GANIL E710

(C. MICHELAGNOLI ET AL)

UNDERSTANDING COSMIC ABUNDANCE OF ^{22}NA

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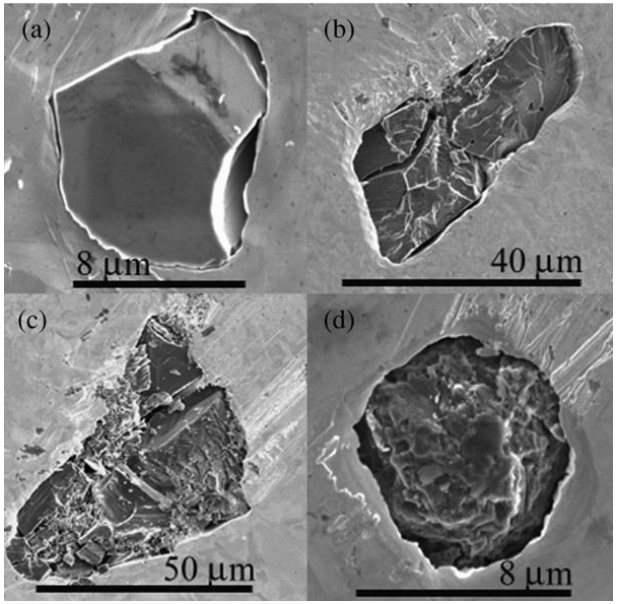
Astrophysical context : Novae

Nova = white dwarf (WD) star accreting matter from red giant

Thermonuclear events at WD surface

Novae model uncertainties
- Amount of admixed WD material with accreted matter
- Total ejected mass



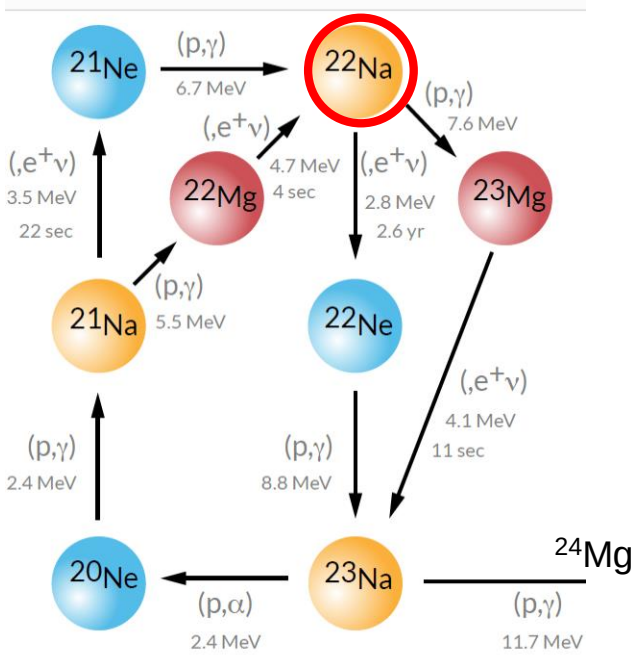
Impact
- Abundances of nuclei
- Test of Nova models
- Isotopic anomaly presolar grains in meteorites
- Excess of ^{22}Ne in the galactic cosmic rays
- Number of supernovae SNIa (dark energy)

Astrophysical context : Novae

ONe novae : synthesis of radioactive nuclei

^{22}Na τ=2.6yr

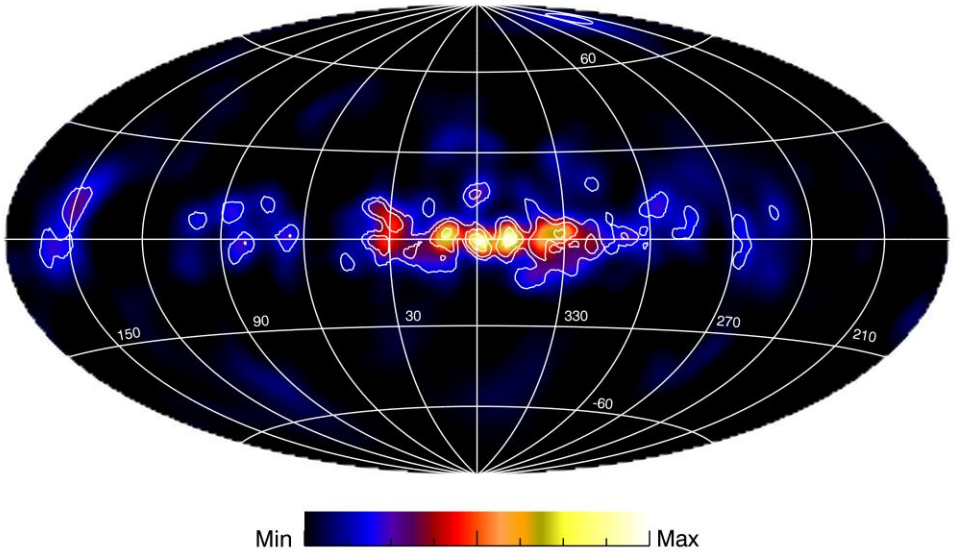
- Transparent to thermonuclear medium
- Space correlation with Nova



Ne-Na Cycles

T_{nova} =0.04 < T_9 < 0.4

γ-ray telescopes observation
(SPI/INTEGRAL, COMPTEL/CGRO…)



Example : sky map from SPI 3yr exposure at E_γ = 1.809 ^{26}Al (esa)

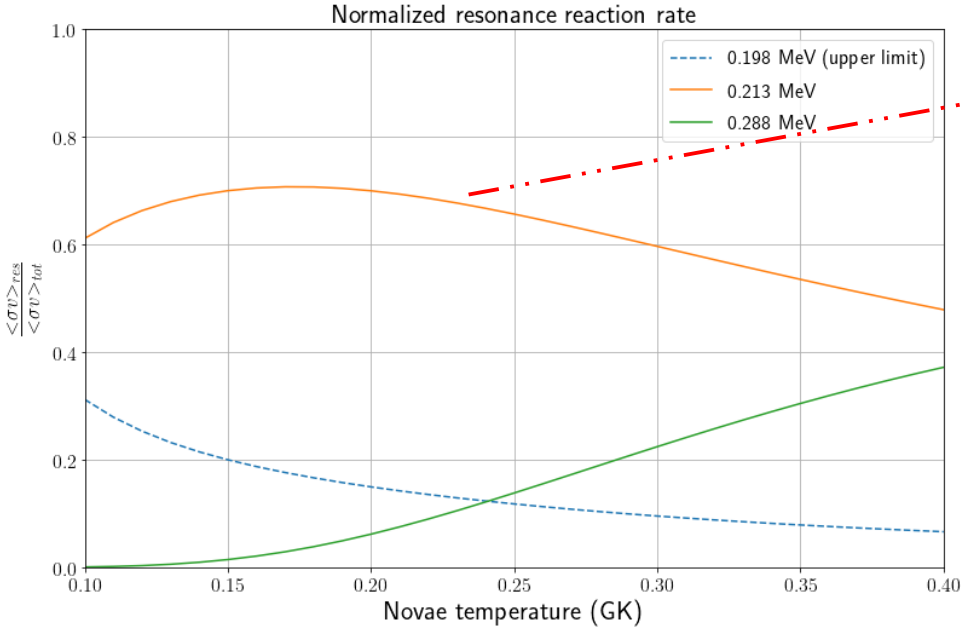
^{22}Na E_γ = 1.275 MeV has never been observed

Destruction reaction ^{22}Na(p, γ)^{23}Mg

Resonant reaction = Breit Wigner cross section
=> nuclear reaction rate linear to ωγ resonance strength

$$< \sigma v >_{total} = \Sigma_{resonance} \left(\frac{2\pi}{\mu_{(^{22}Na,p)} k_B T} \right)^{\frac{3}{2}} * \hbar^2 * \omega\gamma * \exp\left(-\frac{Er}{k_B T}\right)$$

Direct measurements of ωγ (TRIUMF/Canada experiment ^{22}Na(p, γ)^{23}Mg)



Dominant resonance
(^{23}Mg* E_x=7.786 MeV, Er=0.213 MeV)

Measurements	ωγ (meV)
Direct (Bochum, Germany)	1.8 ± 0.7
Direct (TRIUMF, Seattle team)	$5.7^{+1.6}_{-0.9}$
Indirect (TRIUMF, Canada team)	$1.4^{+0.5}_{-0.4}$

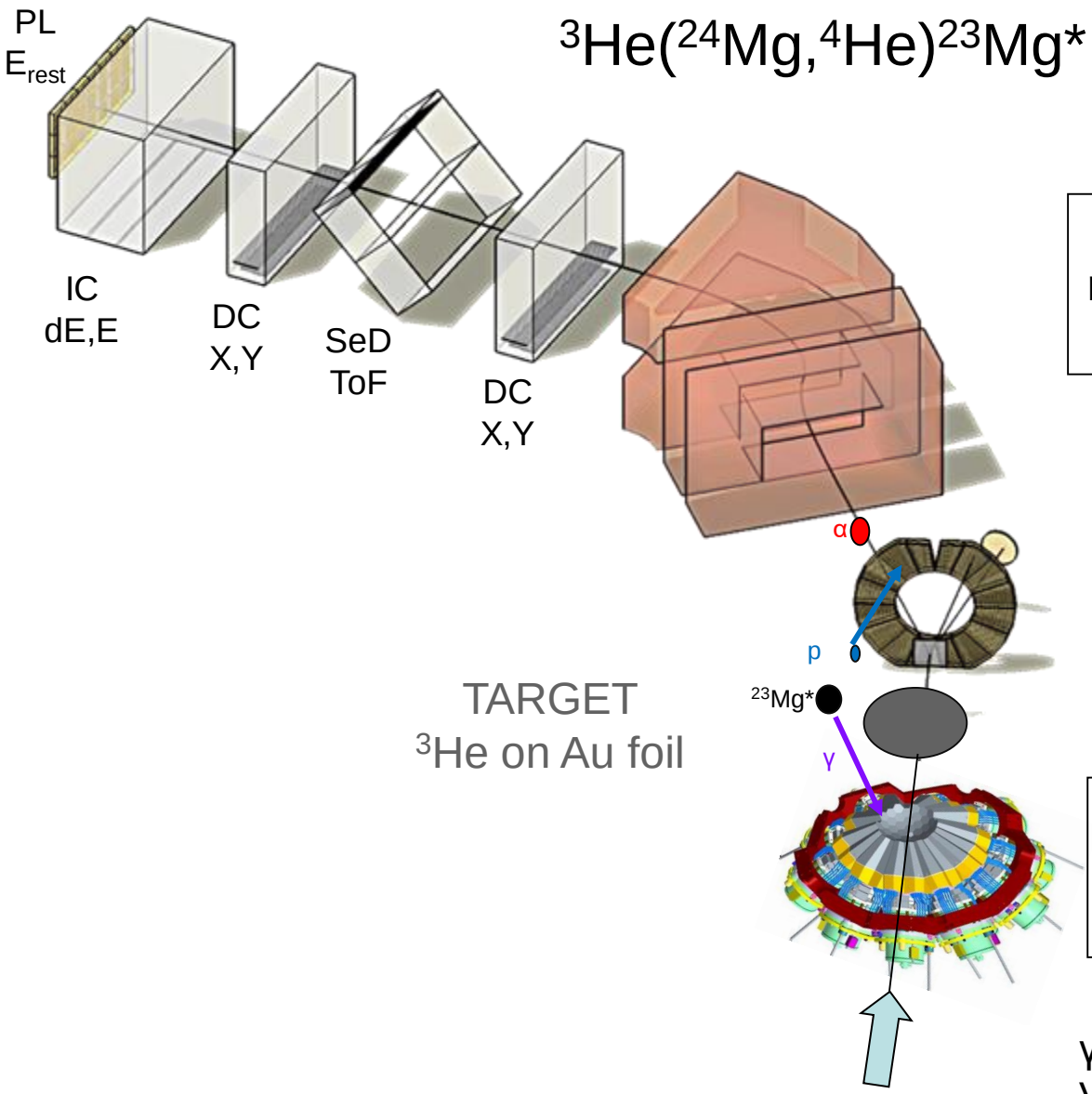
Disagreement on $\omega\gamma_{0.213}$

$$\omega\gamma = \frac{2J+1}{(2J_{^{22}Na}+1)(2J_p+1)} * \frac{\hbar}{\tau} * B_p(1-B_p)$$

GANIL E710 indirect method
$^{23}Mg_{7.786}$ lifetime τ (AGATA fs resolution by DSAM (1)) and B_p => $\omega\gamma_{0.213}$

GANIL E710 : Experimental setup

$^{3}He(^{24}Mg,^{4}He)^{23}Mg^{*}$



VAMOS
magnetic spectrometer
=> ^{4}He

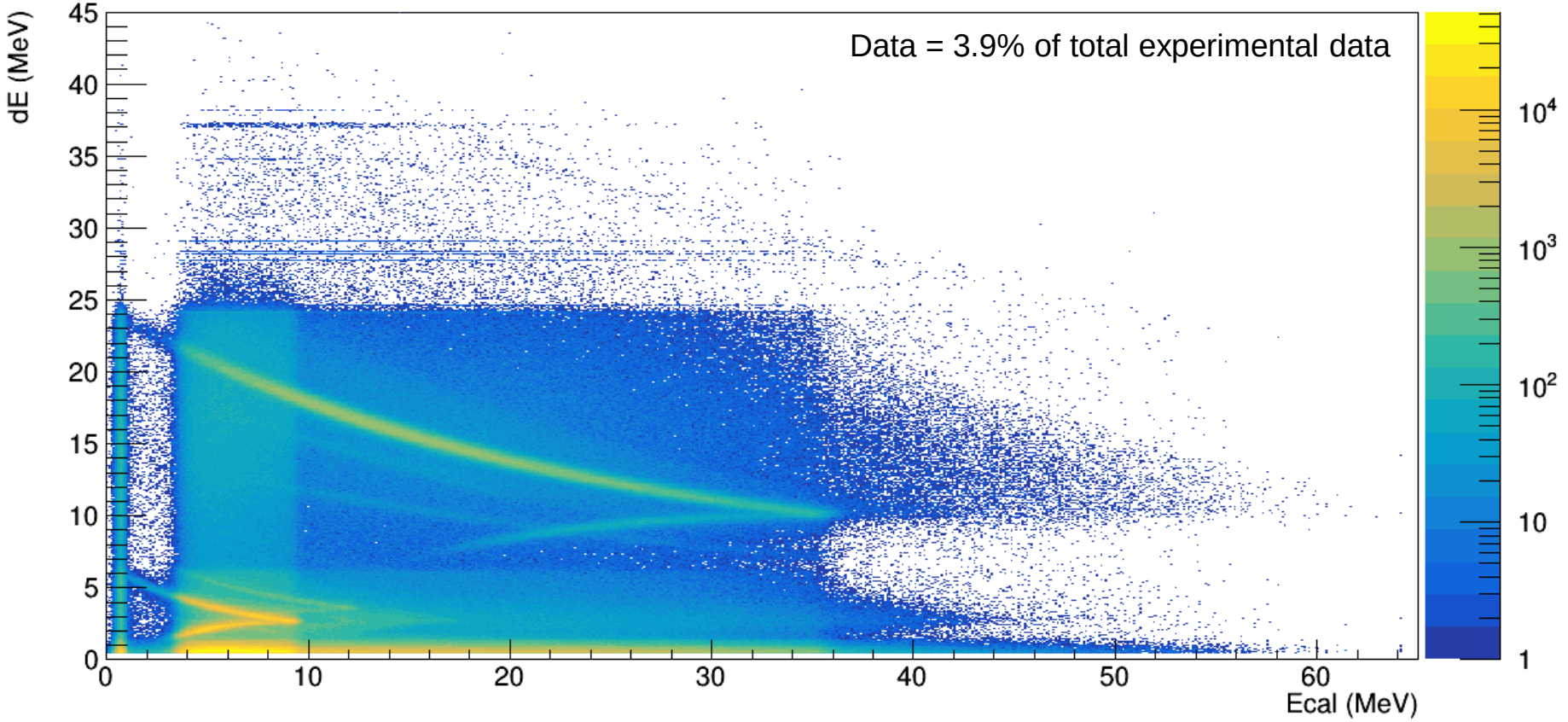
SPIDER
dE-E Si detector
=> p

AGATA
segmented Ge array
=> γ from $^{23}Mg^{*}$

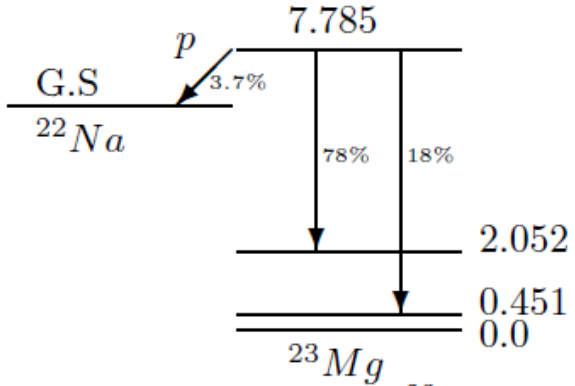
γ in AGATA coïncidence with particles in VAMOS or SPIDER

SPIDER first results

Identification of light reaction elements (p, ^{4}He)



- Quantify independently B_p branching ratio
- Constrain coïncidence γ spectra with E_{4He}



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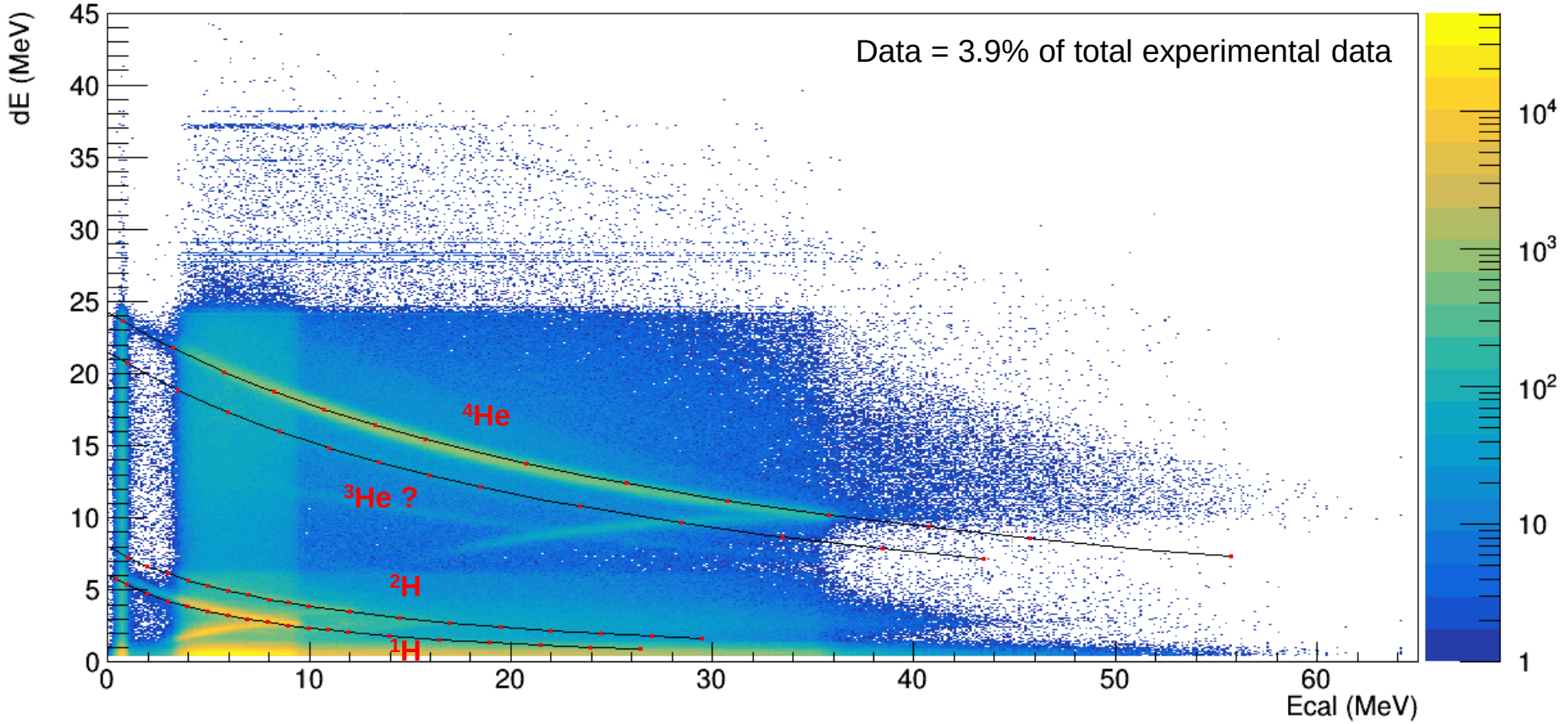

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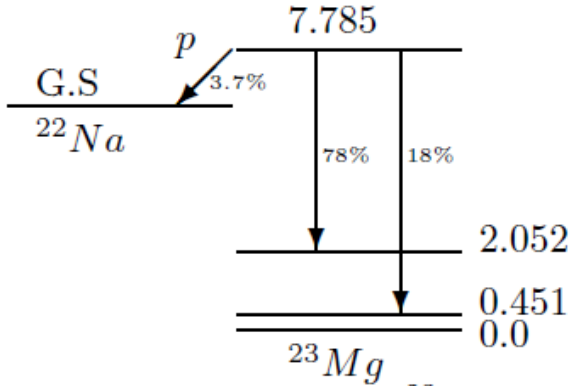

Identification of γ lines from ^{23}Mg

γ rays = Doppler redshifted

$$E_\gamma = E_{\gamma,0}\frac{(1-\beta^2)^{\frac{1}{2}}}{1-\beta\ cos\theta_\gamma}$$

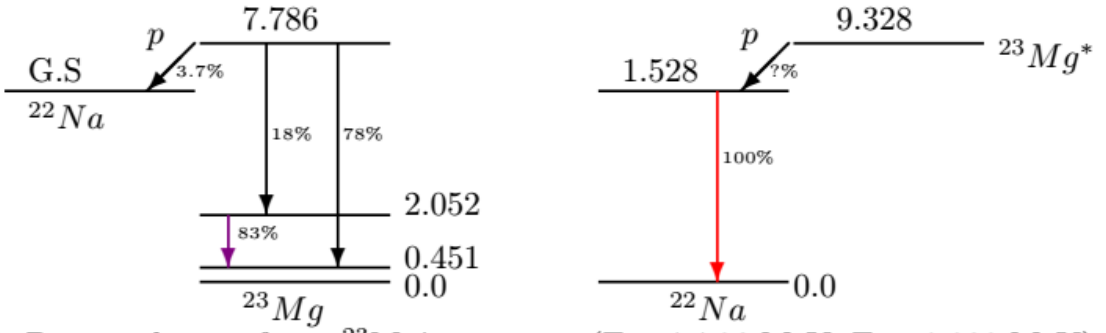

Figure 4: Decay scheme of two ^{23}Mg* states, at (E = 7.786 MeV, E = 9.238 MeV).

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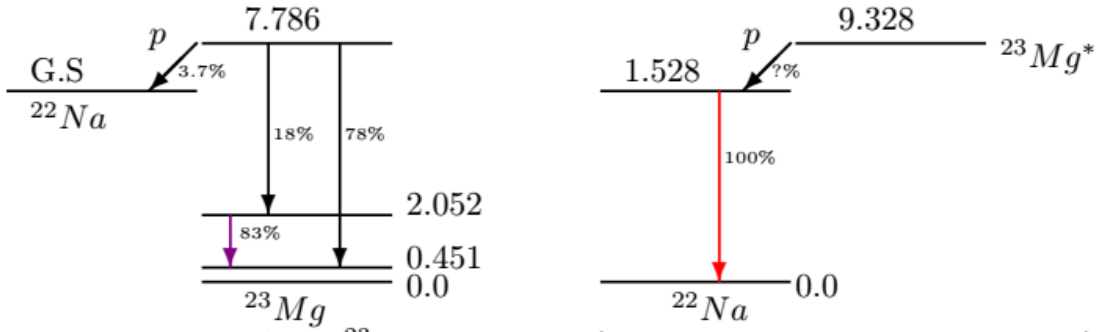

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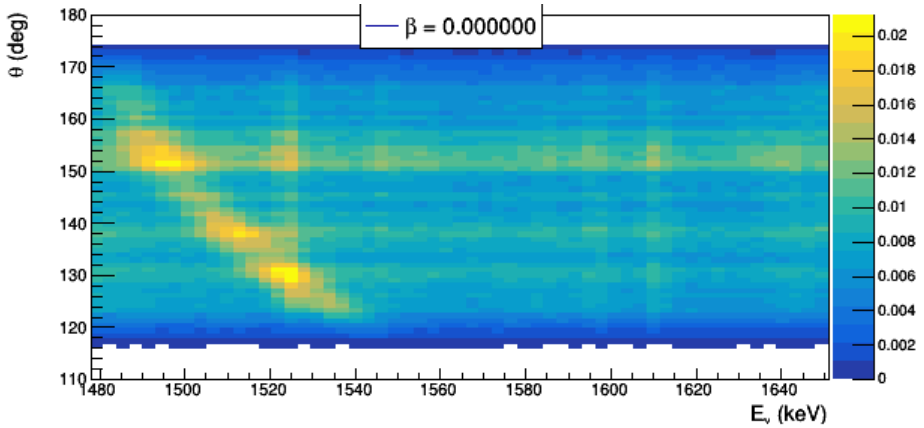

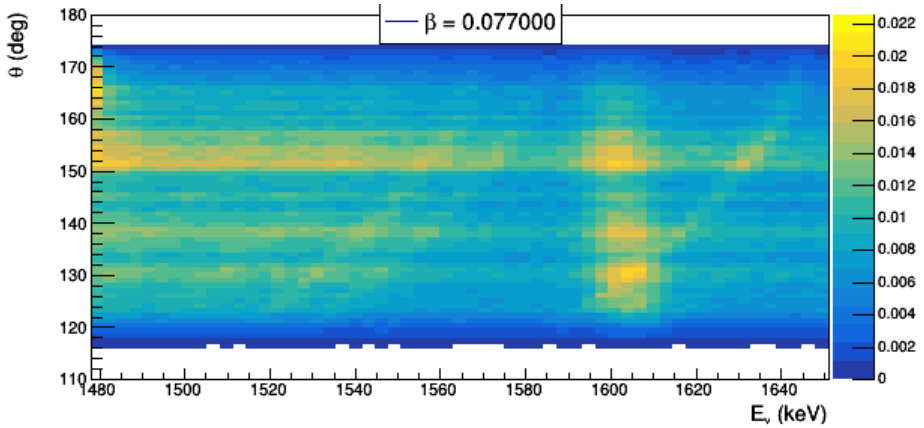

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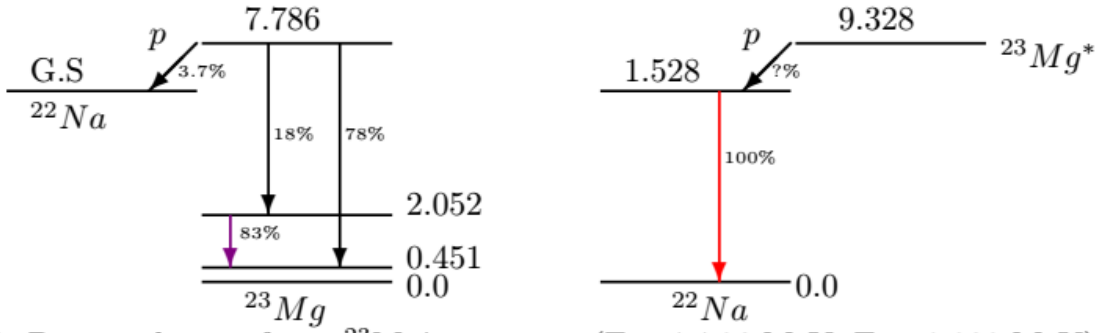

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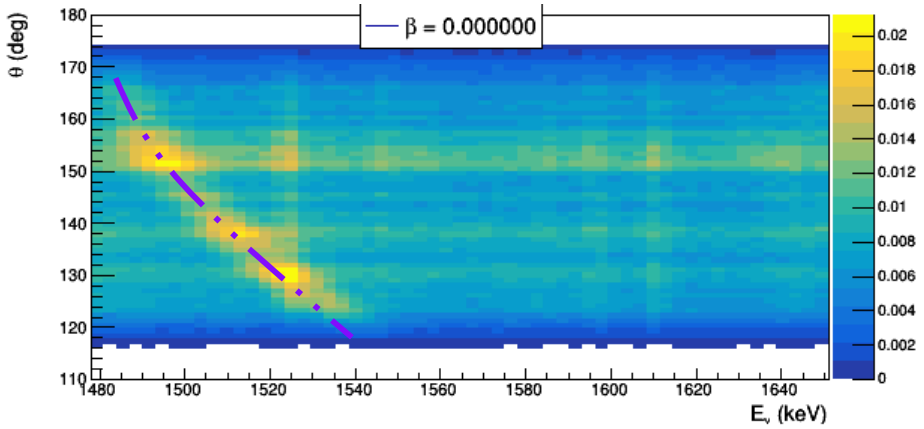

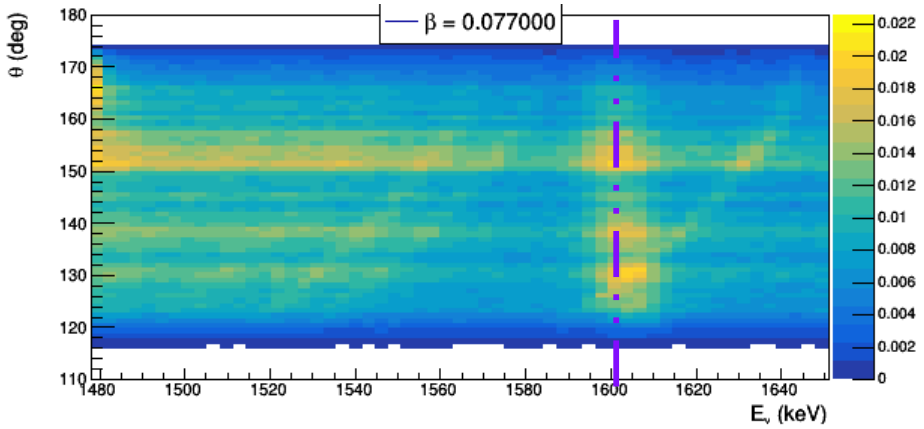

Preliminary measurement of β = 0.077 +/- 0.003

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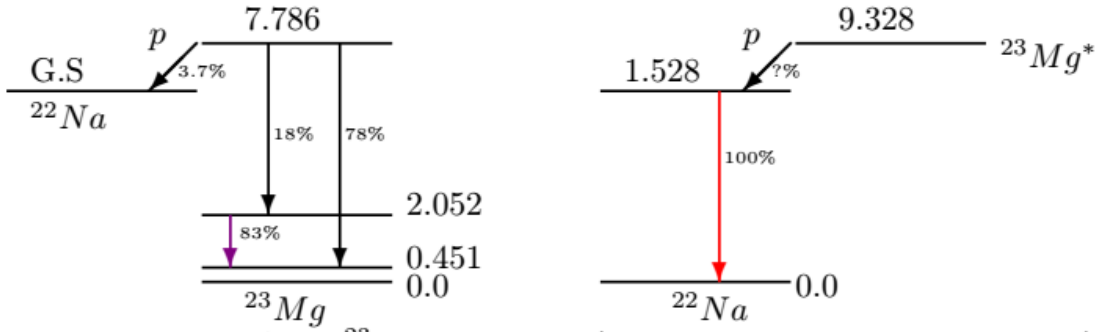

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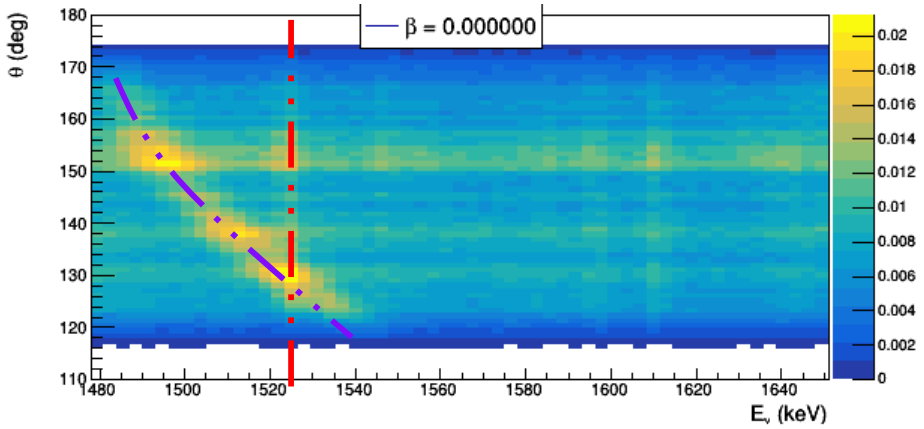

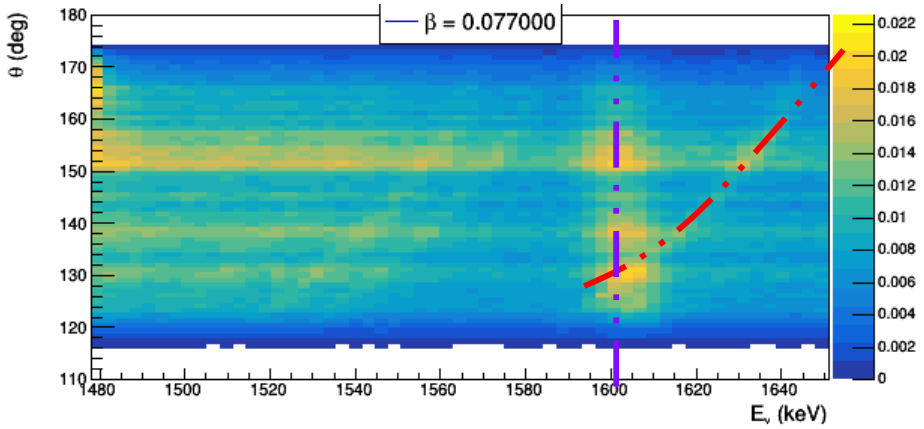

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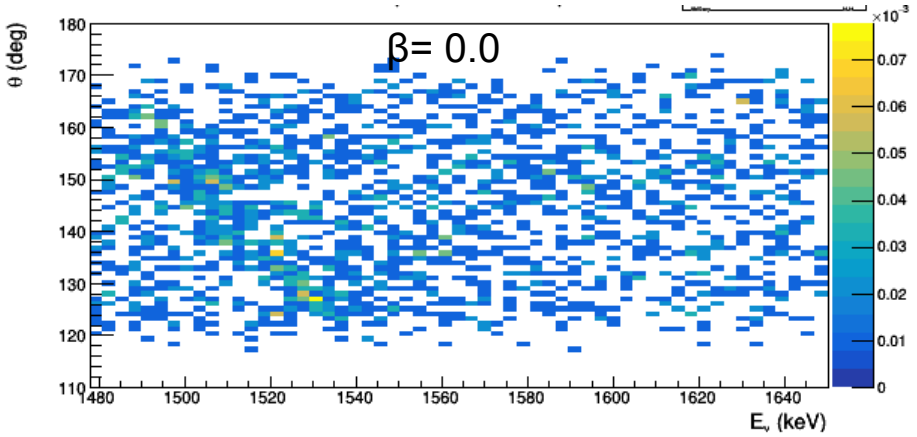
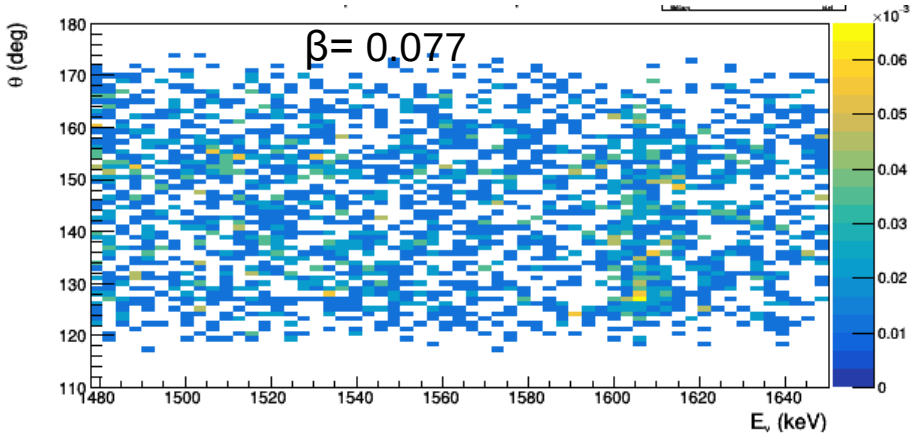
Background reduction in γ spectra

Coïncidence with VAMOS ^{4}He

^{4}He Bρ є [1.018;1.023] T.m





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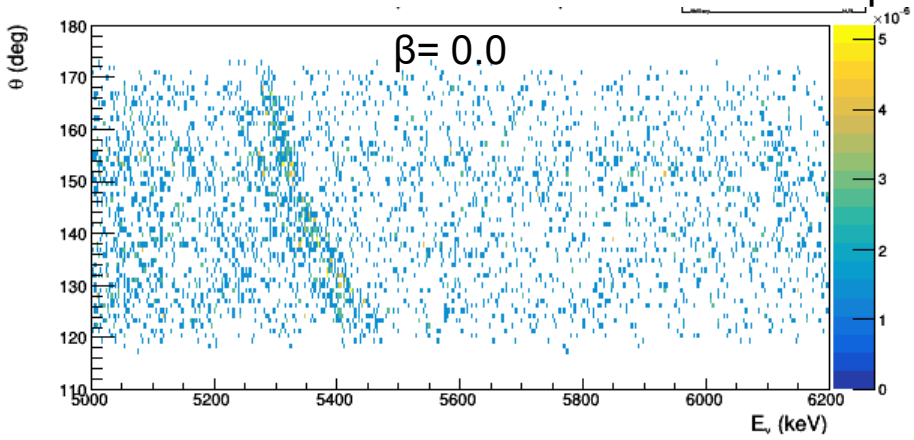

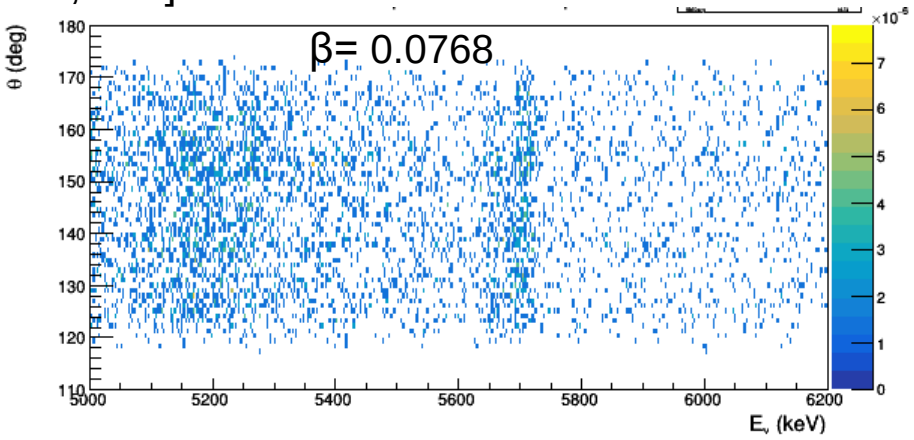

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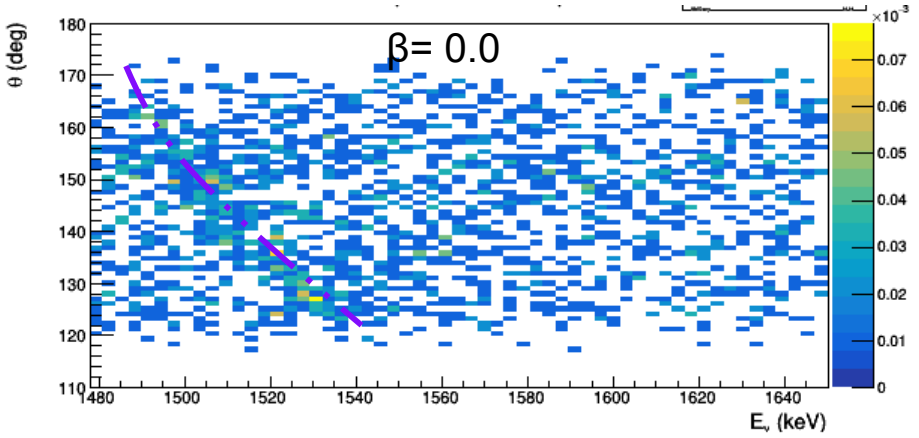
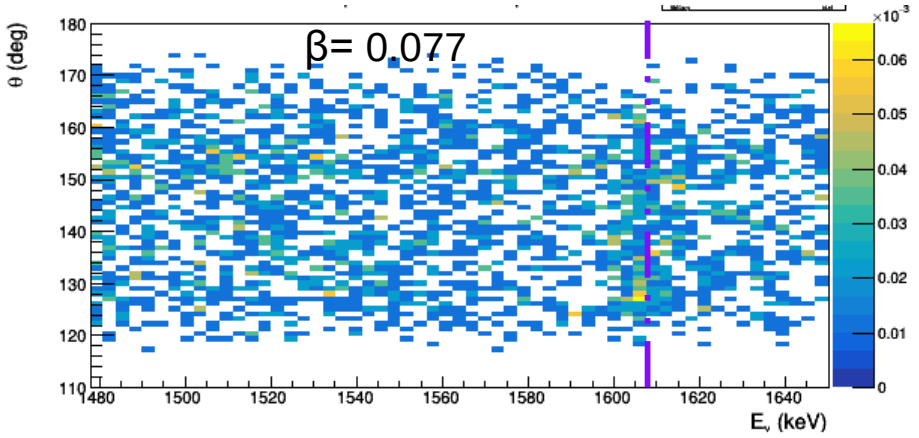
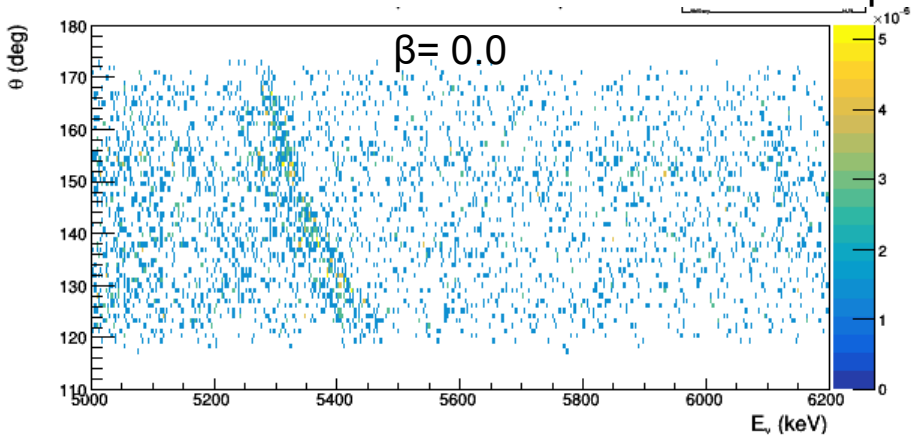
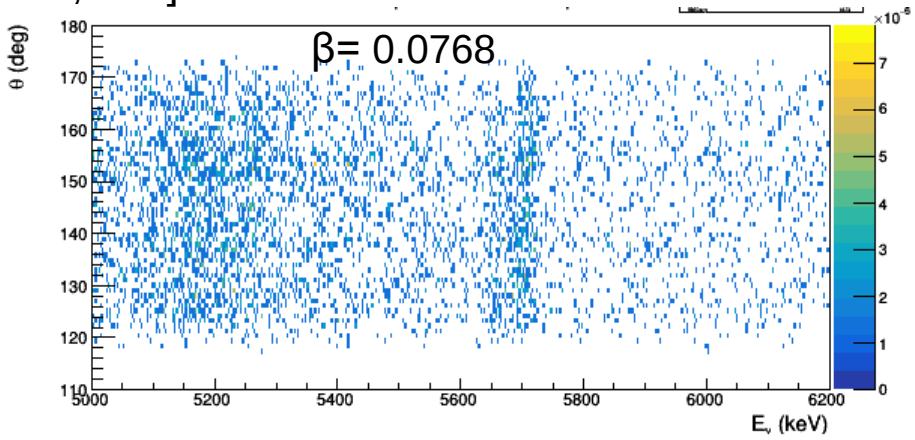




^{23}Mg* E_γ = 1.601MeV

^{4}He Bρ ϵ [0.93;0.95] T.m





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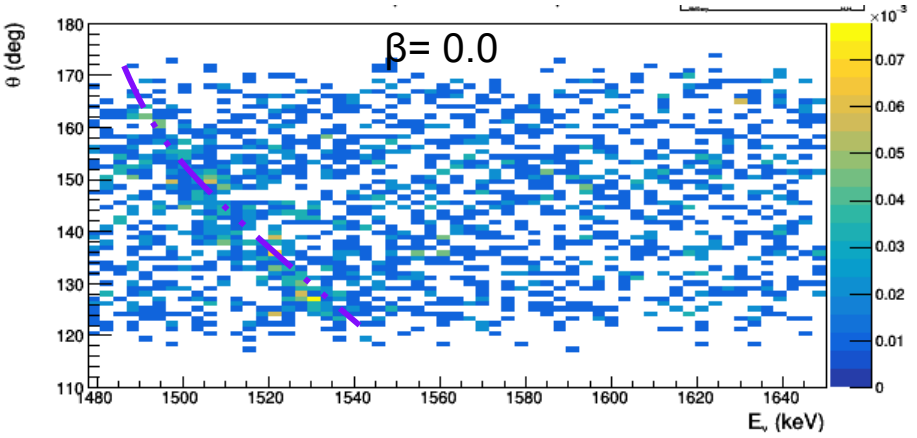

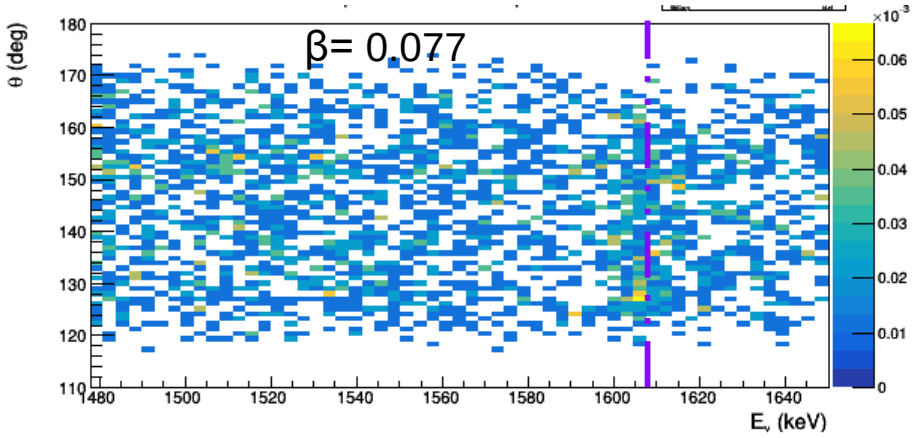

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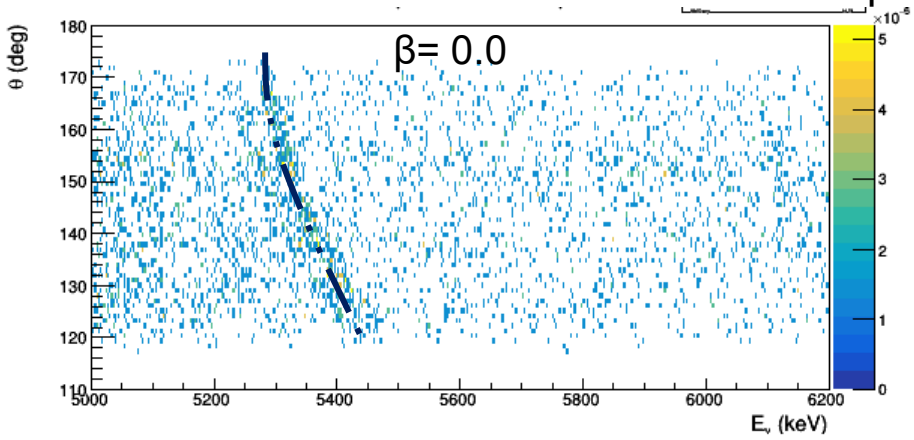

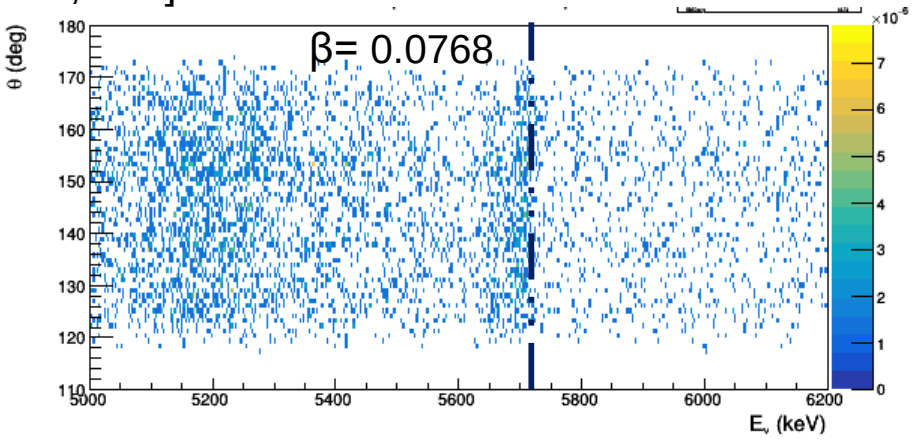

^{23}Mg* E = 5.711MeV

Preliminary results on τ

Simulated γ spectra as a function of τ ^{23}Mg* states

=> Doppler shifted simulated γ peak broader as τ larger

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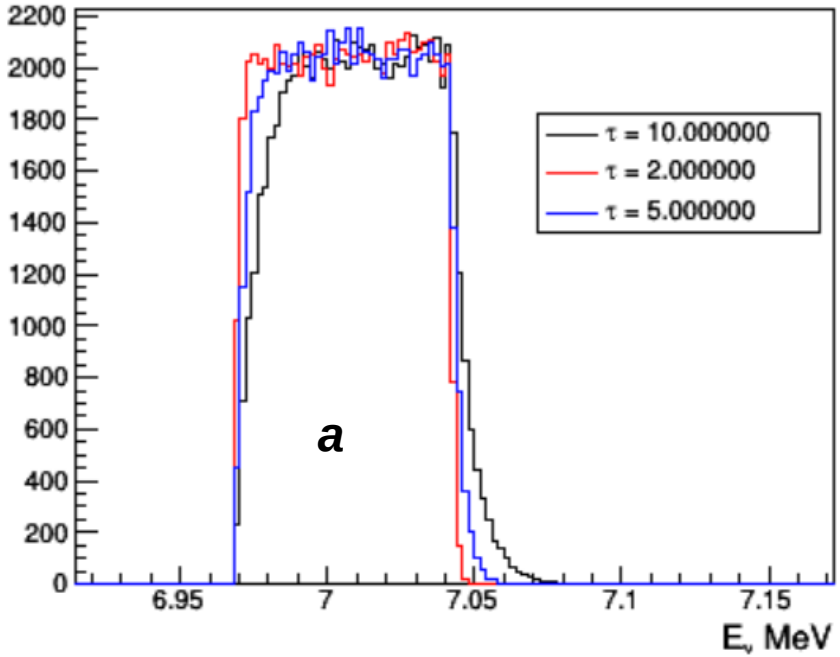

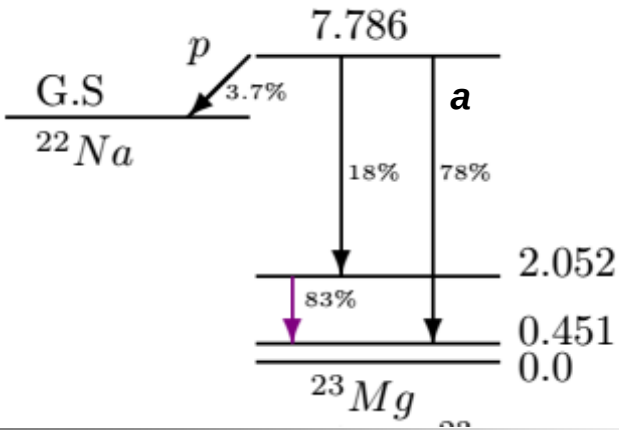

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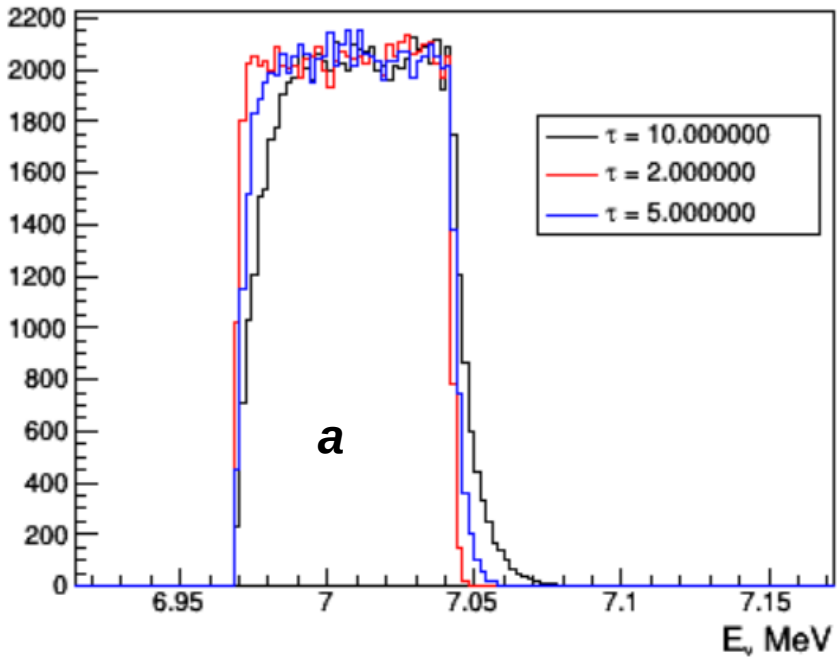
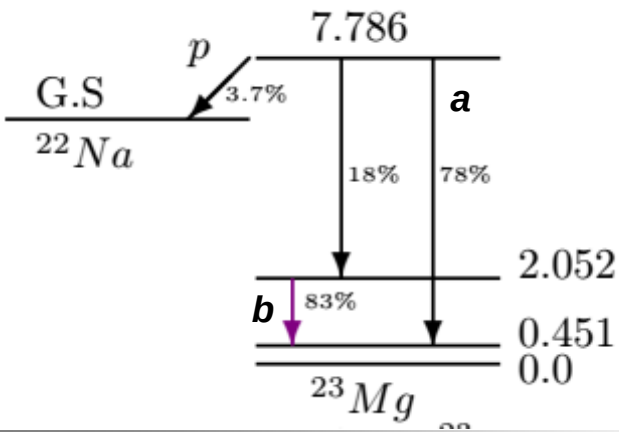
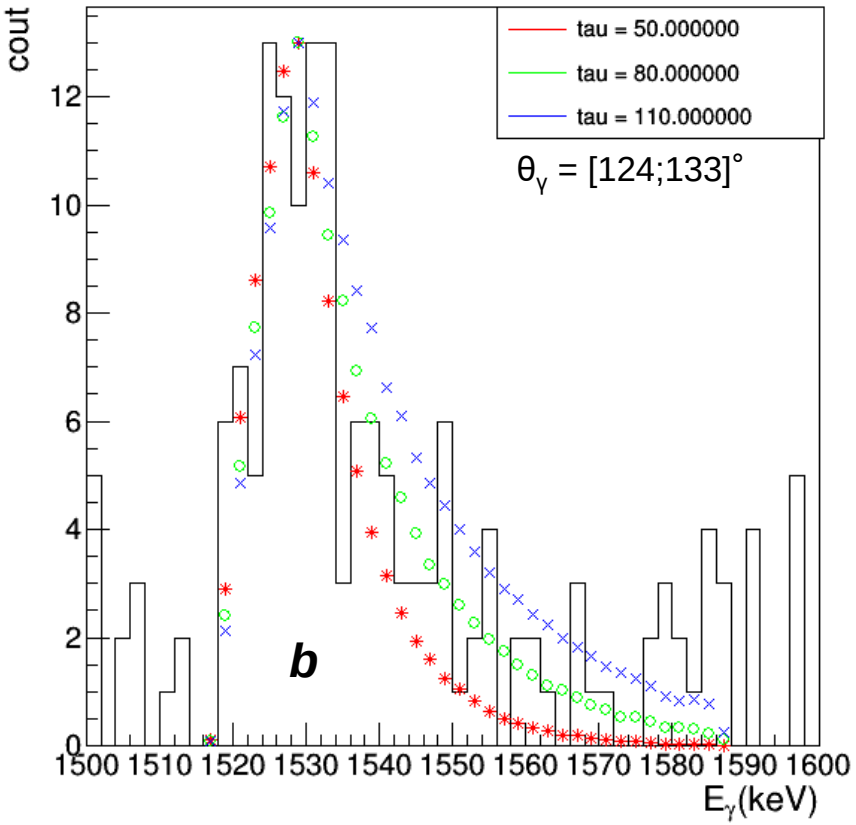




Reference values :

- τ = 80 fs (NNDC)
- τ = 105 +/- 18 fs (2)

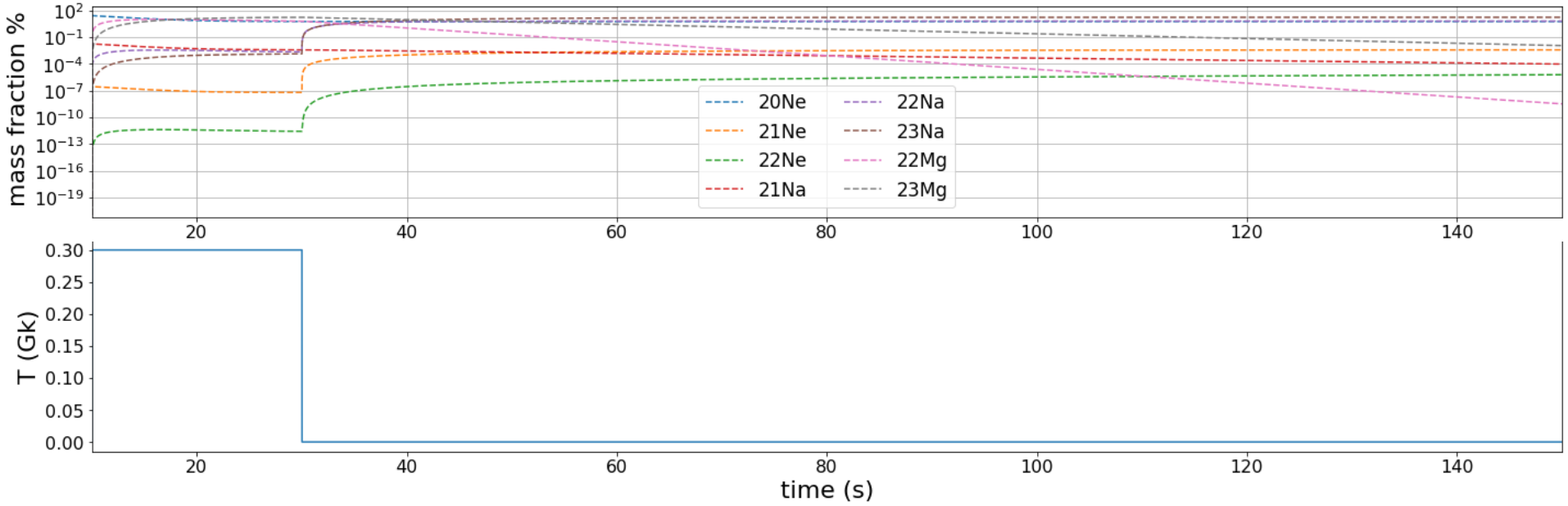


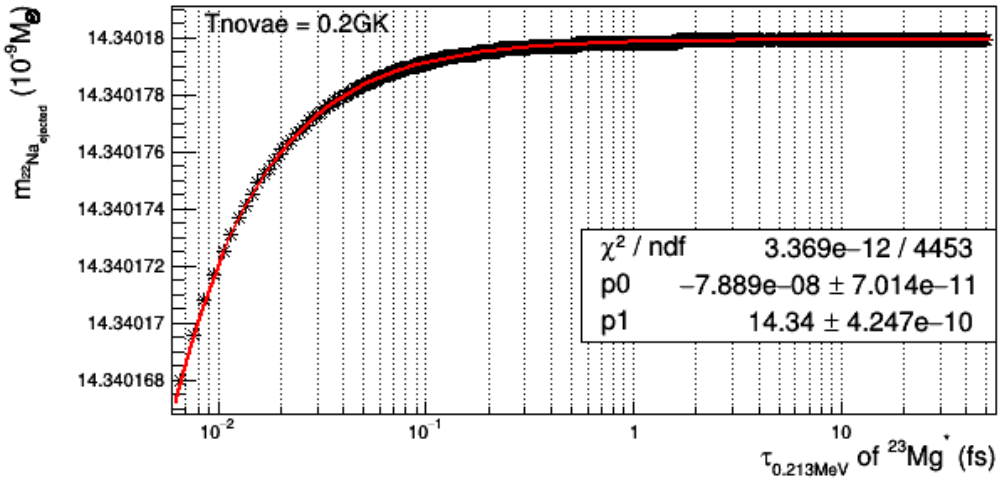
τ = 80 +/- 20 fs ($E_{^{23}Mg}$ = 2.052 MeV)

Chi2/ndf = 0.628146 (τ = 50fs)
Chi2/ndf = 0.518619 (τ = 80fs)
Chi2/ndf = 0.669682 (τ = 110fs)

My Nova simulation : heuristic model

NeNaMg nuclear network simulation (T_{nova} = 0.2 GK during 20s)





- Nucleus mass fraction = constant at the end of nova explosion

- Nova ejected ^{22}Na mass ~ 10^{-8} $M_\odot$
  Law with τ (^{23}Mg*$_{7.786}$)

$$m_{22Na}(ejected) = A - \frac{B}{T}$$

Conclusion

1. **ONe Nova nuclear network :** 0.213MeV dominant resonance on destruction $^{22}Na(p, \gamma)^{23}Mg$ confirmed
   Nova simulation : ^{22}Na ejected matter dependence on τ ($^{23}Mg^*_{7.786}$)
   ⇒ τ =10fs, Flux = **$2.47\ 10^{-5}$ ph.cm^{-2}.s^{-1}** (Nova 1kpc) vs SPI sensitivity **3.10^{-5} ph.cm^{-2}.s^{-1}**

2. **E710 GANIL indirect experiment :** $^{3}He(^{24}Mg,^{4}He)^{23}Mg^*$ with particle detectors (SPIDER/VAMOS) and γ ray detector AGATA

3. **E710 first results** on particle/γ data
   - SPIDER : identification of (p, ^{4}He) dE-E curbs
   - AGATA : DS/notDS lines from $^{23}Mg^*$, $^{22}Na^*$
     preliminary estimations of β ($^{23}Mg^*$) and τ ($^{23}Mg^*_{2.052}$)

Outlook

1. Proton branching ratio B_p
2. Excited $^{23}Mg_{7.786}$ lifetime (shape analysis with simulated γ spectra)
3. Impact of derived resonant destruction rate on nova ^{22}Na abundance (simulation with more complex models)

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Thank you for your attention

References

(1) - The lifetime of the 6.79 MeV state in ^{15}O as a challenge for nuclear astrophysics and γ–ray spectroscopy : a new DSAM measurement with the AGATA Demonstrator array.
C. Michelagnoli, Thesis (2013)

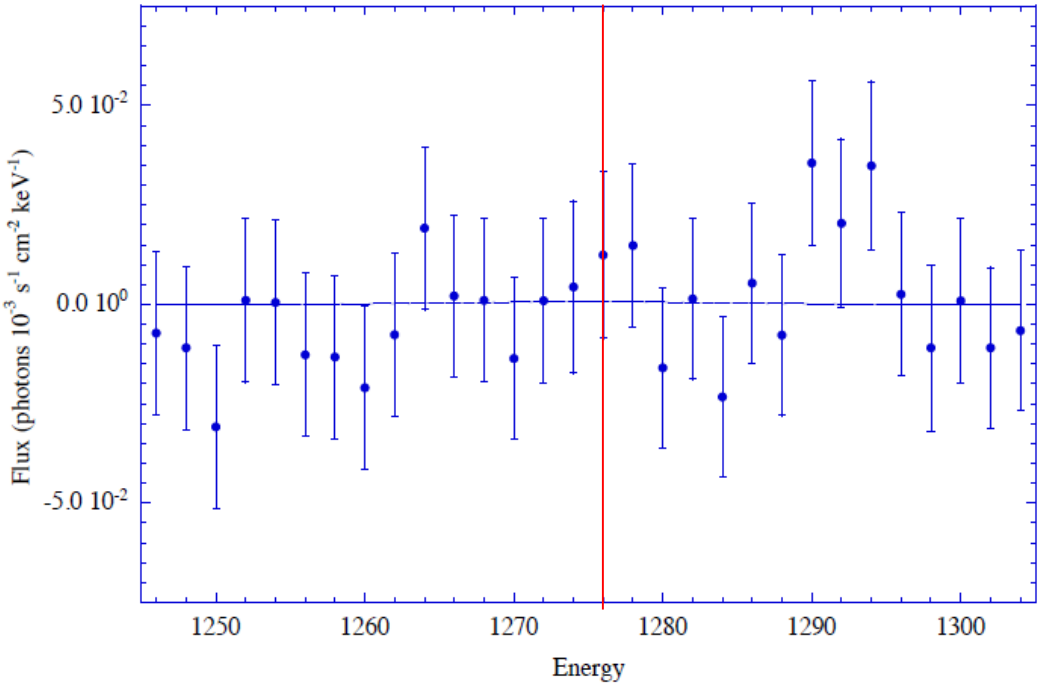
(2) - Measurements of lifetimes in ^{23}Mg.
O.S Kirsebom et al. Physical Review Letters (2016)

- Direct Measurements of $^{22}Na(p, \gamma)^{23}Mg$ Resonances and Consequences for ^{22}Na Production in Classical Novae.

A.L Sallaska et al, Physical Review Letters (2010)

Appendice

Astrophysical search for ^{22}Na line at 1.275 MeV



Gamma spectrum resulting from observation with SPI over 3years (1). The flux represents cumulative emission toward Galatic Center fitted by novae assumed spatial distribution.

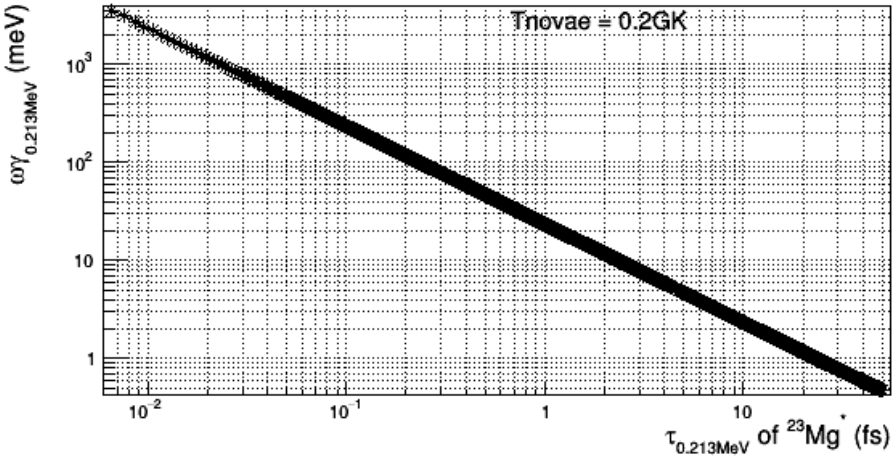
⇒ Line at 1.275 hardly seen : 1.3 10^{-5} ph.cm^{-2}.s^{-1} (1σ)

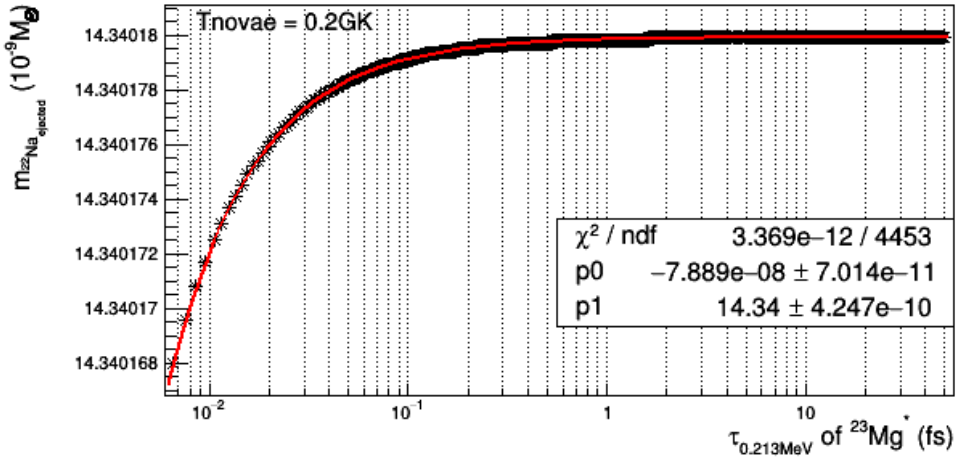
⇒ With 1/3 One novae at rate 30 per year, derived ejected mass upper limit 2.5-5.7 10^{-7} $M_\odot$ per outburst

Important issue to tackle : instrument background level high at the energy looked at (activation by Cosmic Rays of aluminium material near detector)

(1) Cosmic Gamma-Ray Spectroscopy, R. Diehl (2013)

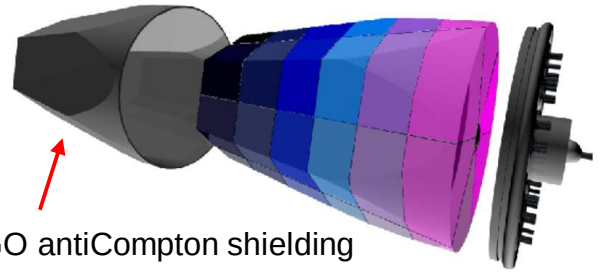
A. Lifetime vs resonance strength



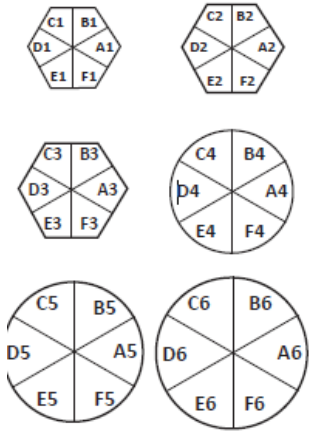


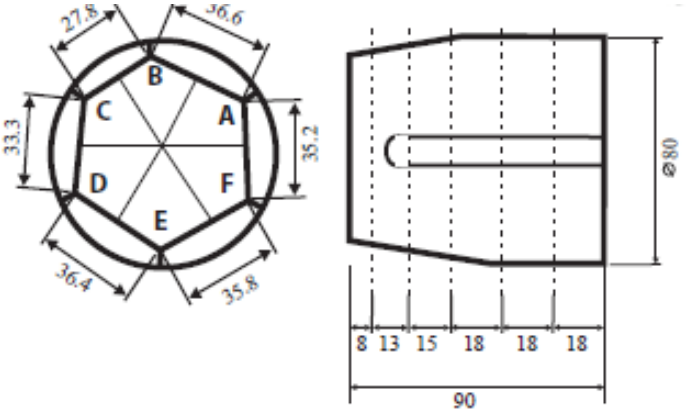
A. Detectors

AGATA PSA and position tracking => (E_γ, θ), 32 Crystals

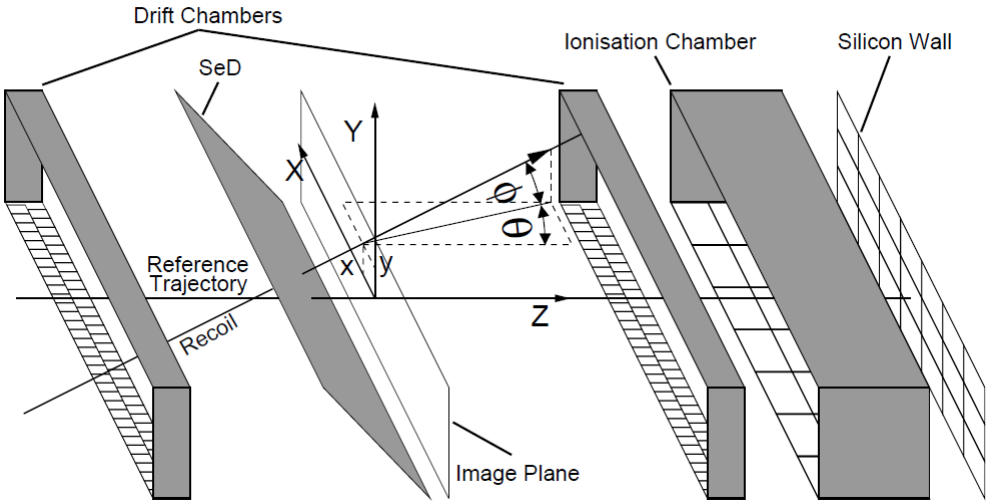


BGO antiCompton shielding





VAMOS



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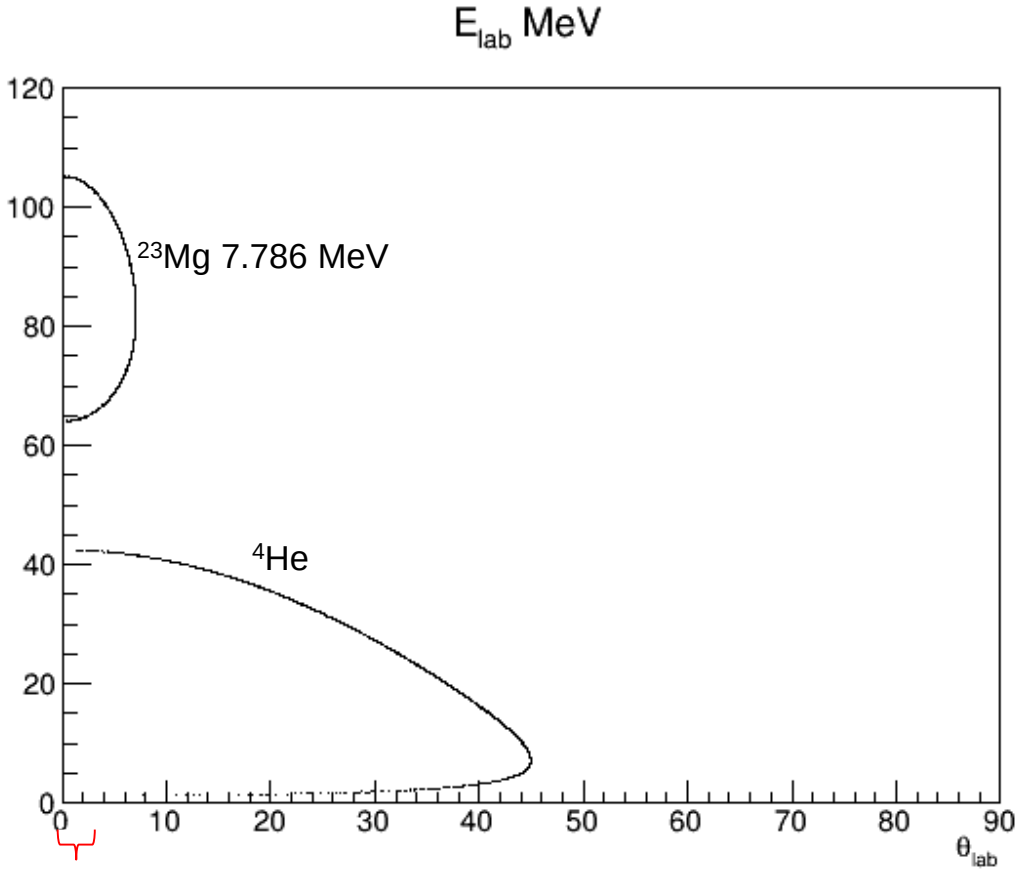
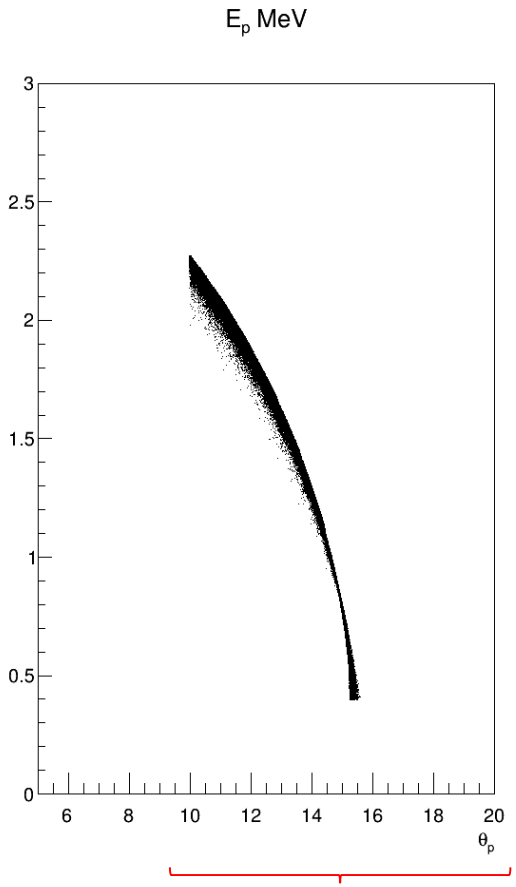
A. Reaction kinematics

Simulation of reaction products (^{23}Mg, ^{4}He) and p

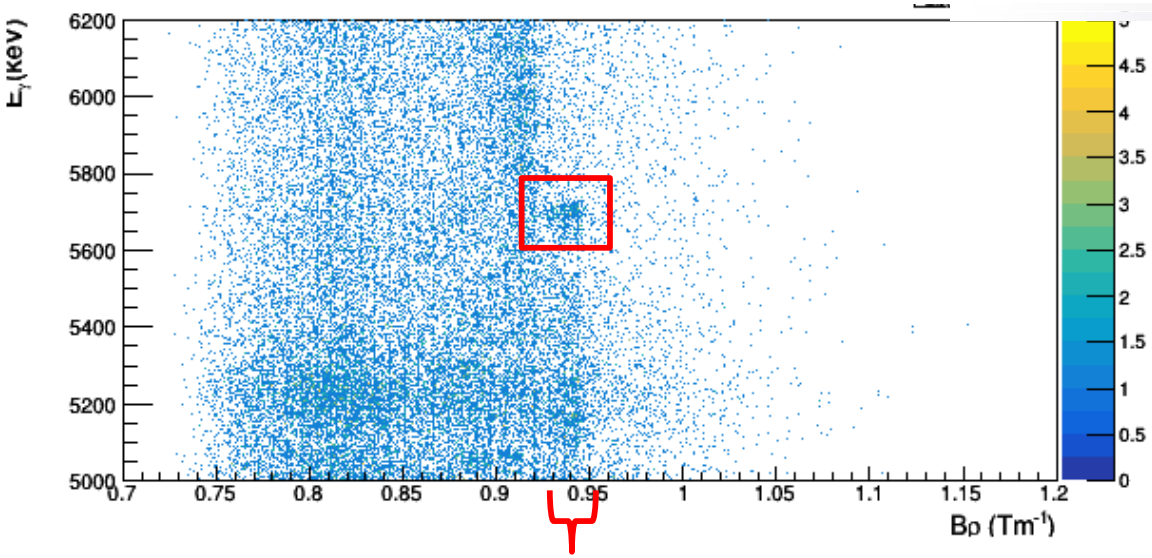


VAMOS aperture

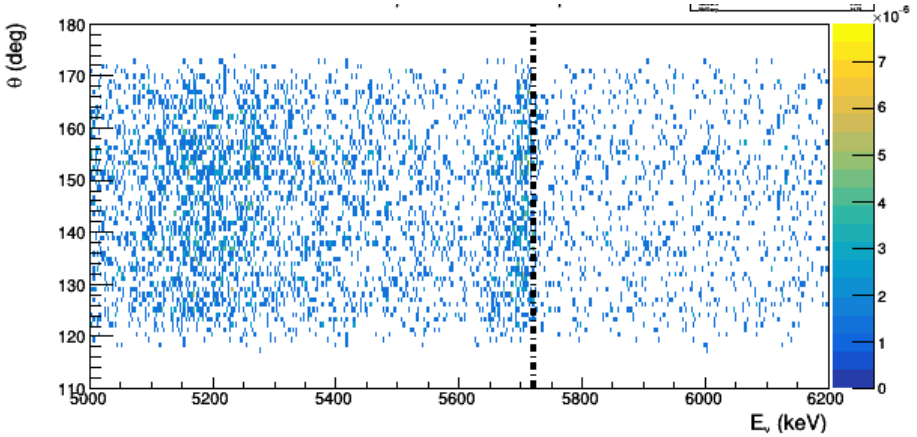


SPIDER aperture

A. Coïncidence with ^{4}He



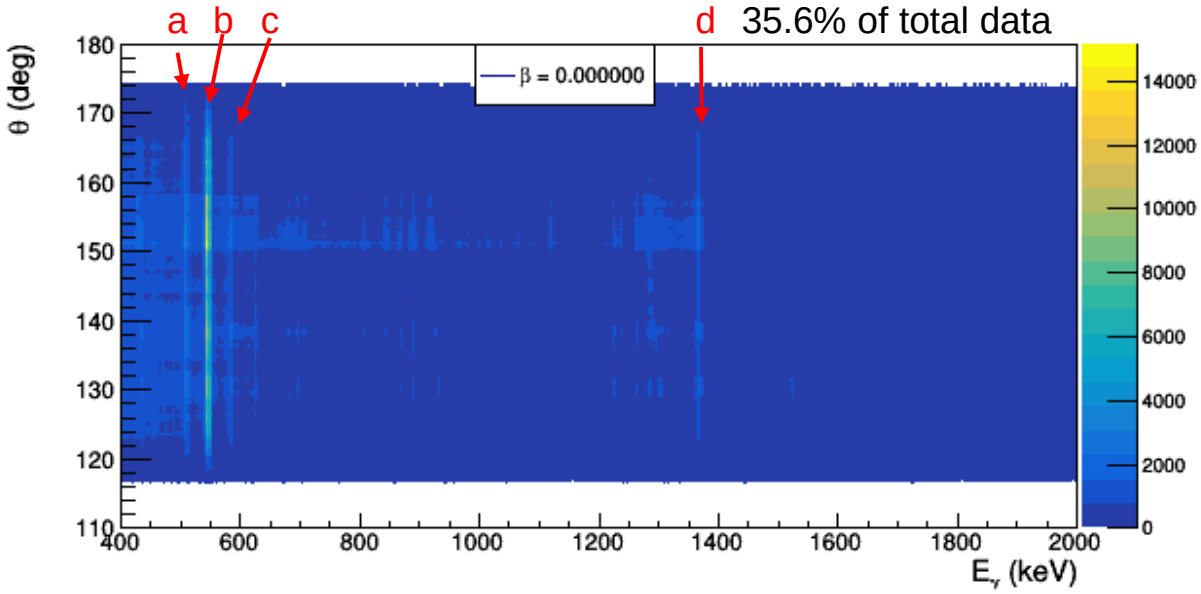
[0.93;0.95] T.m^{-1}



First results : AGATA γ lines

γ rays = Doppler redshifted (moving source from detector)

$$E_\gamma = E_{\gamma,0}\frac{(1-\beta^2)^{\frac{1}{2}}}{1-\beta\ cos\theta_\gamma}$$



Vertical lines = not Doppler shifted
a. E_γ= 511 keV Pair annihilation
b. E_γ= 548 keV Au activation
c. E_γ = 585 keV ^{22}Na* (τ = 243ns)
d. E_γ = 1370 keV Au activation

Curved line = Doppler shifted => at proper β, vertical transition (e) E_γ = 2840 keV ^{28}Si* (τ = 37fs)