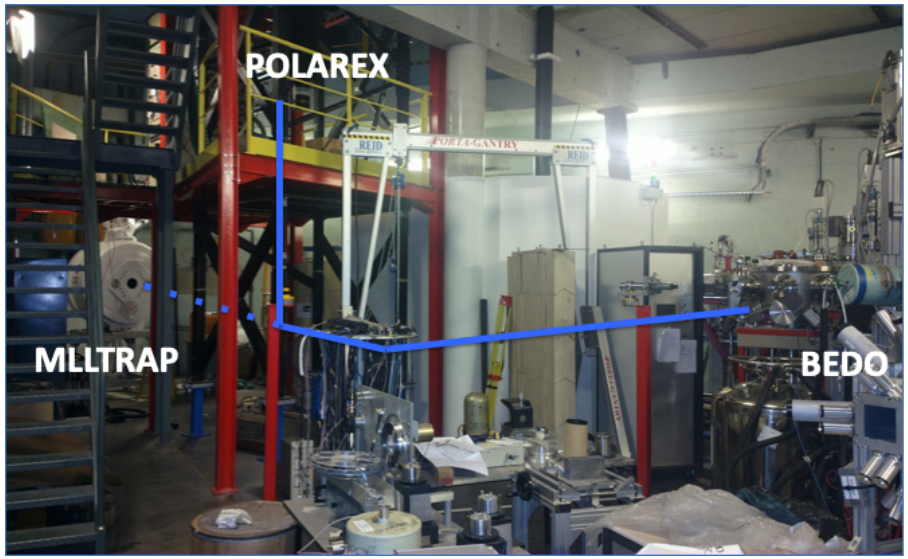
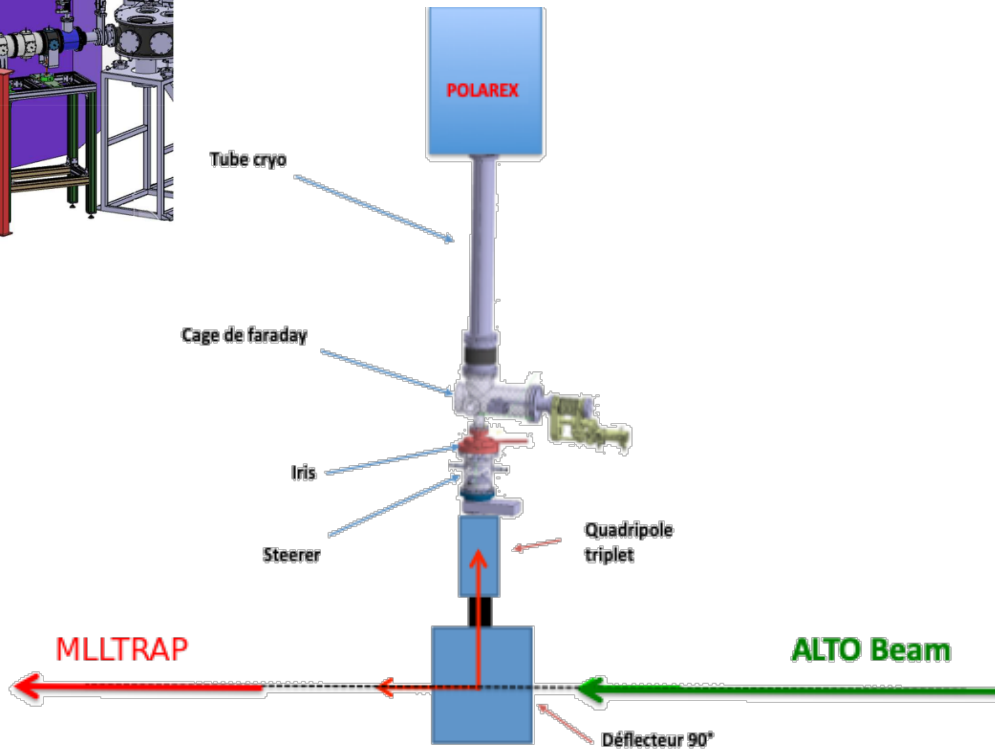
Thank you for your attention

Thanks to collaborators : I. Deloncle, C. Gaulard, F. Ibrahim, F. Le Blanc, S. Roccia, D. Verney and ALTO staff

New line under construction

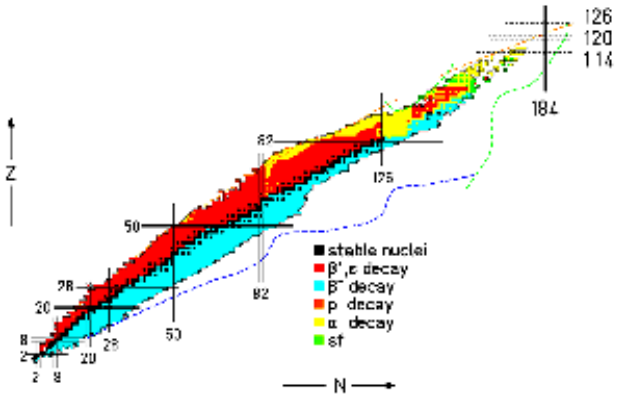






Polarex : Which Nuclei ?

- Limitation on the life-time
  - Need time to reach a thermal equilibrium
- Minimum flux of 10^3 ions/s ...
- ... and a maximum of 10^7 ions/s
- Need energy of at least 40 keV



⇒ At the end, around 300 nuclei are accessible at ALTO for On-Line Nuclear Orientation method

Off-line study : Pm

- H_{Hf} in Fe is badly known : $400 \pm 100\ T$
- $\mu(^{147}\mathrm{Pm})$ is known by laser spectroscopy : $+2.58(7)$
- Measurement of the resonant frequency (LTNO/NMR)
  $\Rightarrow \Delta E = \mu B / I$
  $\Rightarrow$ Precise H_{Hf} in Fe at Pm site
- Measurement of the magnetic moments of ^{149,151}Pm isotope

^{147}Pm : 2.62 y
^{149}Pm : 53.08 h
^{151}Pm : 28.4 h

LTNO Calculations

$$W(\theta) = \frac{N_{cold}(\theta)}{N_{warm}(\theta)} = 1 + \sum_{\lambda} B_{\lambda}(I_0, T) U_{\lambda} Q_{\lambda} A_{\lambda} P_{\lambda}(cos\theta)$$

$$W(0) = 1 + B_2 U_2 Q_2 A_2 + B_4 U_4 Q_4 A_4$$
$$W(\pi/2) = 1 - \tfrac{1}{2} B_2 U_2 Q_2 A_2 + \tfrac{3}{8} B_4 U_4 Q_4 A_4,$$

$$A_2 = \frac{\frac{3}{8}(1 - W(0)) + (W(\pi/2) - 1)}{-\frac{7}{8} B_2 U_2 Q_2}$$
$$A'_2 = \frac{\frac{3}{8}(1 - W'(0)) + (W'(\pi/2) - 1)}{-\frac{7}{8} B'_2 U'_2 Q'_2}$$

$$\frac{A_2}{A'_2} = \frac{\frac{3}{8}(1 - W(0)) + (W(\pi/2) - 1)}{\frac{3}{8}(1 - W'(0)) + (W'(\pi/2) - 1)}$$
$$\frac{A_4}{A'_4} = \frac{\frac{1}{2}(1 - W(0)) - (W(\pi/2) - 1)}{\frac{1}{2}(1 - W'(0)) - (W'(\pi/2) - 1)},$$