Where is the companion of the 391 keV γ-ray in the measured ^{61}Fe γ-ray spectrum?

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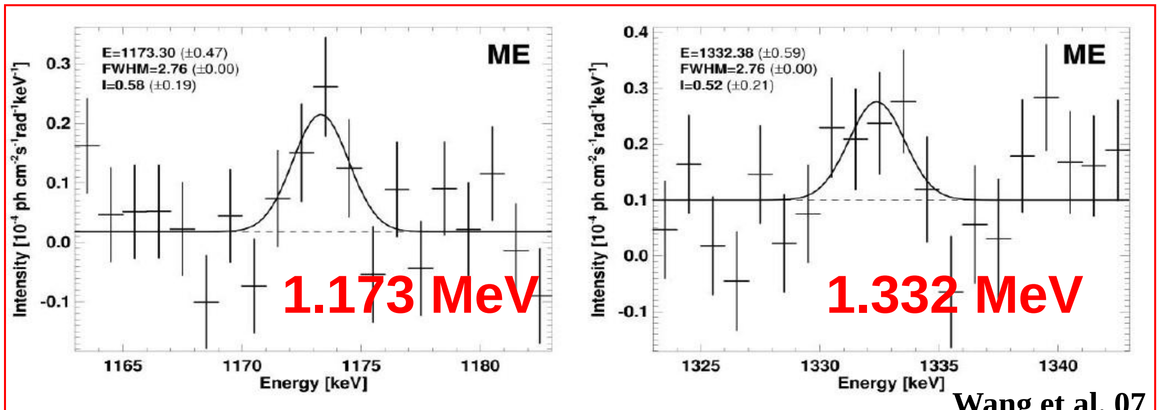
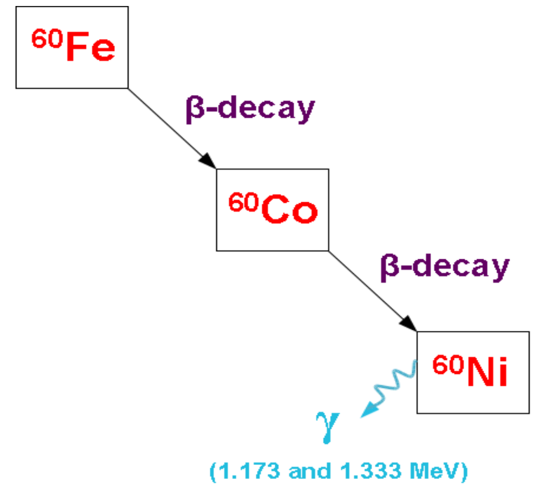
Workshop MUST2 - Saclay, 4-5 Juin 2015

Astrophysical motivation

Detection of ^{60}Fe by RHESSI (2004) & INTEGRAL (2006)

^{60}Fe ($T_{1/2}$=2.6 10^6 yr)





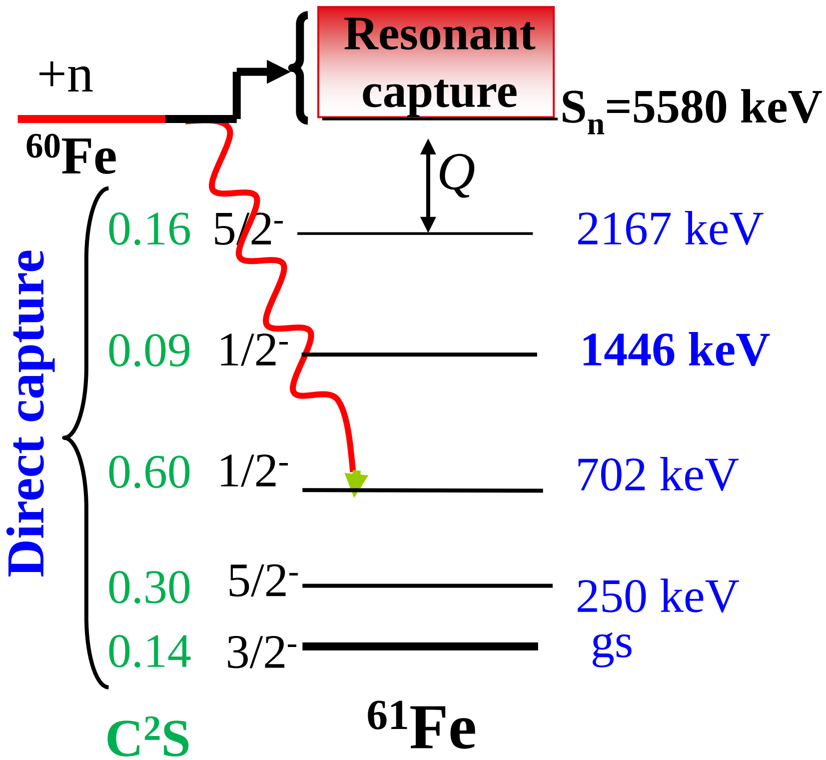
^{60}Fe mainly produced in massive stars
& released in ISM by subsequent
core-collapse supernovae type II

→ **tests stellar model and SN rate**

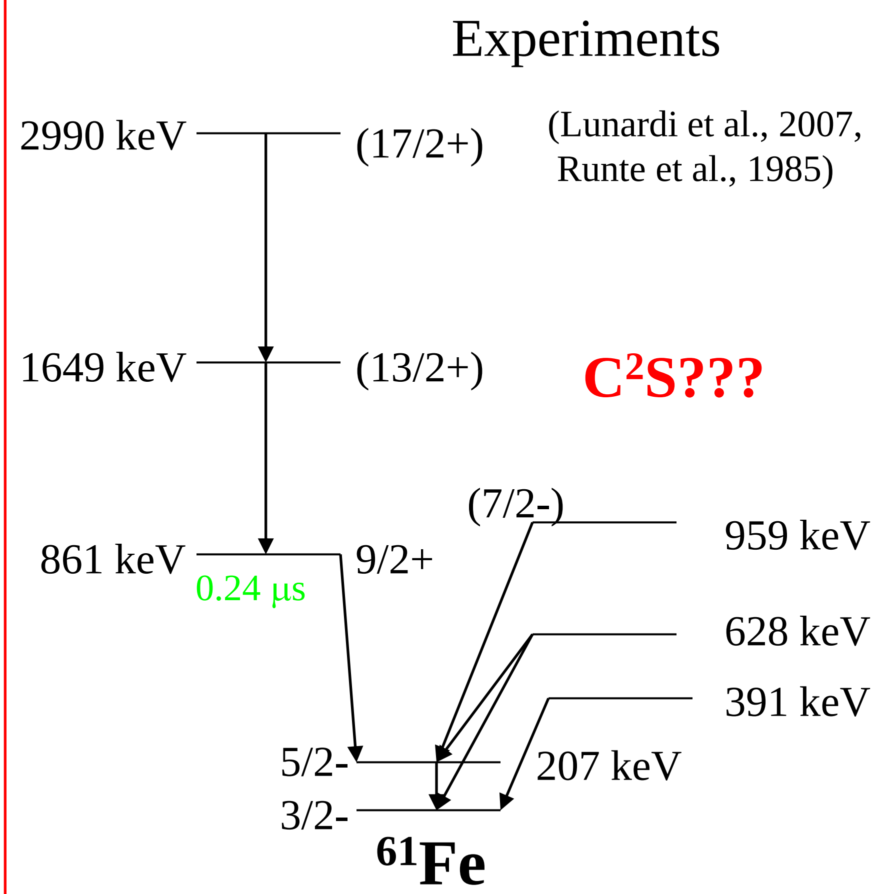
Production of **^{60}Fe** in core-collapse supernovae type II depends strongly on the uncertain ^{59}Fe(n,γ)^{60}Fe & **^{60}Fe(n,γ)^{61}Fe** cross sections

$^{60}Fe(n,\gamma)^{61}Fe$ status in 2005-2009

Reaction rate: HF calculations (resonant capture) + shell-model (direct capture)



Shell Model calculations
G. Martinez-Pinedo



Direct $\sigma_{60Fe(n,\gamma)61Fe}$ → E_x, l & C^2S of ^{61}Fe → (d,p) transfer reaction

Note: Recent $^{60}Fe(n,\gamma)^{61}Fe$ activation measurement (Uberseder et al, 2009)

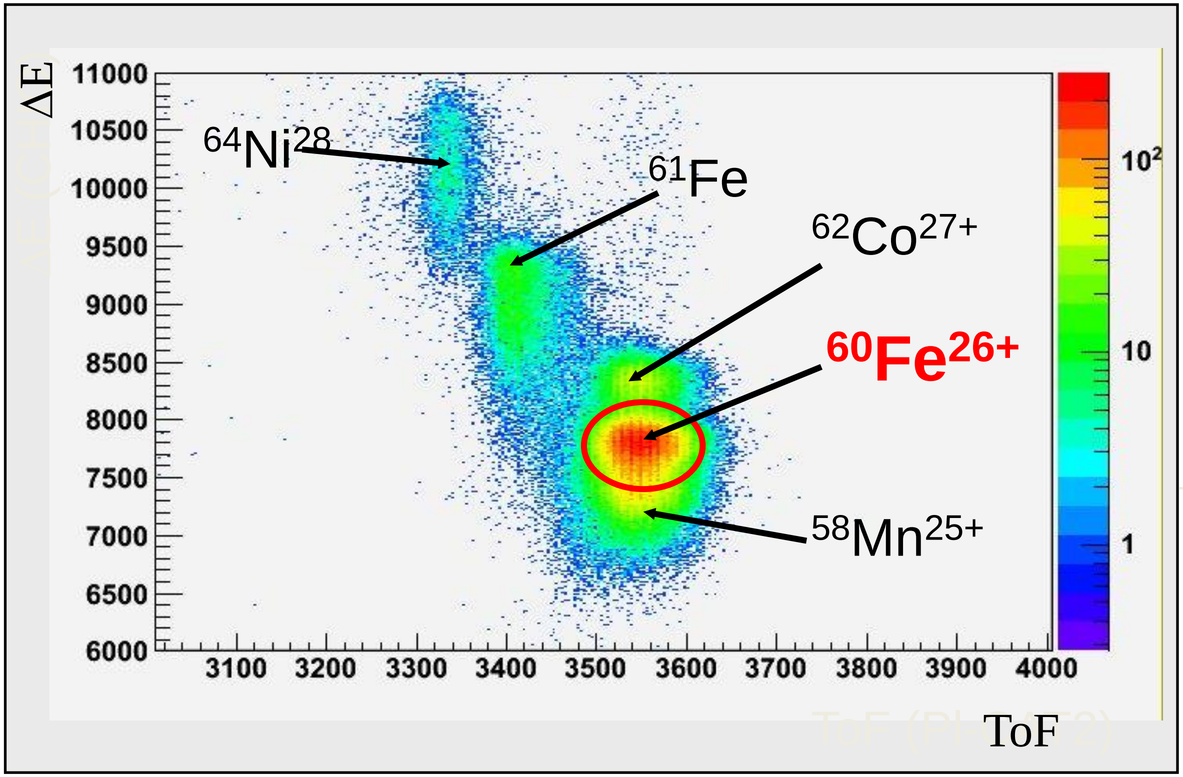
d(^{60}Fe,pγ)^{61}Fe experiment @ LISE/GANIL

- Fragmentation of $^{64}Ni^{28+}$ (500enA) @ 55 A MeV on ^{9}Be LISE target (500 μm) + ^{9}Be wedge degrader (568 μm)

↓

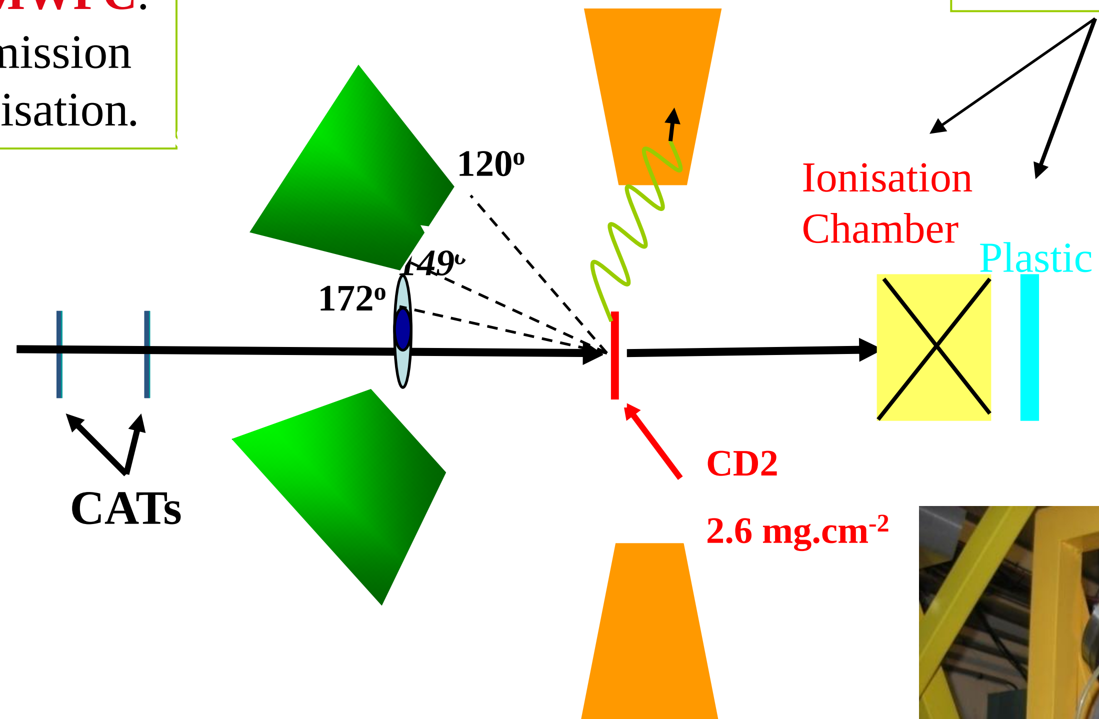
^{60}Fe secondary beam

- 27 A.MeV
- ~ 10^{5} pps I_{60Fe}
- ~ 60 % purity



Experimental Setup

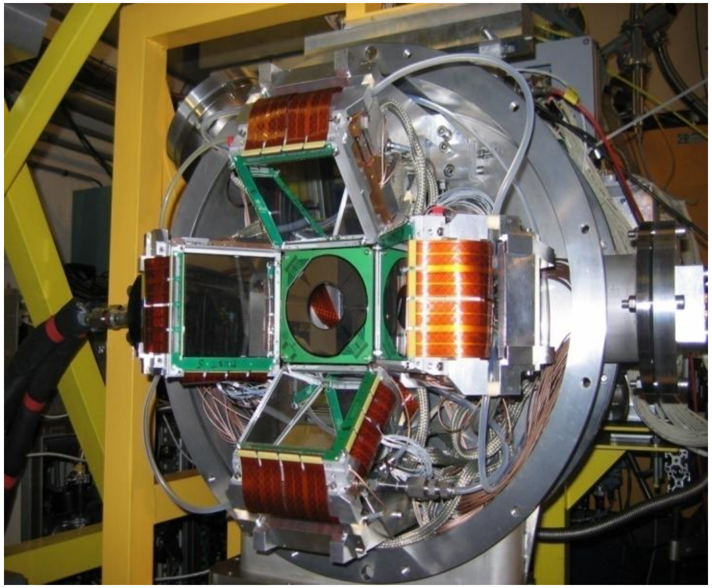
CATS: - **MWPC**.
-Proton emission point localisation.



MUST2 : **Si Strip (300µm)**
+ **SiLi** (4.5 mm) detectors.

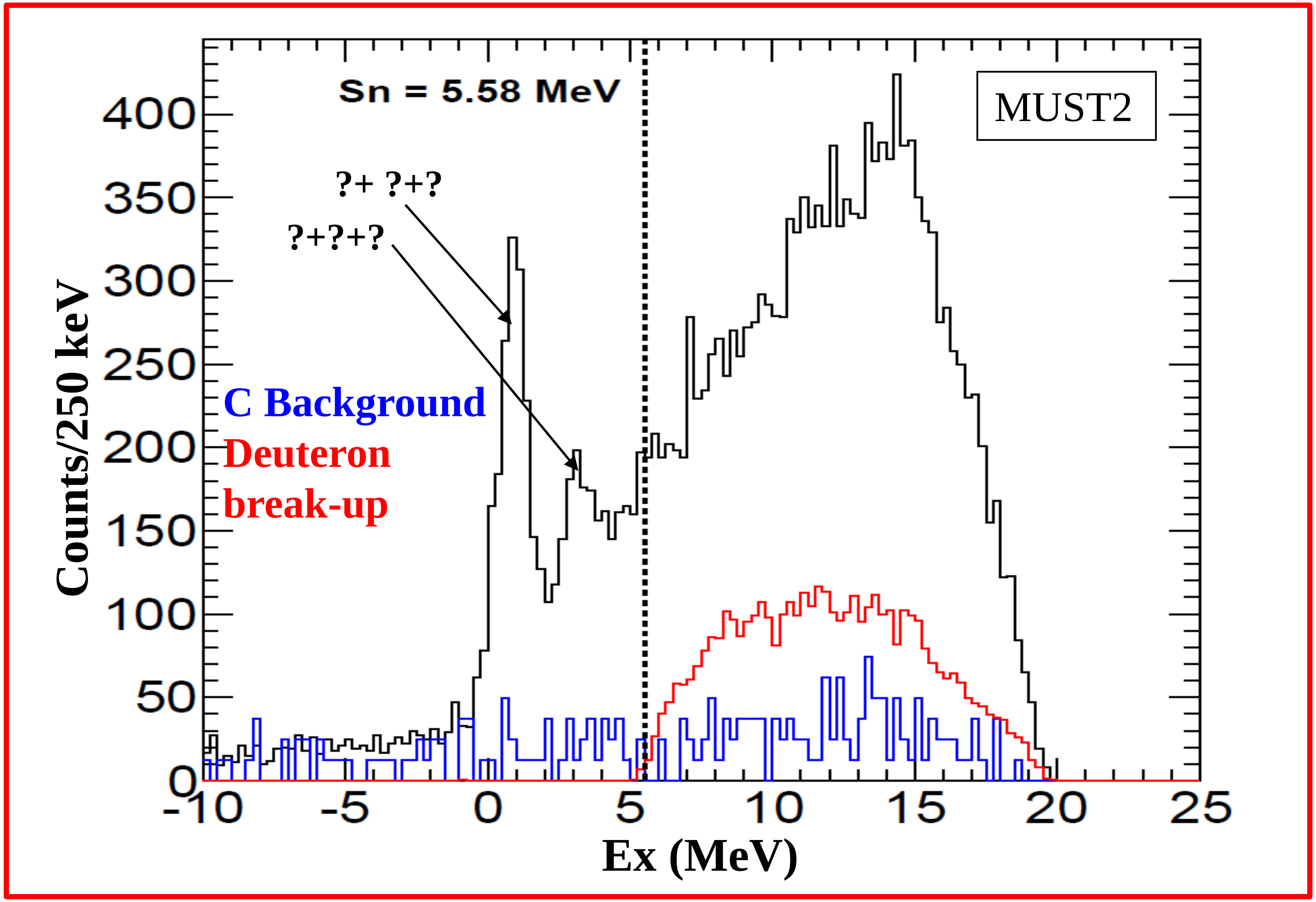
- Proton **impact localisation.**
- Proton **energy** measurement

S1: Annular Si (500 µm, 64 strips in Θ and 16 in Φ)



^{61}Fe Excitation energy spectrum

S. Giron PhD thesis

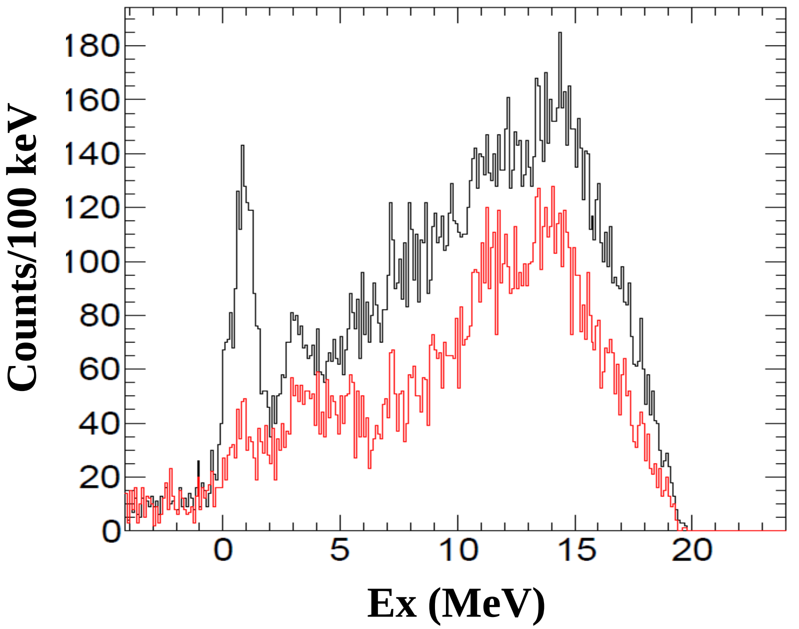


➢Width of the peaks > 800 keV (expected energy resolution) ➔ population of 2-3 states

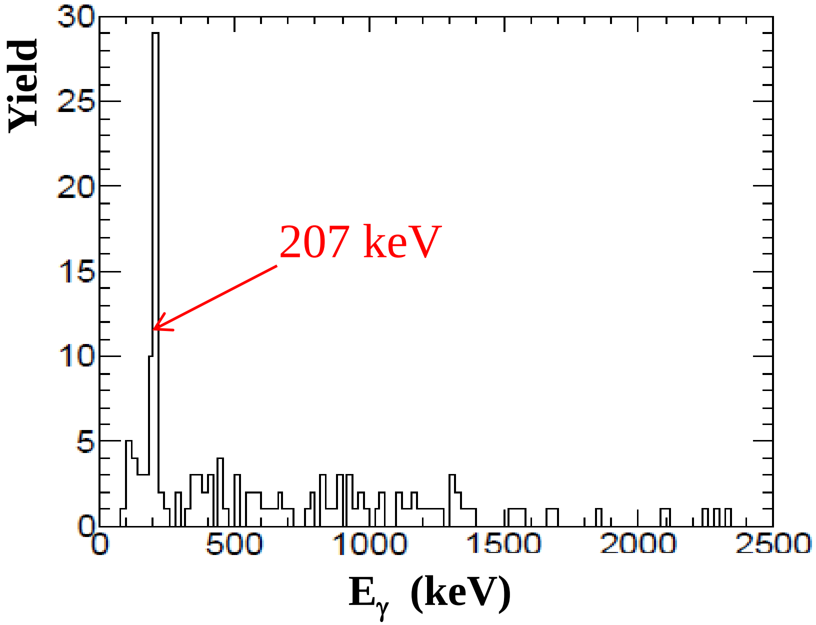
⇒ need to analyze the γ-ray spectra → disentangle the ≠ populated states ?

^{61}Fe Excitation energy spectrum & γ-ray spectrum

— No γ coincidence
— With γ coincidence



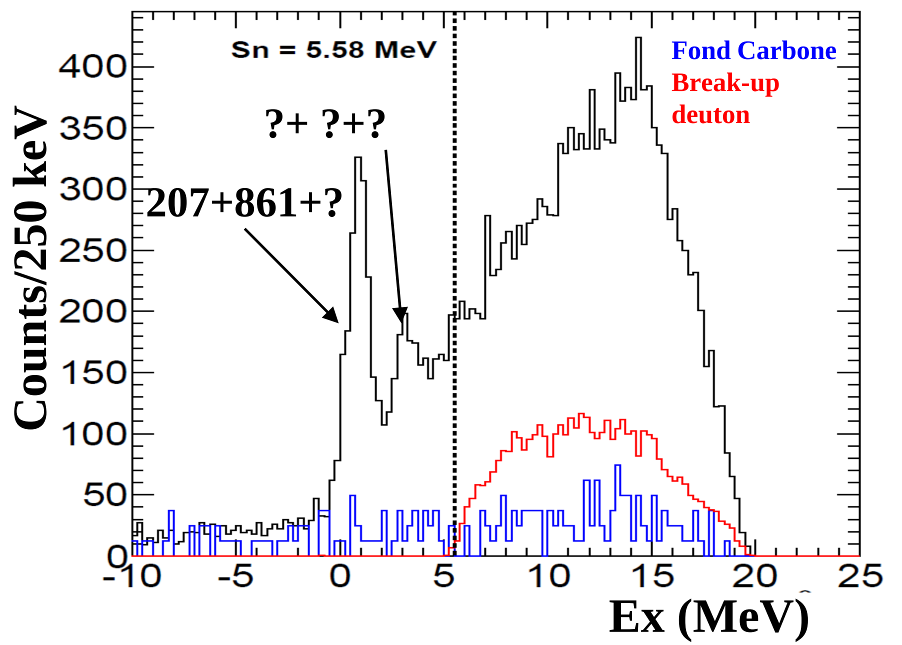
0<Ex<500 keV



Population of the isomeric state
@ **861 keV**

Population of **207 keV** state

First analysis (S. Giron PhD thesis-2011)



Peak widths > expected energy resolution

↓

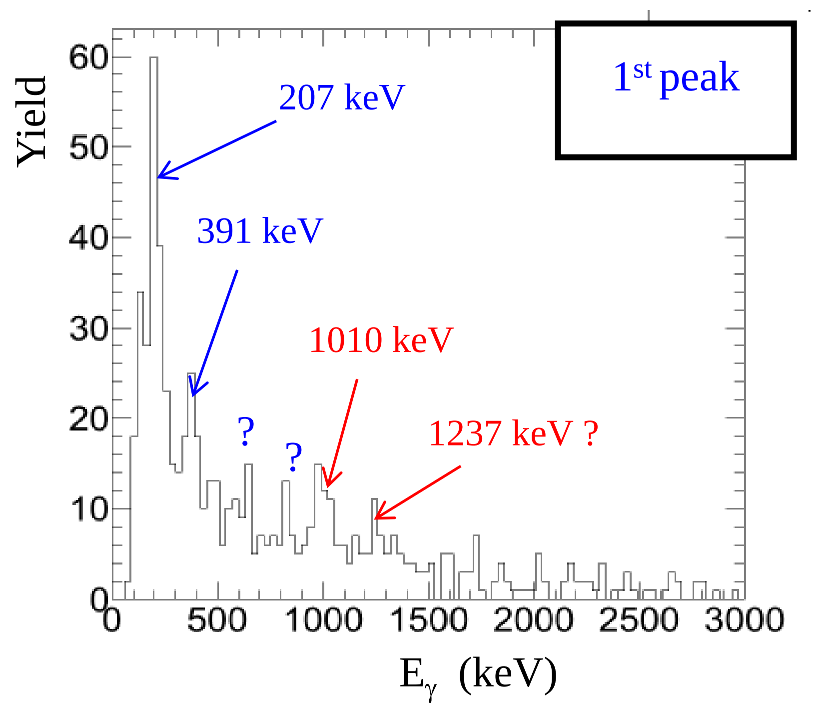
population of various states (2,3 or 4?)

⇓

γ spectra analysis

↓

Discrimination of ≠ populated states ?



Identification of **207, 861 & 1401 keV** states of ^{61}Fe in the 1st peak

↓

dσ/dΩ +DWBA

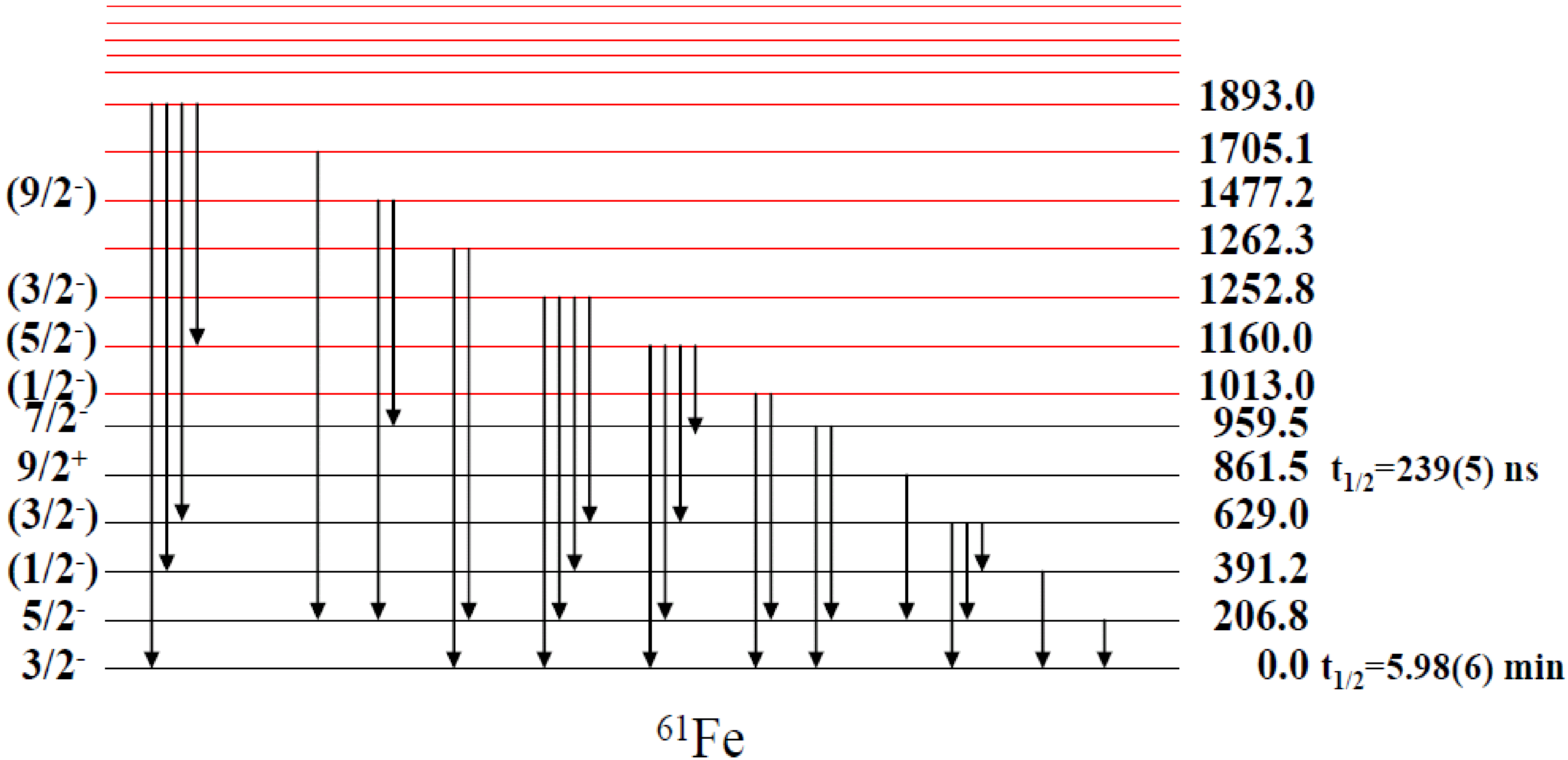
⇓

S_n & L

New state: 1401 keV (L=1)

Recent measurements of ^{61}Fe level scheme

- Recent results of β decay measurements of ^{61}Mn to ^{61}Fe levels **Radulov et al. PRC88, 014307 (2013)**



- The observed γ-ray @ ~1010 keV→ decay of 1013 keV state to the gs of ^{61}Fe
- Observation of many new states

$^{60}Fe(d,p\gamma)$ ^{61}Fe data reanalysis

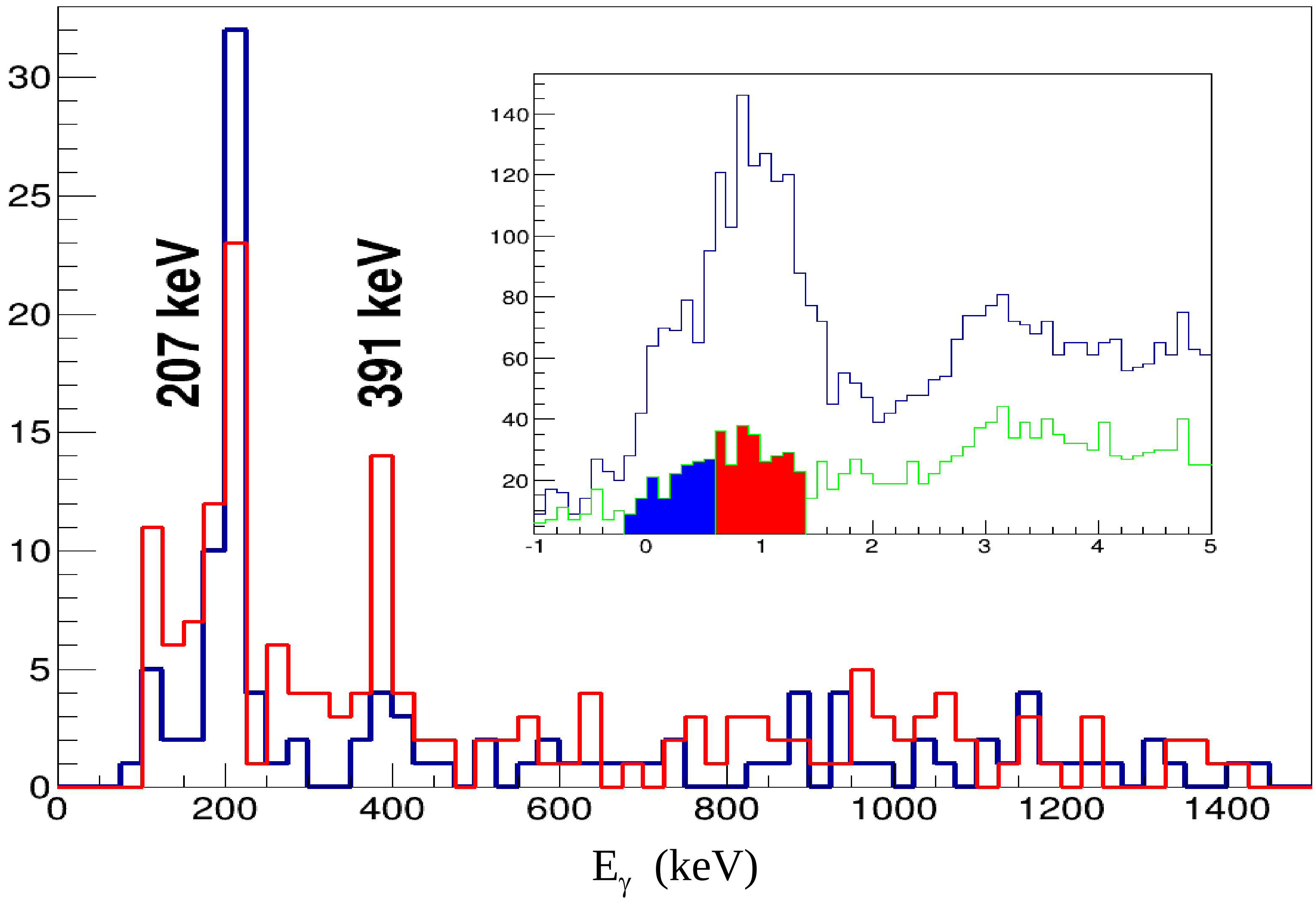
Many tests were done to improve the spectra , reduce the background and constrain the results:

- Check of the various codes

- Application of various cuts to ”select” the ”good” events :
  - on CATS
  - on the particle angles
  - on γ-ray and particle detectors and even on Ge segments
  - on time
  - on runs
  - on events number
  - …

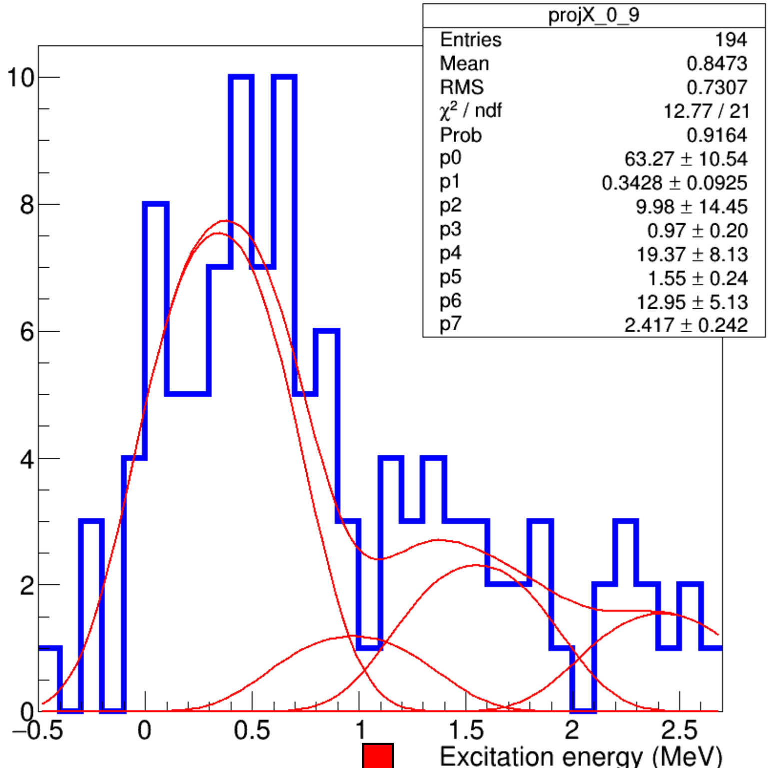
→ An improvement is “maybe” observed but significant decrease on statistics

^{61}Fe γ-ray energy spectrum with gates on Ex

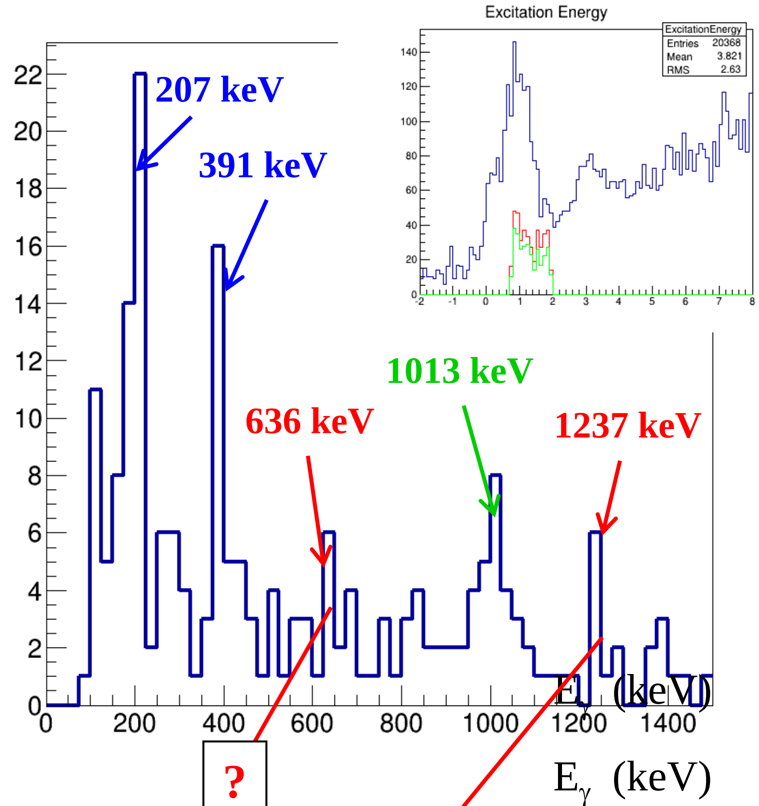


^{61}Fe spectrum: E_x with gate on E_γ & E_γ with gate on E_x

^{61}Fe Ex with gate on Eγ=207 keV



^{61}Fe Eγ with gate on E_x: [0.750-1.950 MeV]



?

?

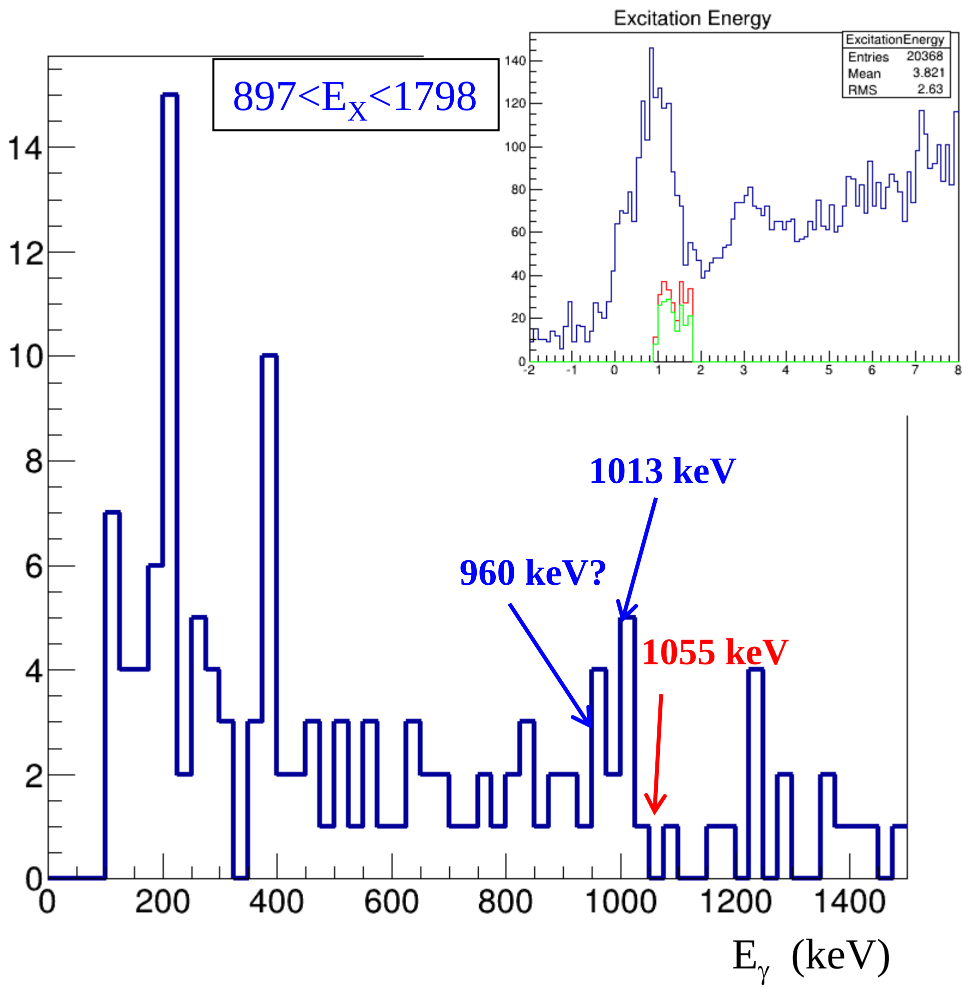
- 207 keV → shift=136 keV
- “0.97±0.2 keV” → Ex= 834 keV → γ of ~ 627 keV
- “1550 keV±240”? → Ex= 1414 keV → γ of ~1207 keV

Population of
Ex=843 keV ?
Ex=1444 keV ?

^{61}Fe Eγ spectrum with gate on Ex around 1260 keV

- Population of 1262 keV or 1252 keV of Radulov et al. ?

→ 1262 keV → γ-rays: 207 keV + 1055 keV
→ 1252 keV → γ-rays: 207 keV+ 1045 keV → **No**



- Population of 1160 keV?

↓

207 keV + 952 keV

↓

Maybe

- Population of 1477 keV?

↓

207 keV + 1277keV

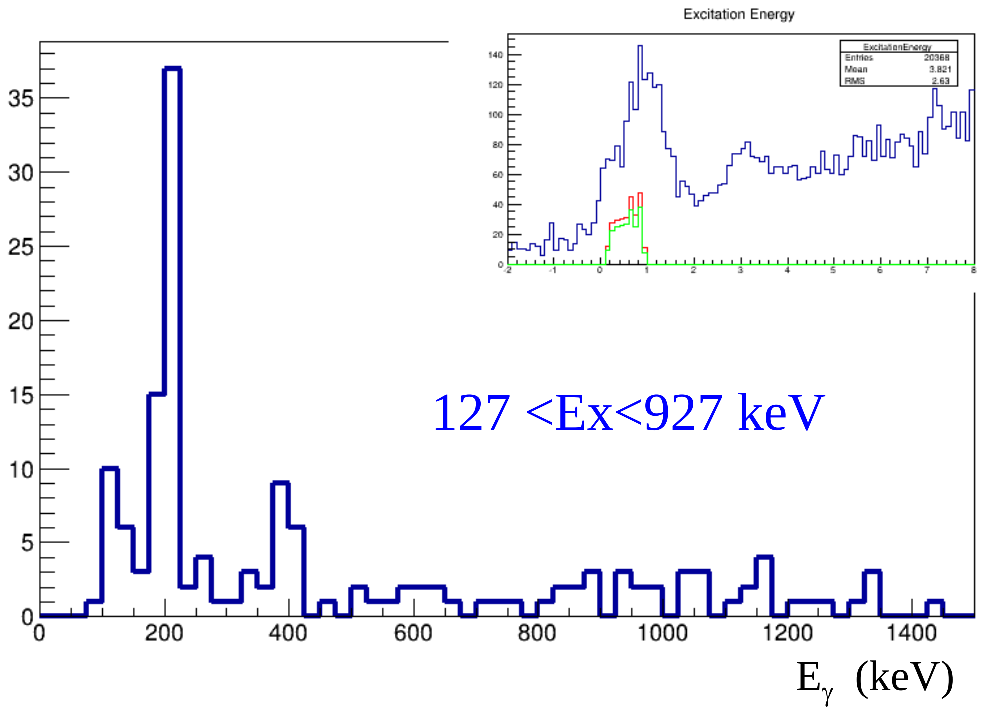
↓

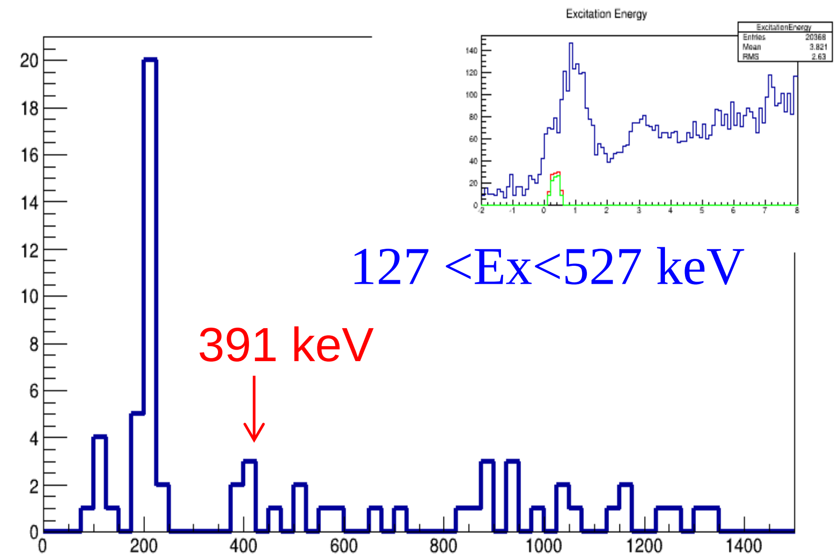
No

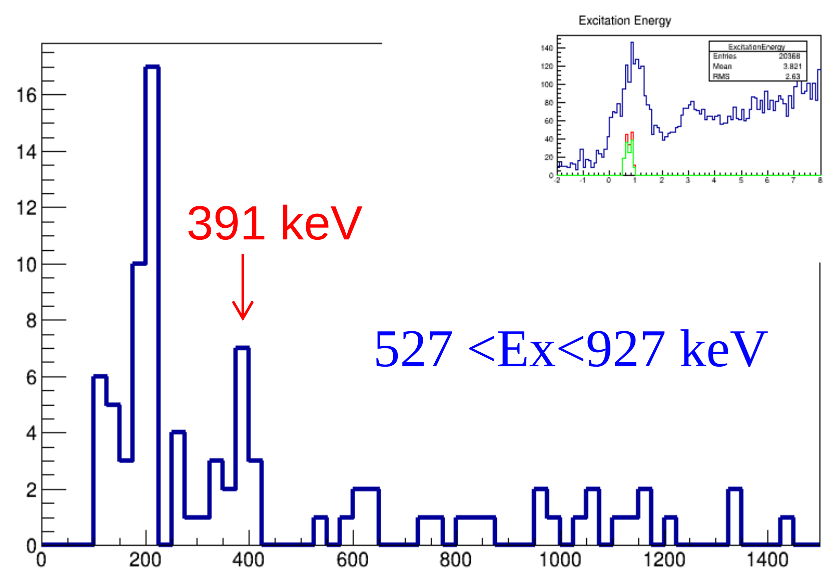
What about the 391keV γ-ray transition?

- Does it come from a direct population of the 391 keV state?

With shift=136 keV

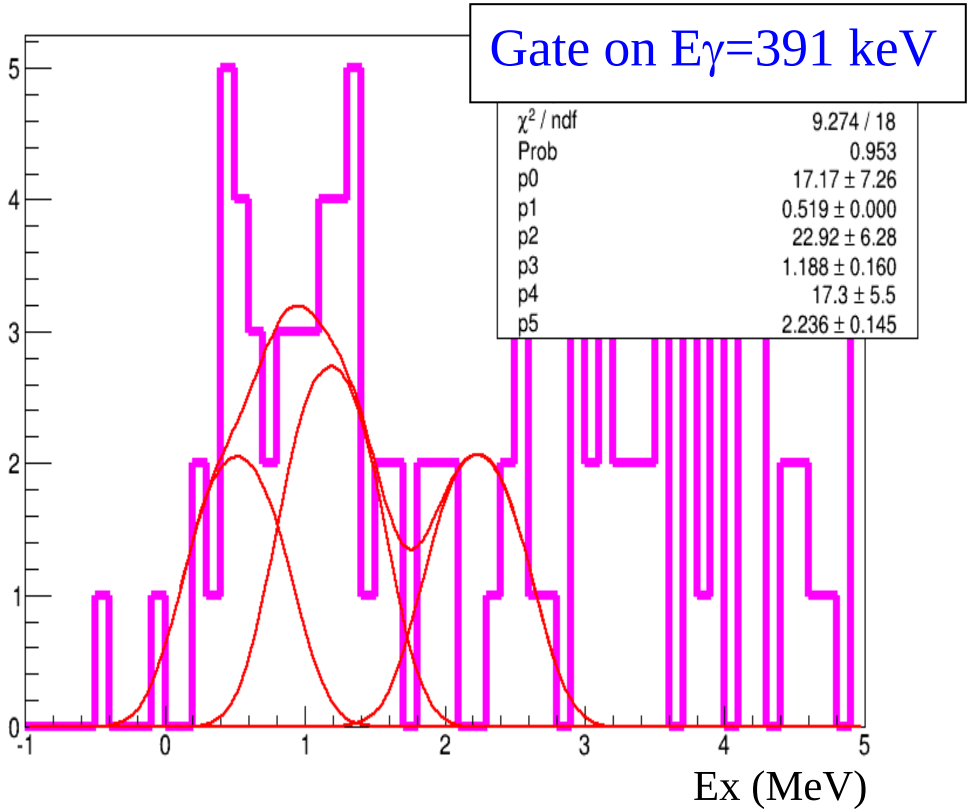




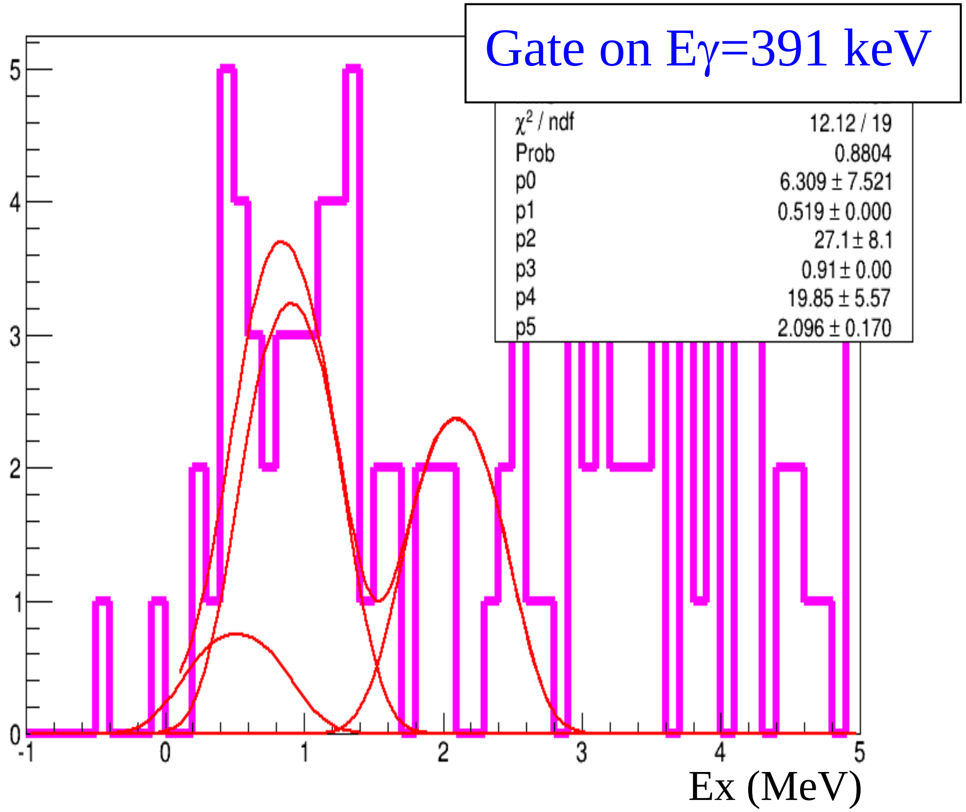


→ Very weak population of 391 keV

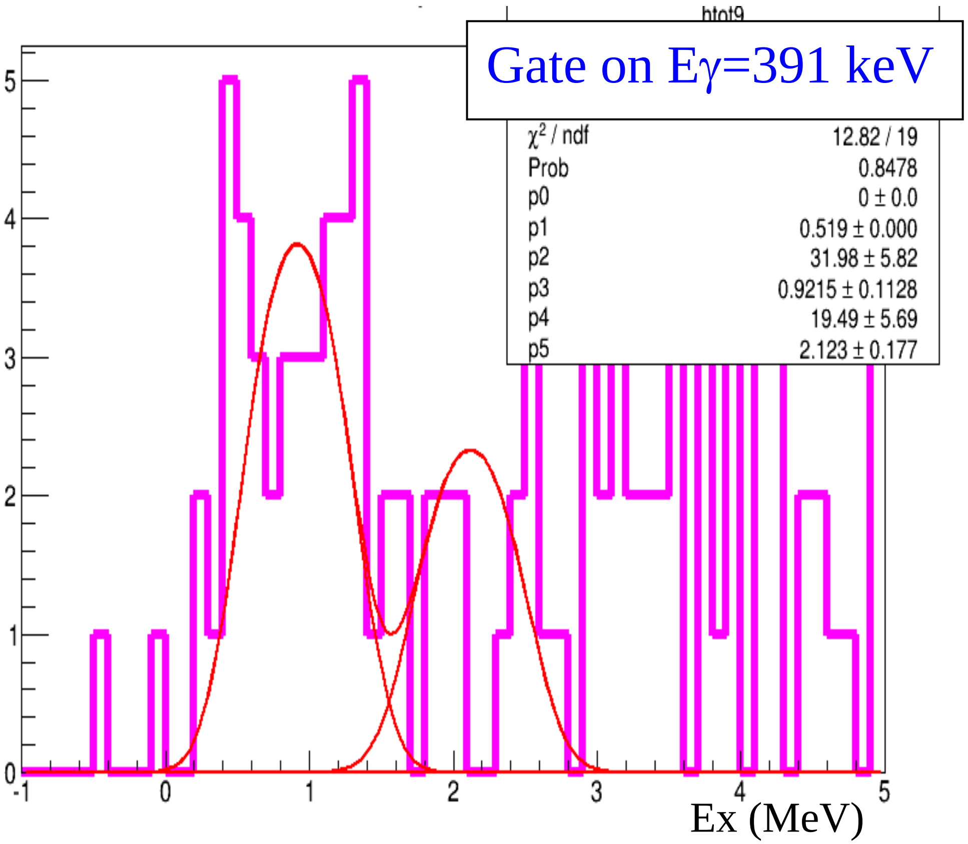
What about the 391keV γ-ray transition?



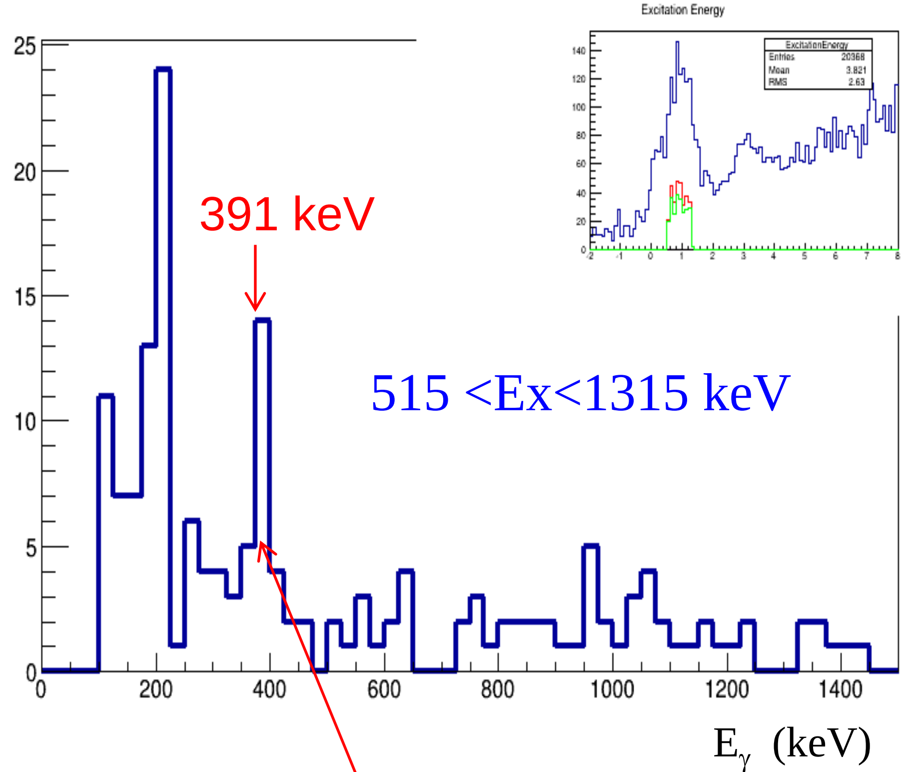
What about the 391keV γ-ray transition?



What about the 391keV γ-ray transition?



- Very weak or no population of 391 keV



- Population of a “~915±110 keV”

↓

Ex= **779 keV**

↓

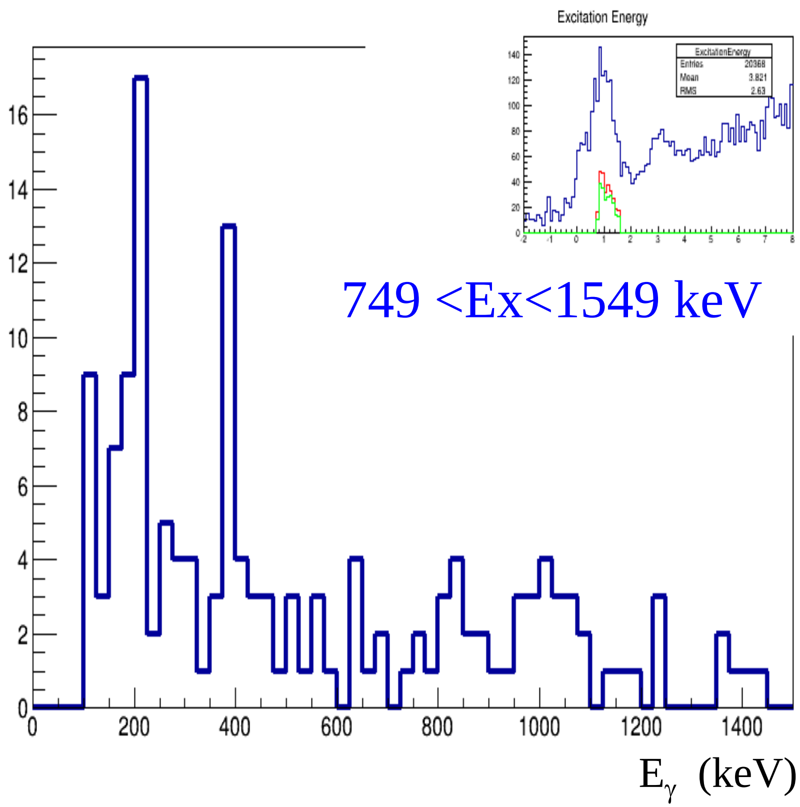
cascade through the **391 keV → Eγ ~ 388 keV**

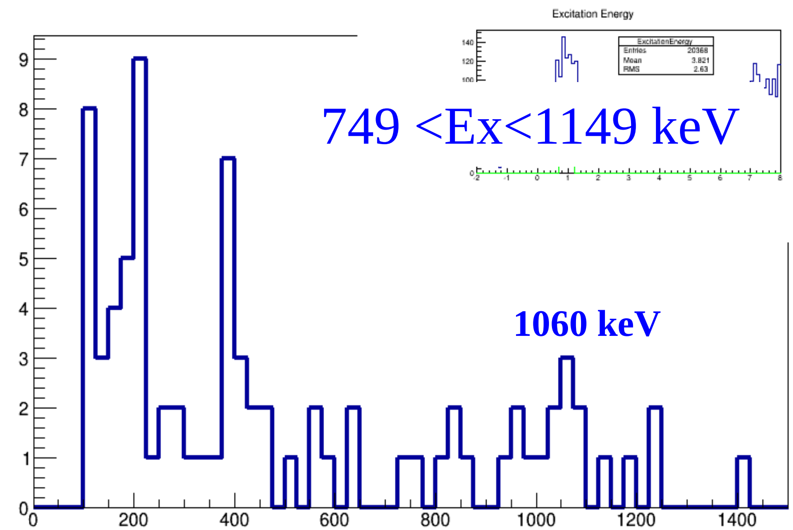
2 γ-rays : 391 keV+ ~388 keV ?

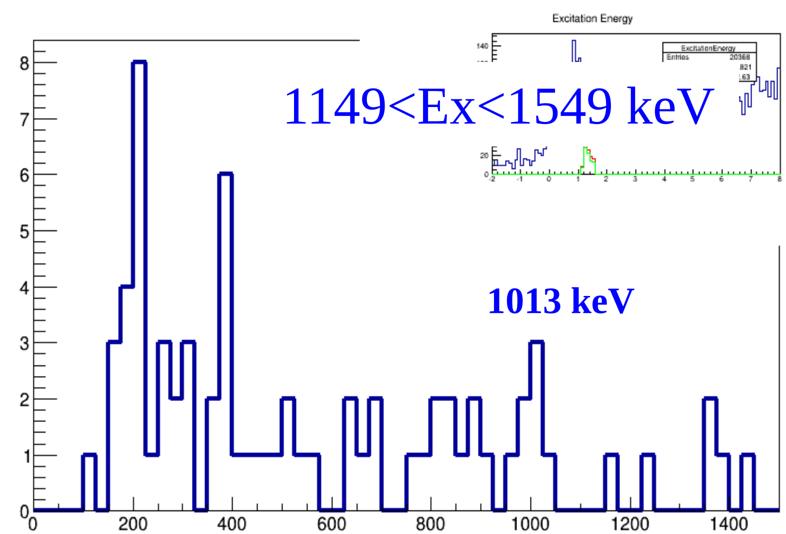
What about the observed 1013keV γ-ray transition?

- Does it come from a direct population of the 1013 keV state?

With shift=136 keV





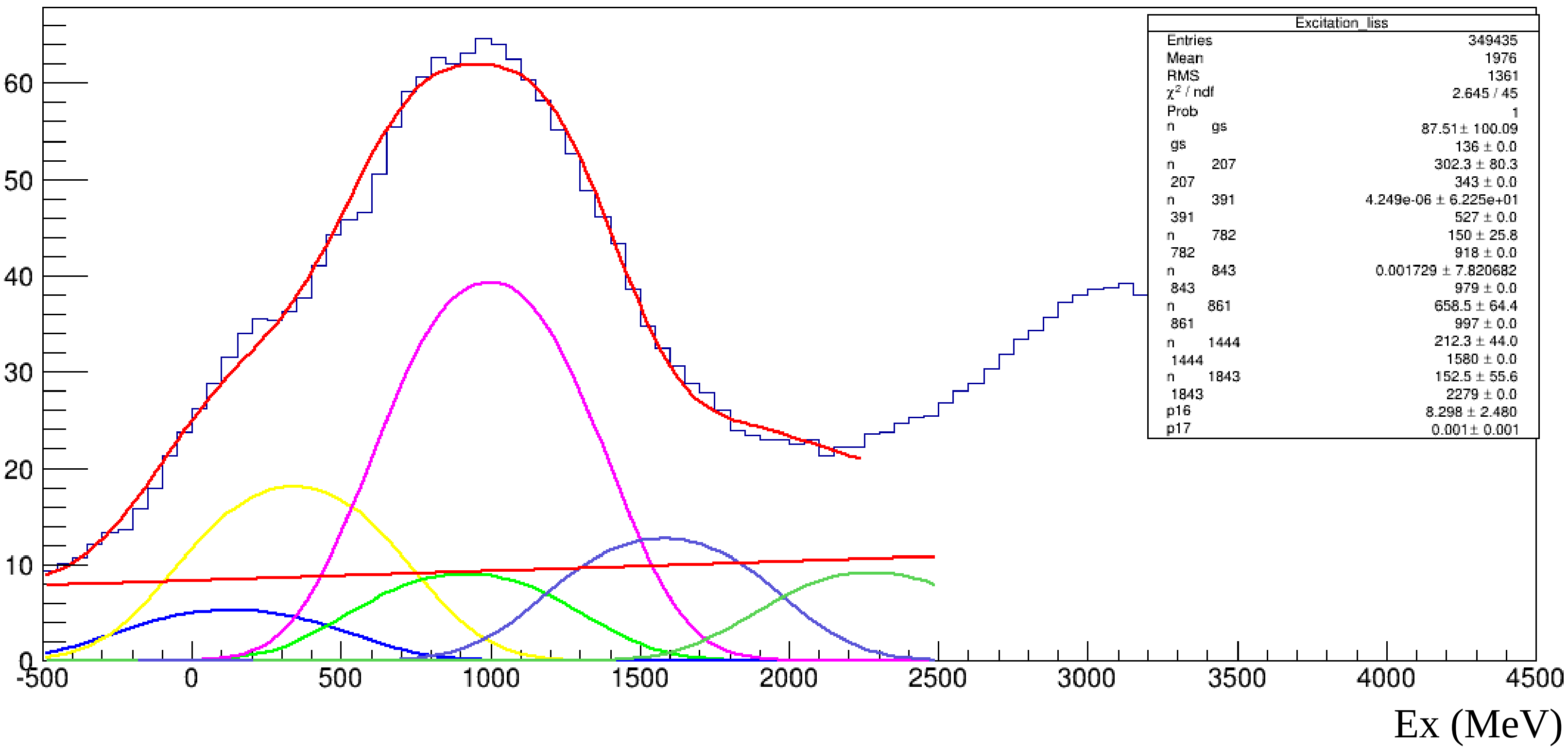


→ No direct population of 1013 keV

→ Populated via a cascade from higher Ex

Results

- Well identified & populated states : 207 keV, $J^{\pi}=5/2^{-}$, 861 keV, $J^{\pi}=9/2^{+}$
- Weakly populated states: gs, 391 keV, $J^{\pi}=(1/2^{-})$, 1160 keV, $J^{\pi}=(5/2^{-})$ (Radulov et al.)
- Assumed states , weakly populated & not observed by Radulov et al. : "~1444 keV", "~779 keV", "~843 keV (very weakly) "



Next: → Extraction of 861 keV dσ/dΩ ⇒ Sn (DWBA)

→ Extraction of 207+gs dσ/dΩ & Sn **?**

Collaboration

S. Giron, F. Hammache, N. de Séréville, P. Roussel, D. Beaumel, S. Franchoo, J. Guillot, F. Maréchal, A. Matta, I. Matea, L. Perrot, J. A. Scarpaci, I. Stefan
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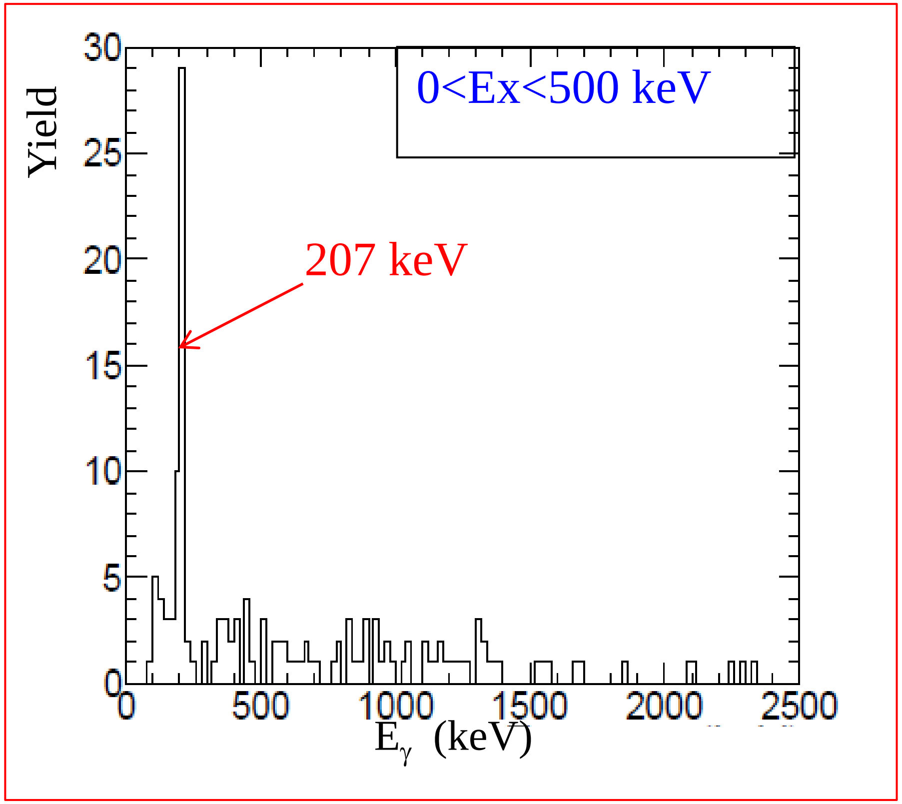
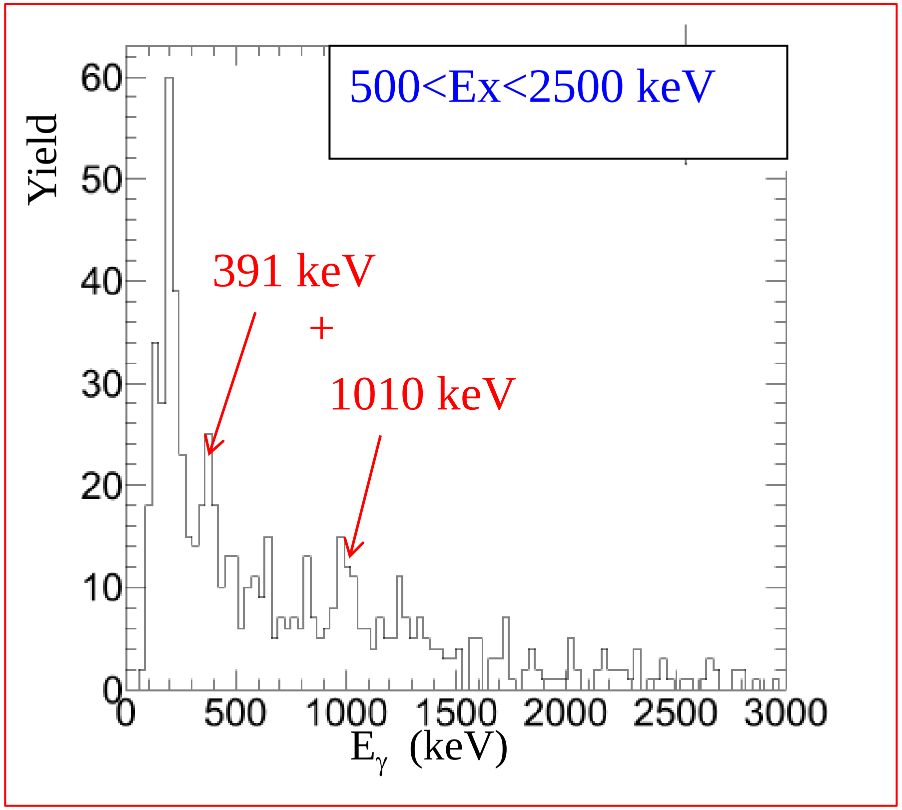
γ-ray spectra

Discrimination of the ≠ populated states of the 1st peak (0< Ex<2.5 MeV)

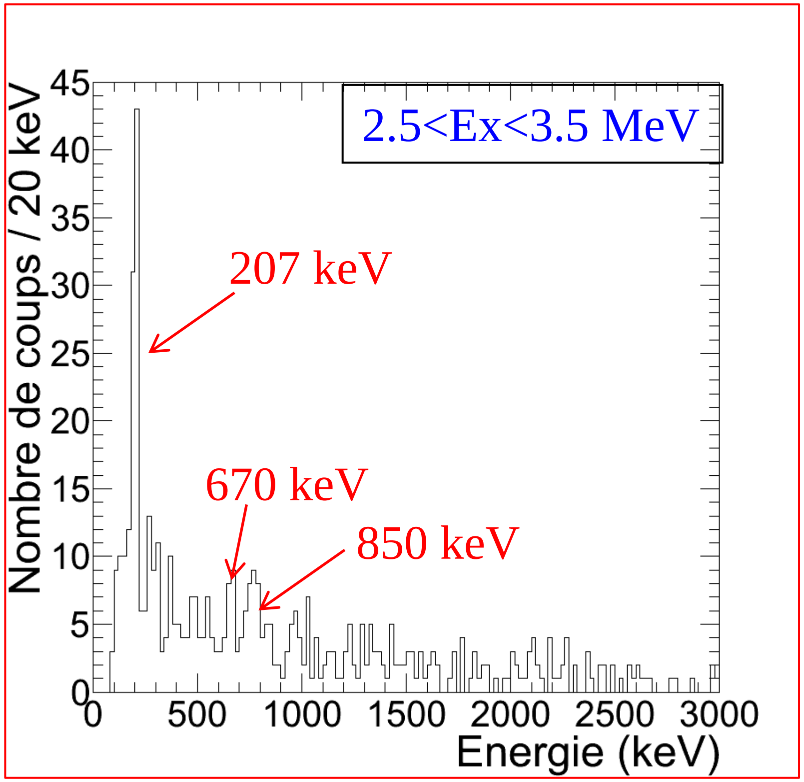


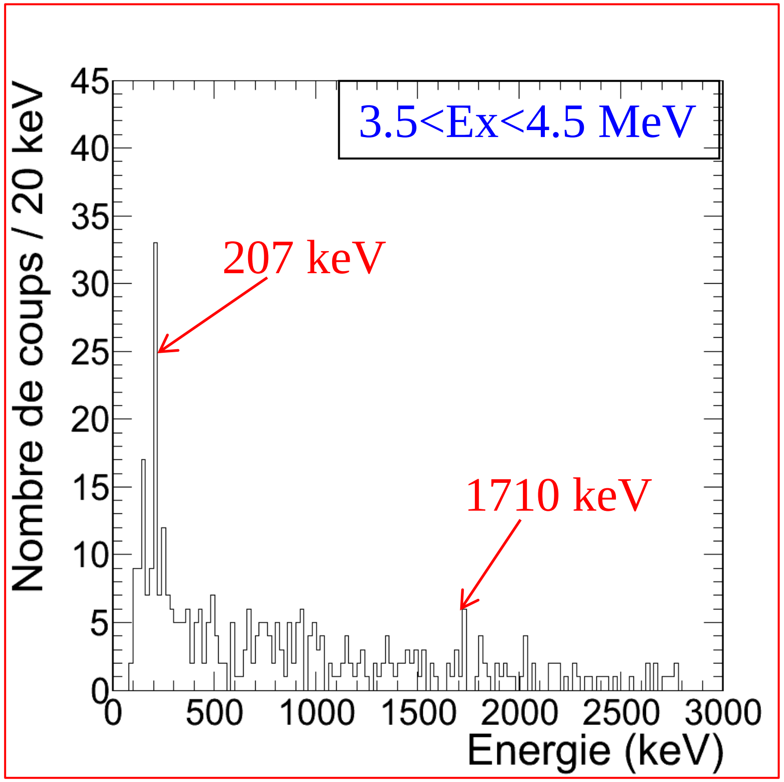


➢ Identification of **207 & 1401 keV** states of ^{61}Fe in the 1st peak

γ-ray spectra

Discrimination of the ≠ populated states of the 2^{nd} peak (2.5< Ex<4.5 MeV) ?



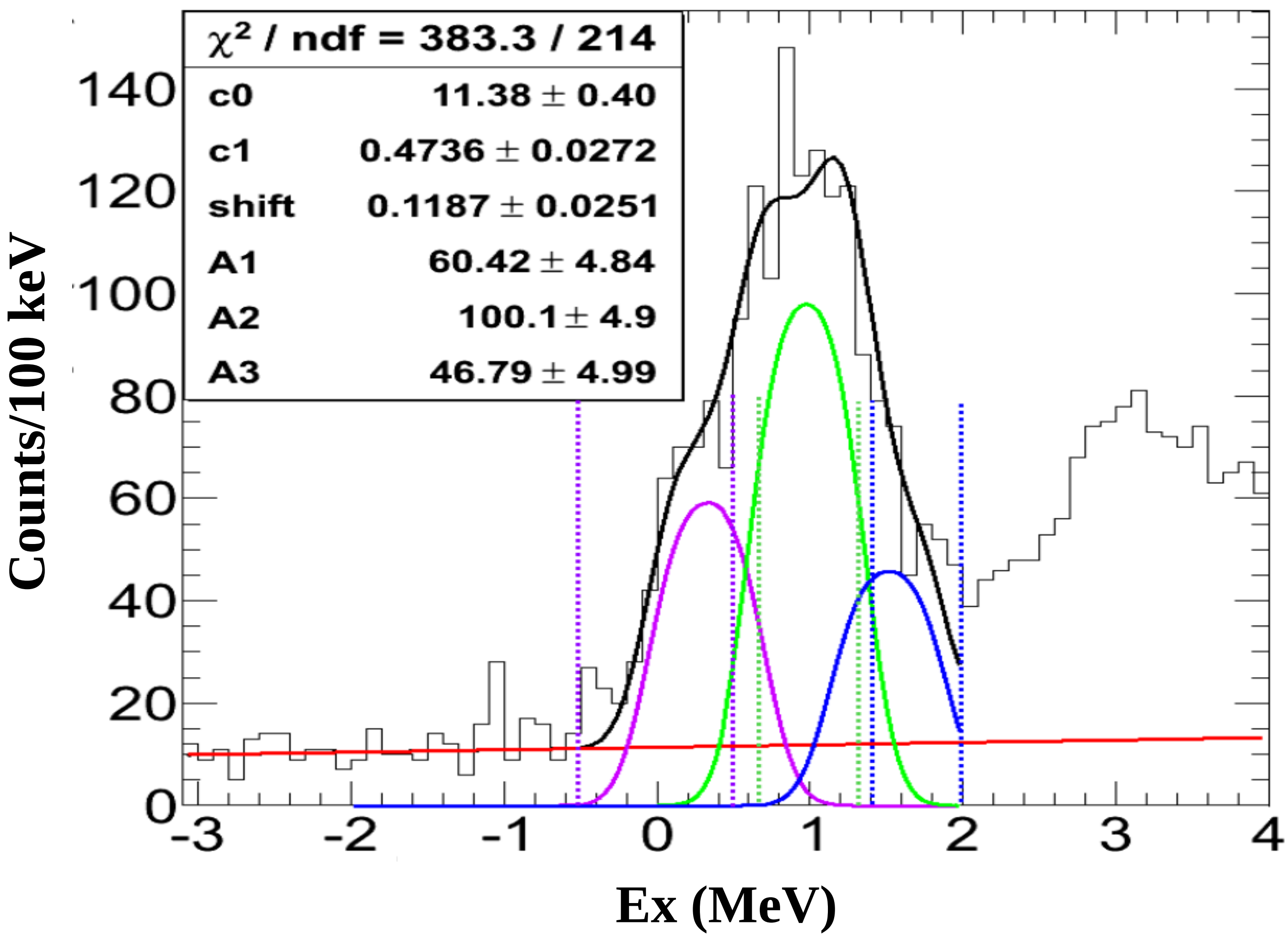


- Difficulties to identify the states in the 2^{nd} peak (2.5< Ex<4.5 MeV)

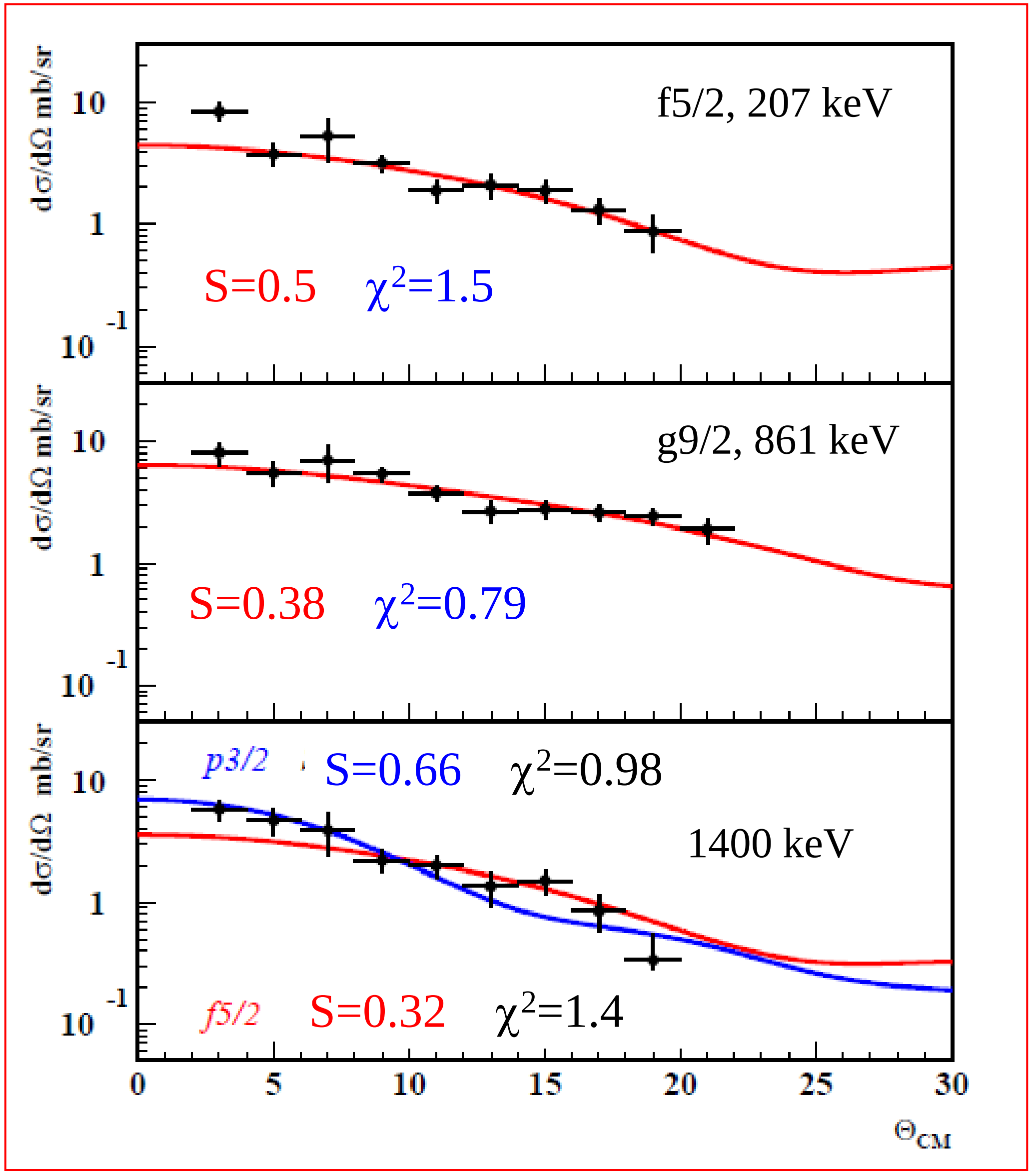
→ too many γ-ray transitions (very low statistics)
\+ missing γ-ray transitions @ high energies → efficiency ↘

Preliminary Results

→Population of 207, 861 & 1401 keV states of ^{61}Fe in the 1st peak



Preliminary results: Measurements & DWBA calculations



→ DWBA calculation

• For the entrance chanel:
→Adiabatic approximation potential
to take into account the
deuteron breakup
G.L.Wales and R.C. Johnson (1976)

• For the exit chanel:
→Varner's et al. global nucleon
optical model potential
Varner et al. (1991)

S =0.50±0.15 (f5/2 207 keV)
S =0.38±0.11 (g9/2 861 keV)
S =0.66±0.19 (2p3/2 1401 keV)